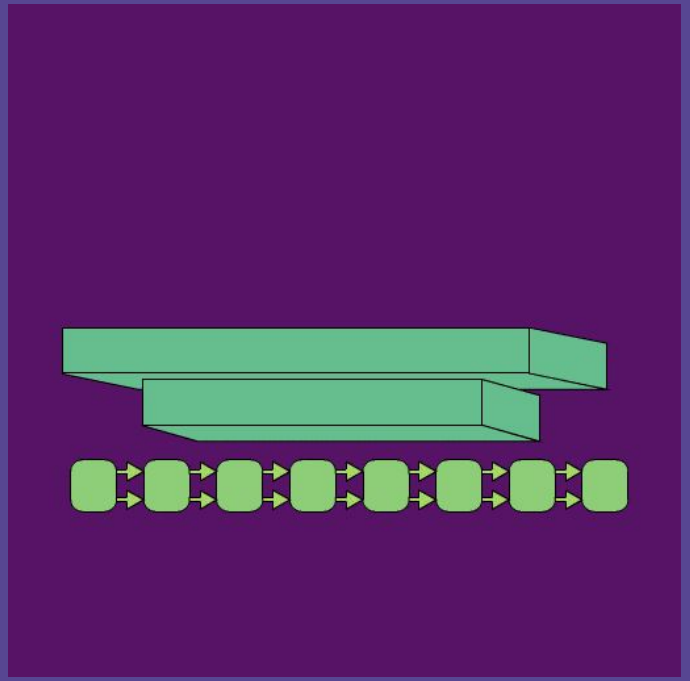
OpenVAK

A neural network framework for researchers studying acoustic behavior



David Nicholson, Yarden Cohen

Scipy 2023

nicholdav.info NickleDave @nicholdav @nicholdav@fosstodon.org

Acknowledgements (part 1)

Dr. Yarden Cohen
Dept of Brain Sciences
Weizmann Institute of Science, Israel
https://www.weizmann.ac.il/brain-sciences/labs/cohen/

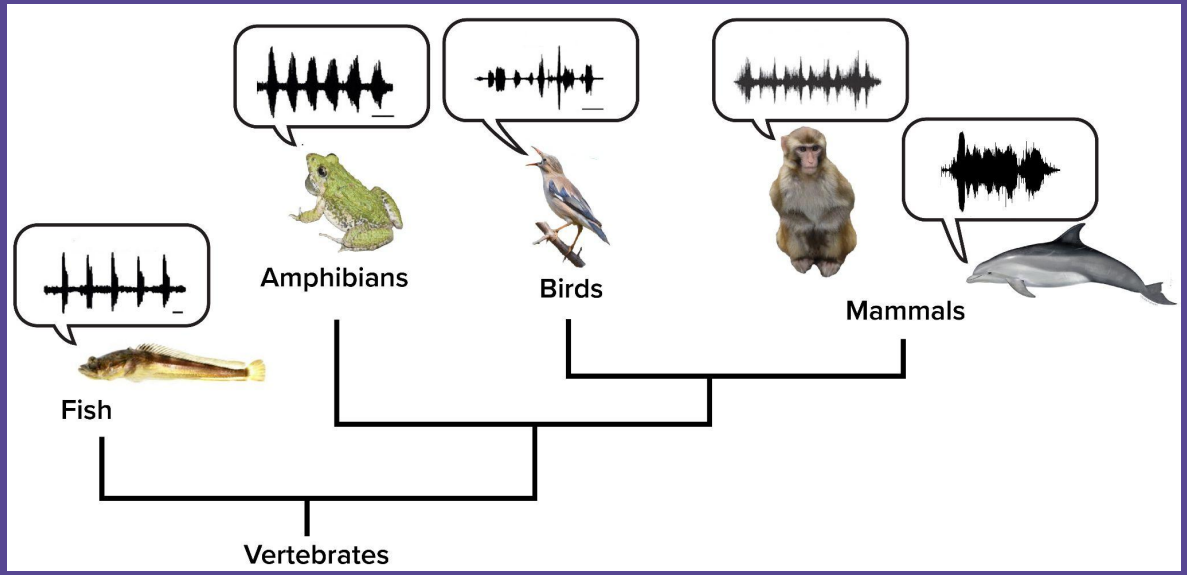
@YardenJCohen

Introduction

Acoustic behavior and animal communication

What makes us human?
Language and speech

How is speech like birdsong and bat calls?



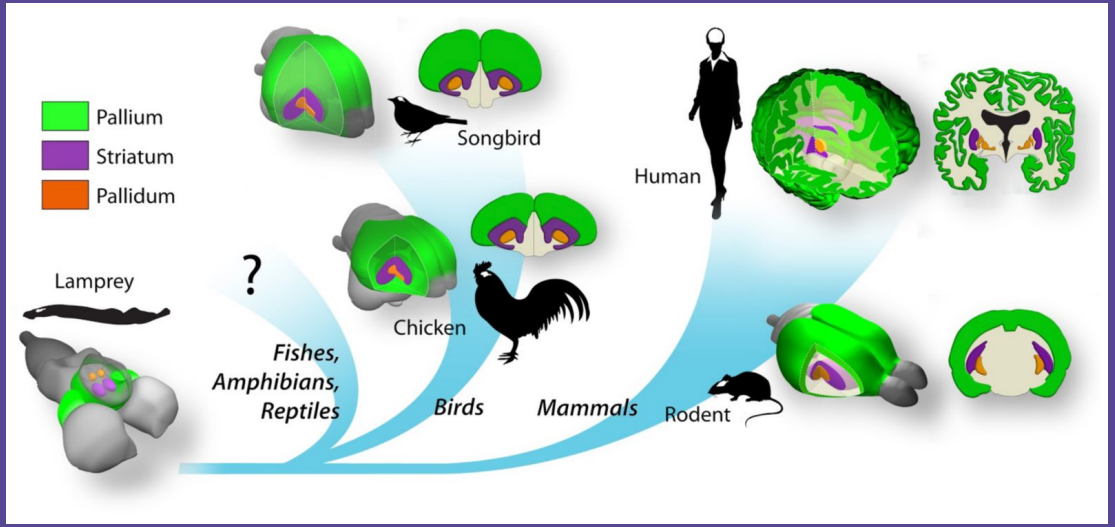
Adapted from: Bass Chagnaud 2012, Branstetter et al. 2016, Chen et al. 2020

Acoustic behavior and animal communication

What makes us human?
Language and speech

How is speech like birdsong and bat calls?

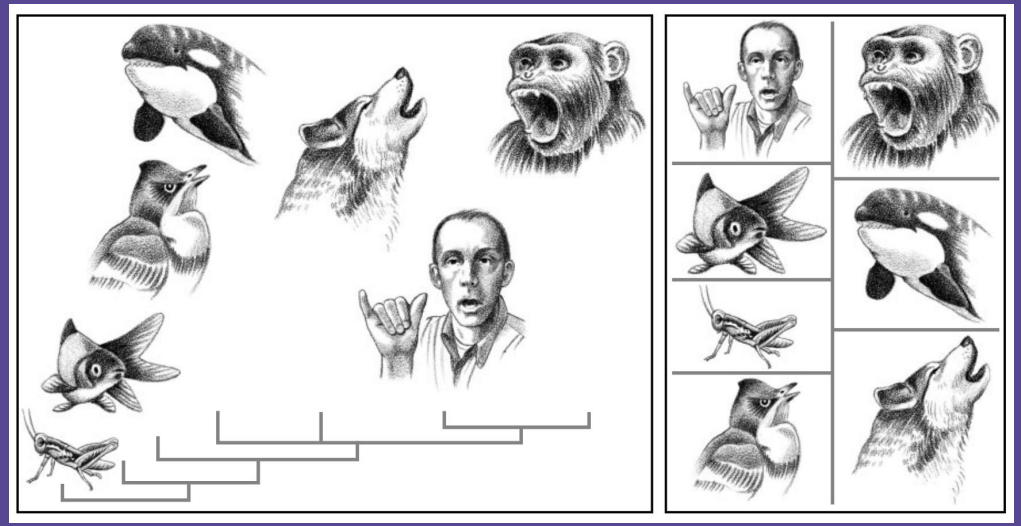
How are the brain areas that produce these behaviors related?



Boraud Leblois Rougier 2014
https://inria.hal.science/hal-01874690

Acoustic behavior and animal communication

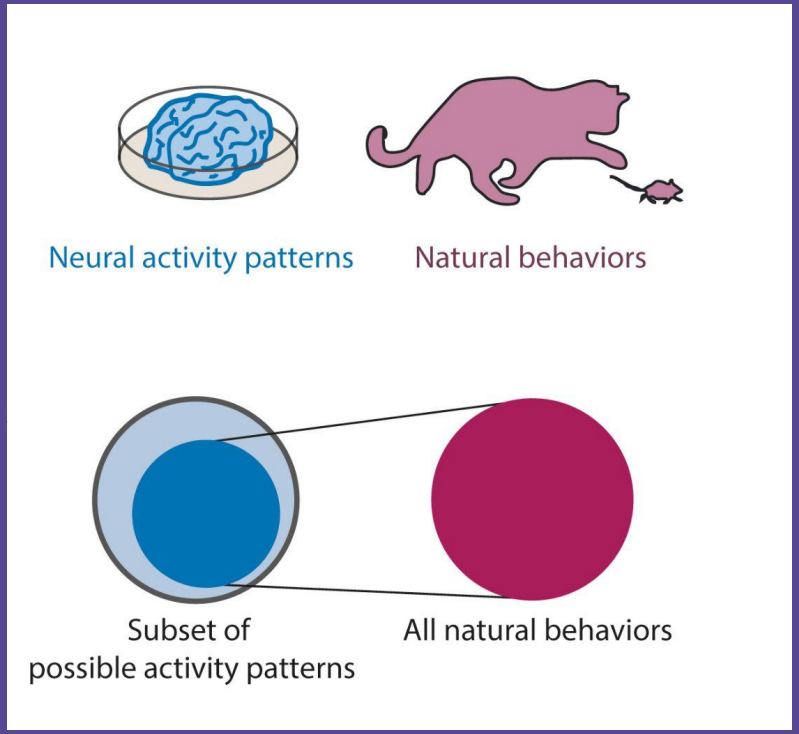
- Interdisciplinary (Wirthlin et al. 2019)
- Big team science (Hauser et al. 2002)
- Cutting edge computational methods
    - **Deep learning, AKA neural network models (Sainburg et al 2021, Stowell 2022)**



Hauser et al. 2002

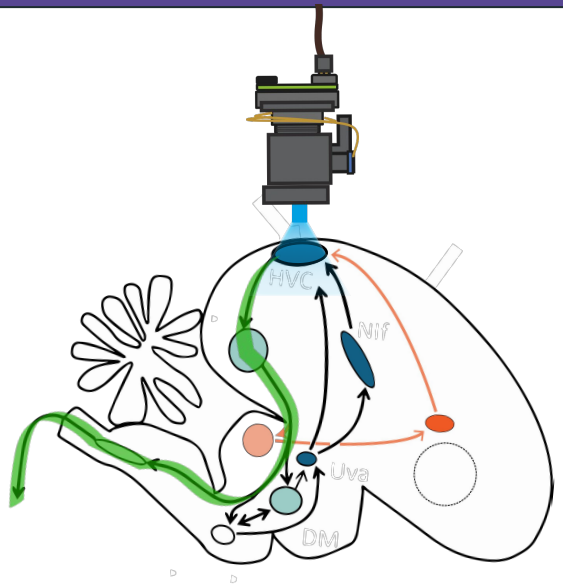
Why "acoustic behavior"?

- We want to understand **behavior** and how the **brain produces it**
- First we must be able to **quantify** and **model** real world behavior



Krakauer et al. 2017

Why "acoustic behavior"?



The premotor song circuit

Why "acoustic behavior"?

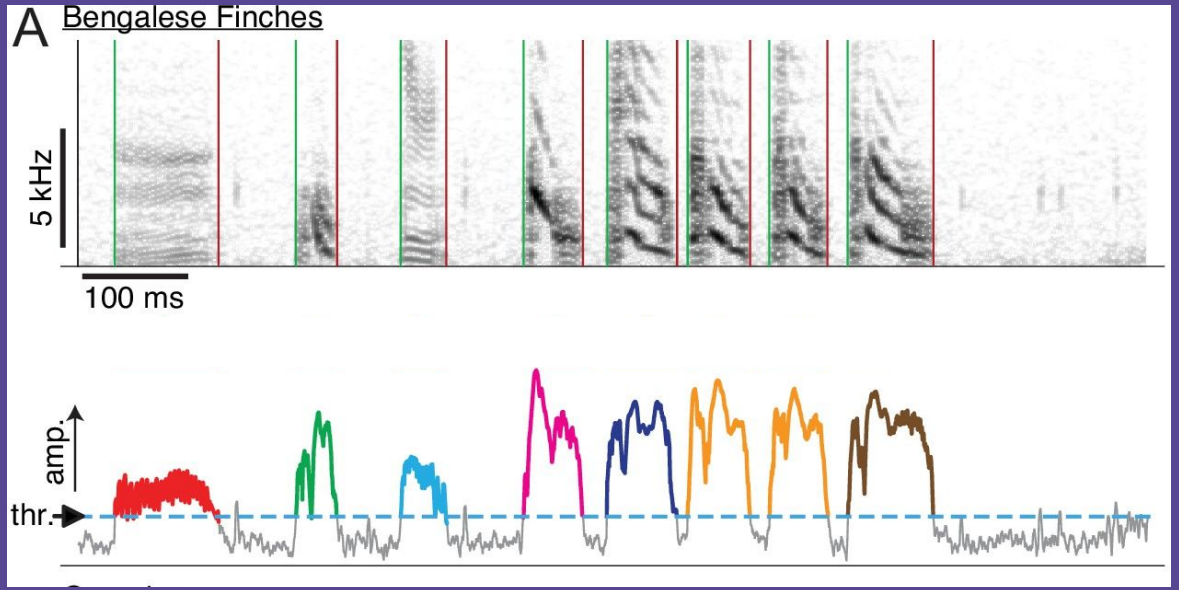
Quantifying and **modeling** real world behavior requires

- Big data
- Automated analyses

Analyses of acoustic behavior

Many analyses consists of a *workflow* focused on *sequences* of *units*

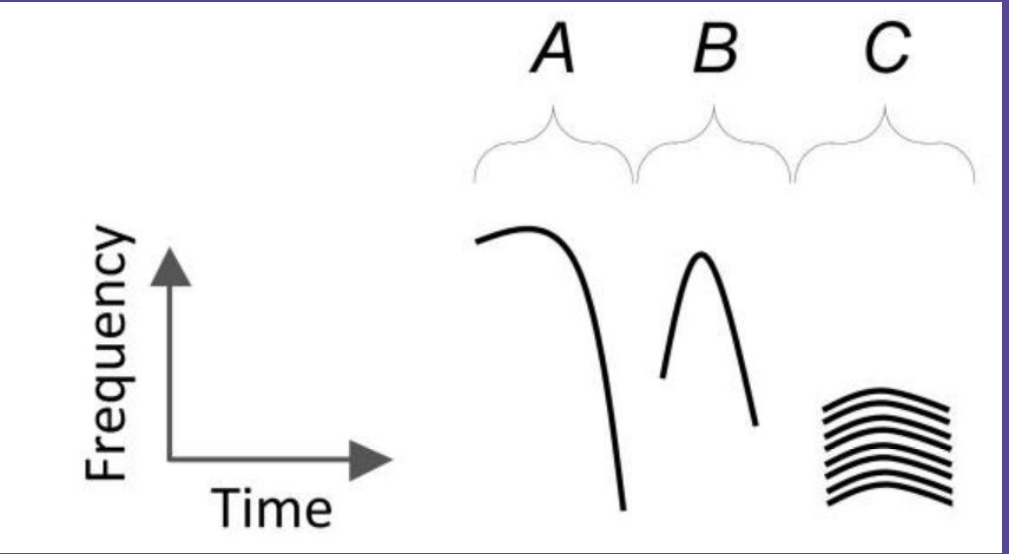
- By *segmenting*, e.g. using *silent gaps*



Analyses of acoustic behavior

Is this the right way to think about acoustic behavior?

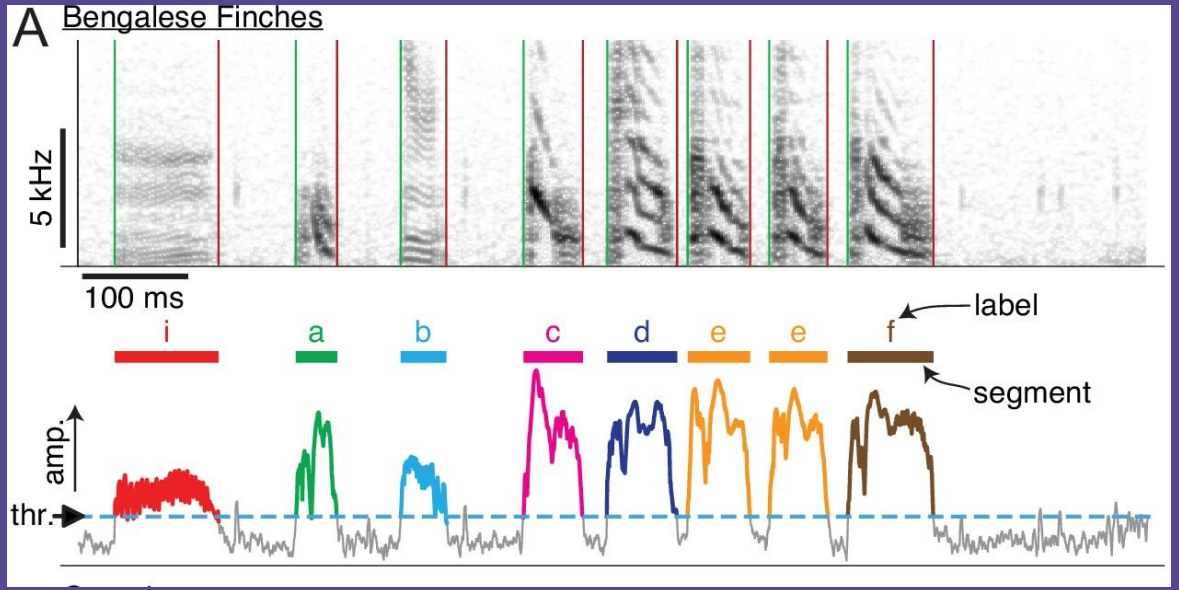
Unclear, in part because doing these analyses has been so hard



Kershenbaum et al. 2015

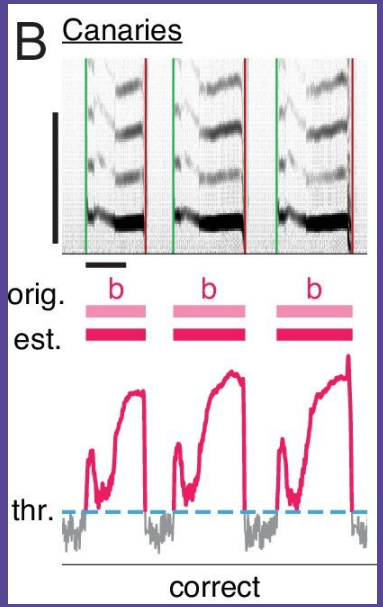
Analyses of acoustic behavior

- Get sequence of units by *segmenting*
- Some analyses require *annotating* the units



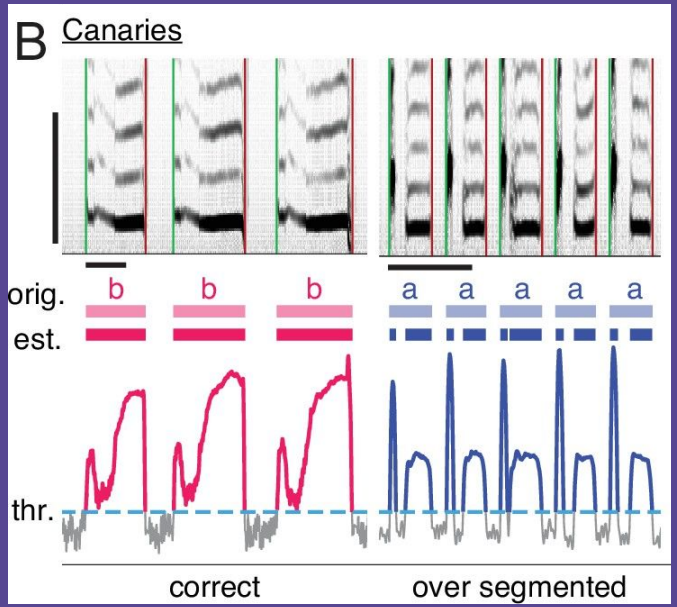
Analyses of acoustic behavior

Off-the-shelf signal processing algorithms for segmenting often don't work



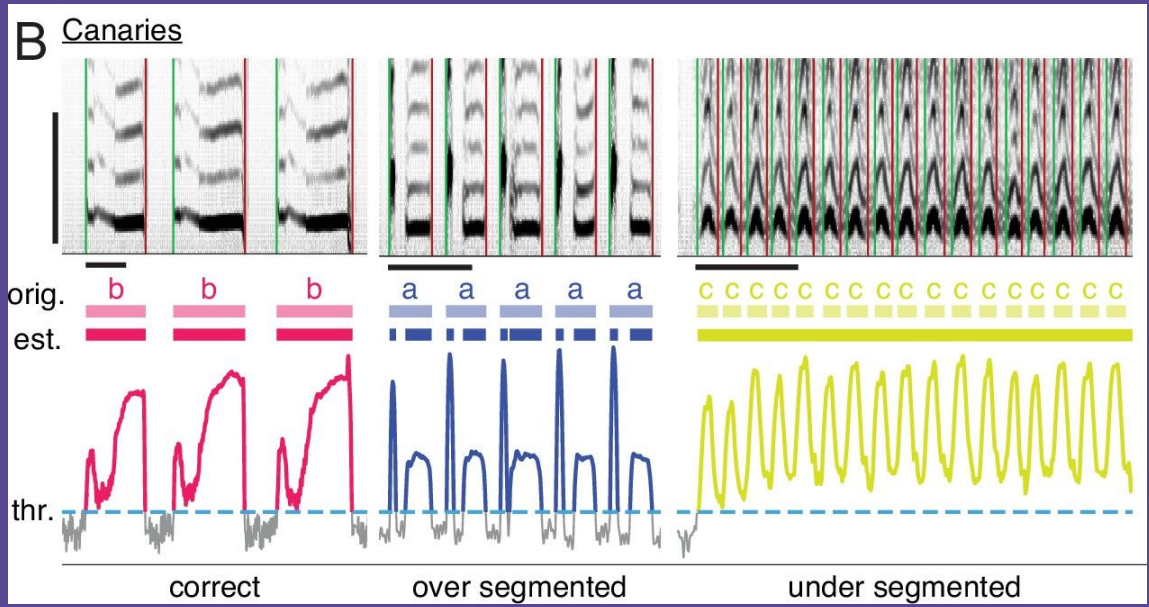
Analyses of acoustic behavior

Off-the-shelf signal processing algorithms for segmenting often don't work



Analyses of acoustic behavior

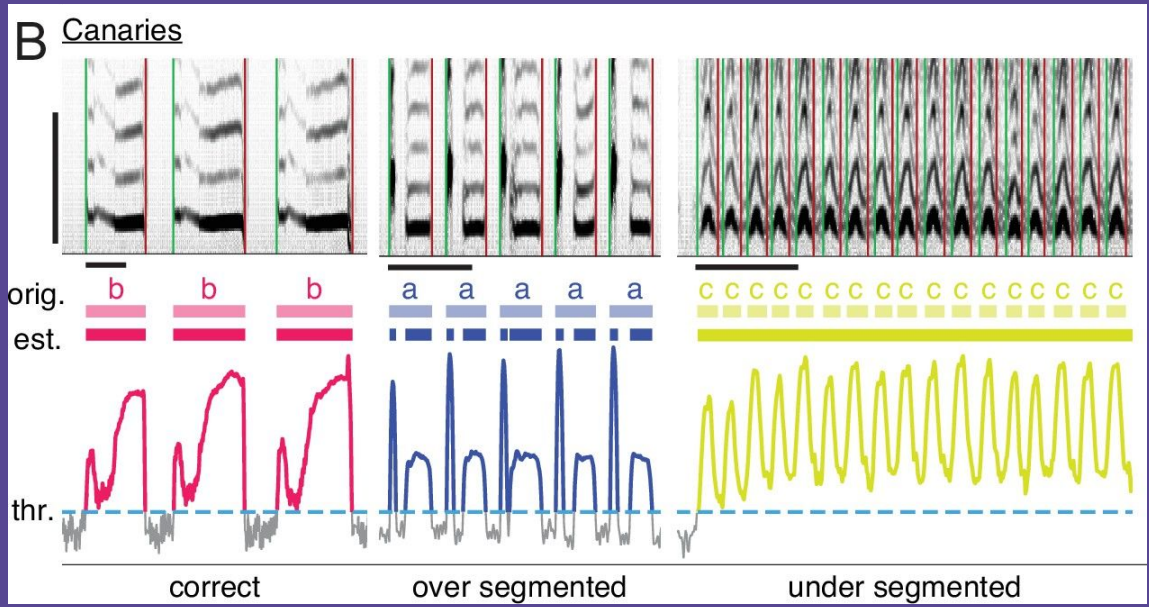
Off-the-shelf signal processing algorithms for segmenting often don't work



Analyses of acoustic behavior

Off-the-shelf signal processing algorithms for segmenting often don't work

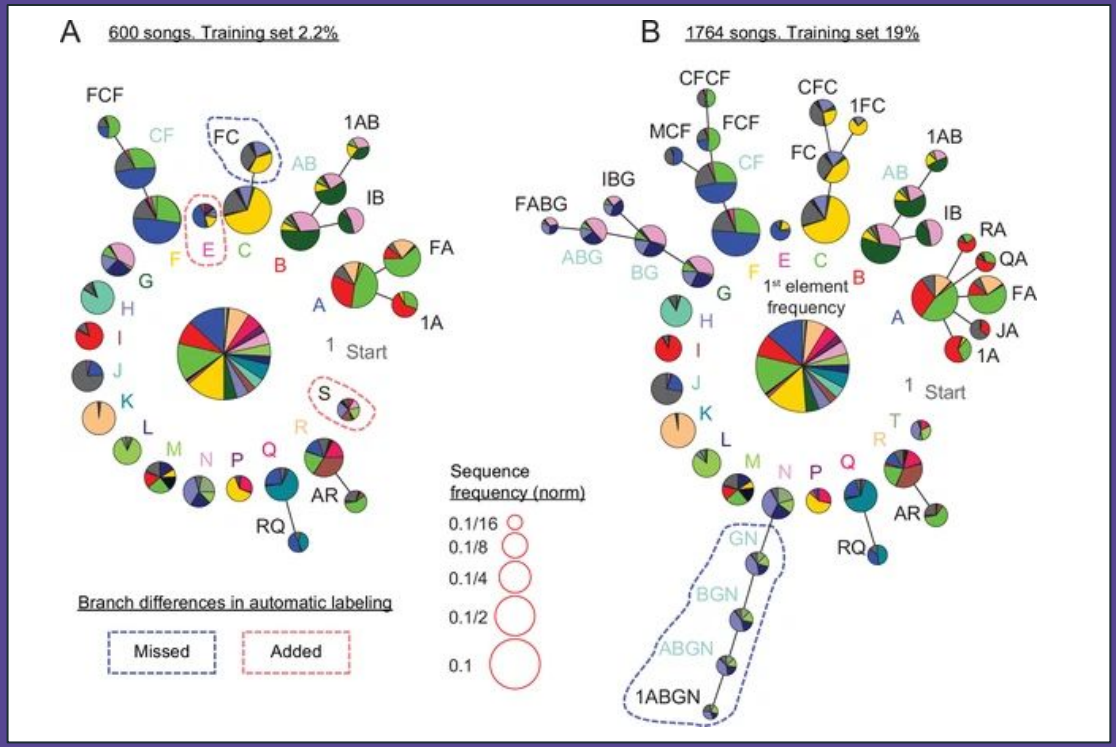
→ Neural network model



Annotation

For behavioral experiments

- e.g., models of syntax



Cohen et al., 2021

Annotation

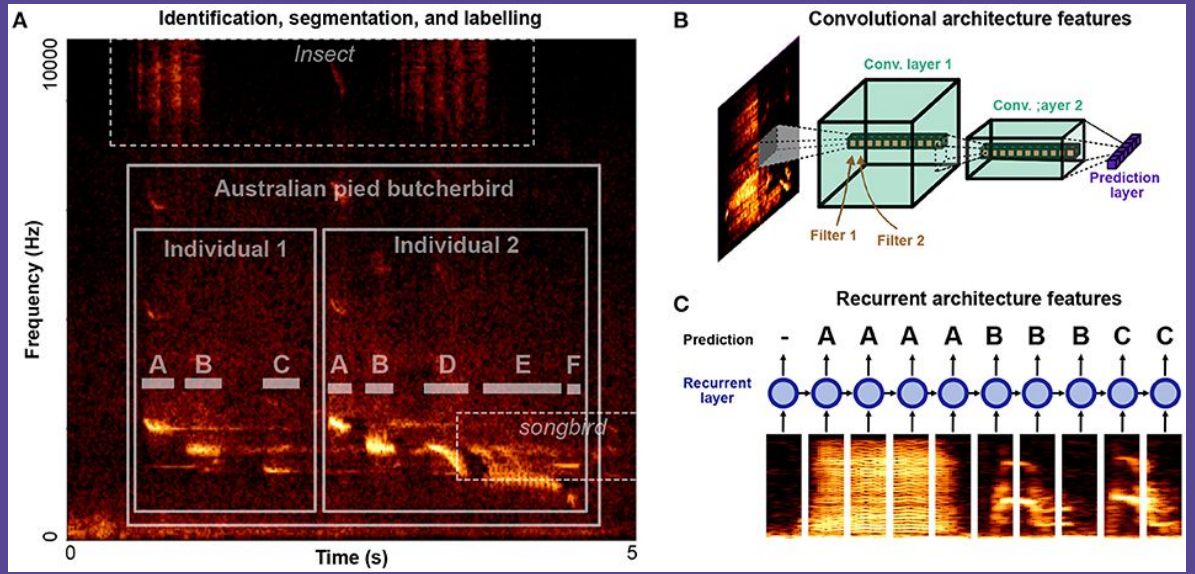
Key Problem:

- Animals produce many more sounds than can be annotated by hand
  - e.g., birds sing 100s-1000s of songs a day

Neural network models for acoustic behavior

Multiple models proposed for related tasks (Sainburg Gentner 2021, Stowell 2021)

Often: familiar **computer vision** models

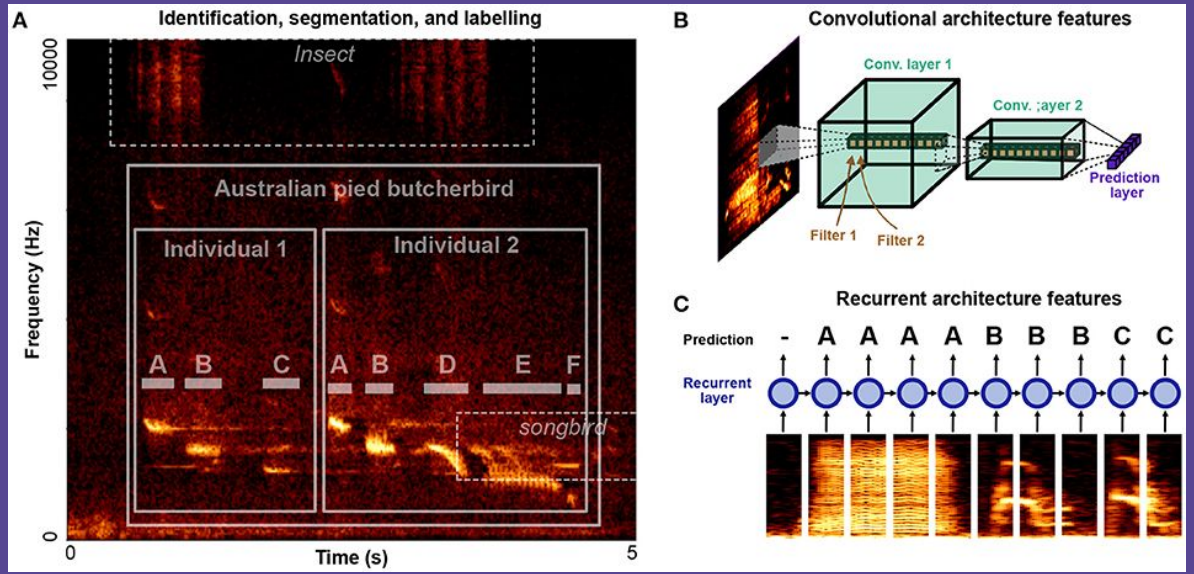


Sainburg Gentner 2021

Neural network models for acoustic behavior

Papers describing these models have software written **with different frameworks**

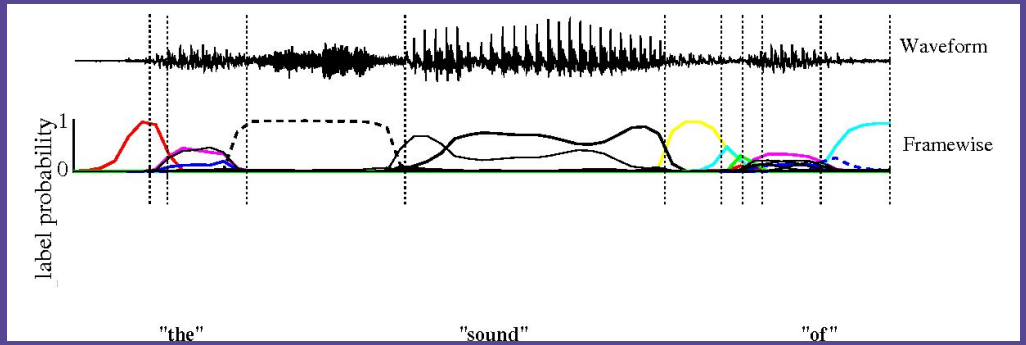
- keras, tensorflow, pytorch, etc.



Sainburg Gentner 2021

Neural network models for acoustic behavior

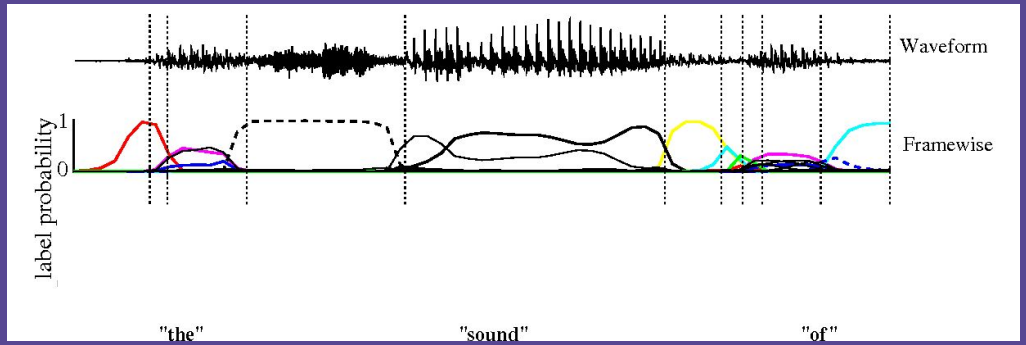
- Annotation as *frame classification* (Graves 2012)
  a. Classify each frame
  b. Recover sequences of labeled units by "segmenting" the classifications



Graves et al 2005

Neural network models for acoustic behavior

- Annotation as *frame classification* (Graves 2012)
- Multiple models proposed for this task
  a. TweetyNet (Cohen 2021, 2022) -- Tensorflow, later PyTorch
  b. DAS (Steinfath 2021, 2022) -- Keras
  c. Koumura 2016 -- Java, custom

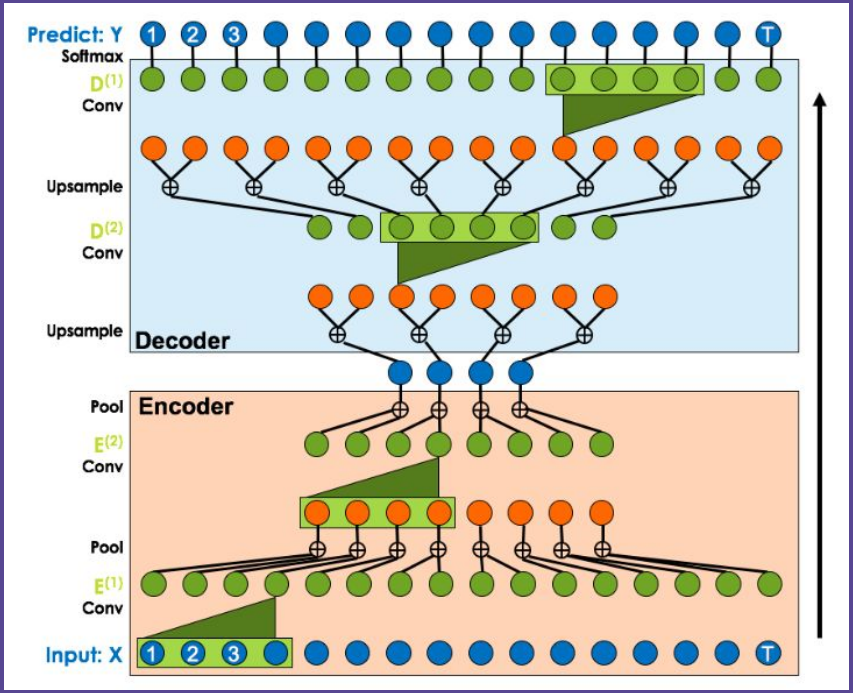


Graves et al 2005

Neural network models for acoustic behavior

Models from other literature could apply here as well:

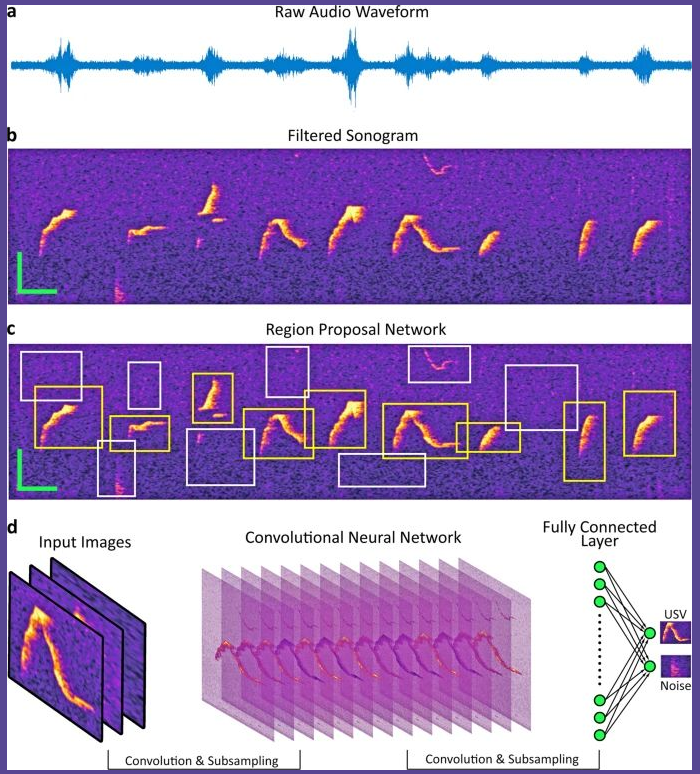
- *Audio event detection*
- *Action segmentation*
  - e.g. Encoder-Decoder Temporal Convolutional Network of Lea et al. 2017



Lea et al. 2017

Neural network models for acoustic behavior

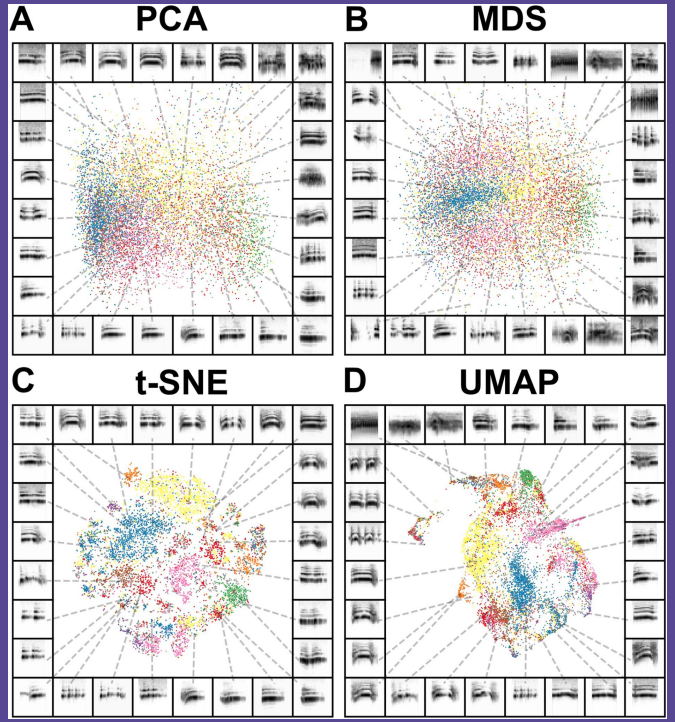
- Annotation as *object detection*
  - Detect units as bounding boxes
  - Often used with mouse ultrasonic vocalizations
- Examples
  - Deepsqueak (Matlab)



Coffey et al 2019

Neural network models for acoustic behavior

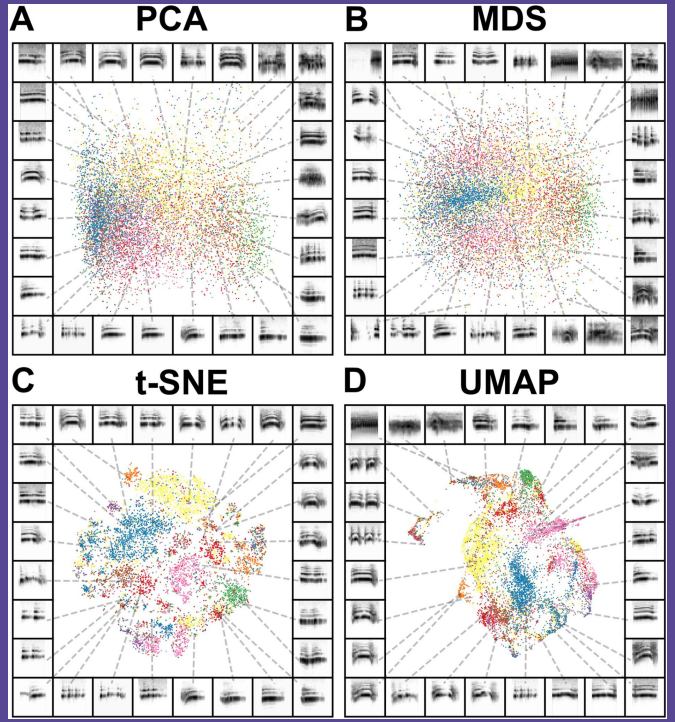
- Unsupervised models
  - For *dimensionality reduction*
    - to *cluster*
    - or measure *similarity*



Sainburg et al. 2020

Neural network models for acoustic behavior

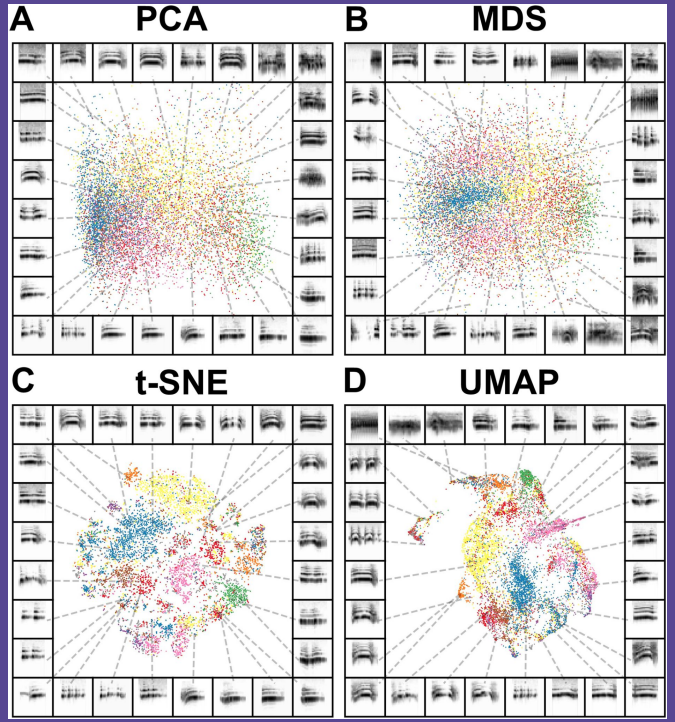
- Unsupervised models
  - Examples
    - Parametric UMAP (Sainburg, Gentner, McInnes)
      - Tensorflow, Pytorch
    - AVA (Goffinet et al. 2021)
      - Pytorch



Sainburg et al. 2020

Neural network models for acoustic behavior

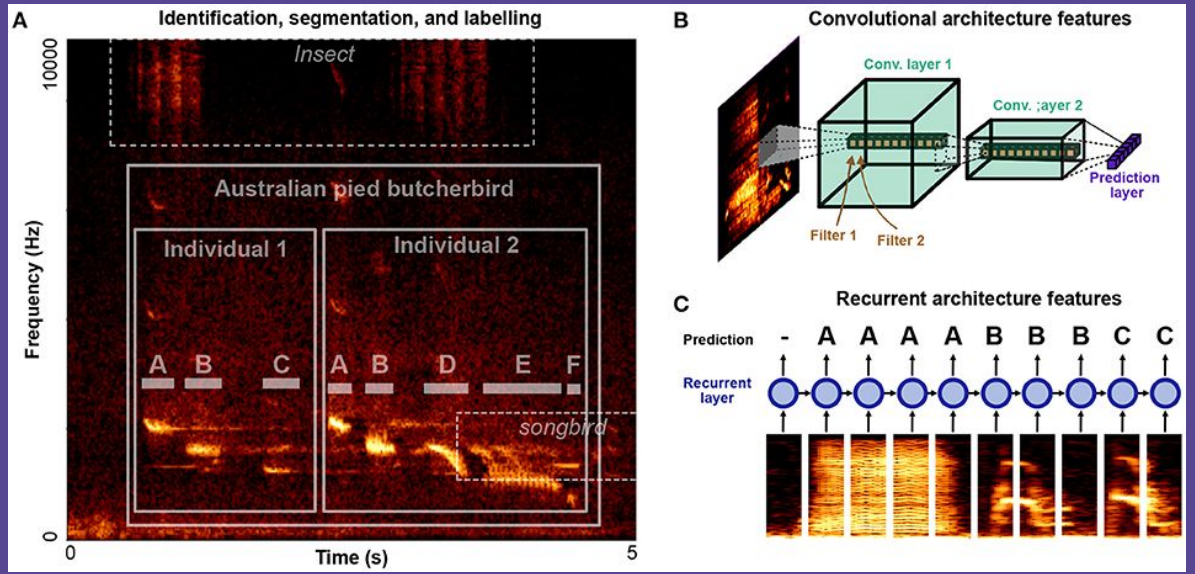
- Unsupervised models
  - Examples
    - UMAP (Sainburg, Gentner, McInnes)
      - Tensorflow, Pytorch
    - AVA (Goffinet et al. 2021)
      - Pytorch
  - Some of these methods **require** segmented audio
    - → Need to measure how results depend on segmentation



Sainburg et al. 2020

Neural network models for acoustic behavior

Need: single framework developed and maintained by research software engineers



Sainburg Gentner 2021

Neural network models for acoustic behavior

Need: single framework developed and maintained by research software engineers

https://us-rse.org/usrse23/

#USRSECON2023

A neural network framework for acoustic behavior

- Single framework, multiple models
- Easily experiment with new models
- Low/no code
- Works with a wide range of data formats
- Easily understand how much (expensive, human annotated) data you need for your task

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Single framework, multiple models

```
@model('MyModelFamily')
class MyModelDefinition:
    network = MyNetwork
    loss = MyLoss
    optimizer = torch.optim.Adam
    metrics = {'acc': metrics.Accuracy}
    default_config = {
        'optimizer':
            {'lr': 1e-3}
    }
```

vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Easily experiment with new models

```
@model(family=FrameClassificationModel)
class TweetyNoLSTMNet:
    """TweetyNet model without LSTM layer"""
    network = TweetyNetNoLSTM
    loss = torch.nn.CrossEntropyLoss
    optimizer = torch.optim.Adam
    metrics = {'acc': metrics.Accuracy,
               'levenshtein': metrics.Levenshtein,*
               'segment_error_rate': metrics.SegmentErrorRate,
               'loss': torch.nn.CrossEntropyLoss}
    default_config = {
        'optimizer':
            {'lr': 0.003}
    }
```

vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Low / no code, command-line interface, with just a few commands

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Low / no code

- command-line interface
  - with just a few commands
  - TOML config files capture options
  - **reproducibility built in by default**

```
[PREP]
data_dir = "~/Documents/data/vocal/bird1/week2"
output_dir = "./data/prep/bird1"
audio_format = "wav"
annot_format = "simple-seq"
train_dur = 900
val_dur = 80
test_dur = 400

[SPECT_PARAMS]
fft_size = 512
step_size = 64
freq_cutoffs = [ 500, 10000,]

[LEARNCURVE]
model = "TweetyNet"
train_set_durs = [ 30, 45, 75, 120, 180, 480, 600,]
```

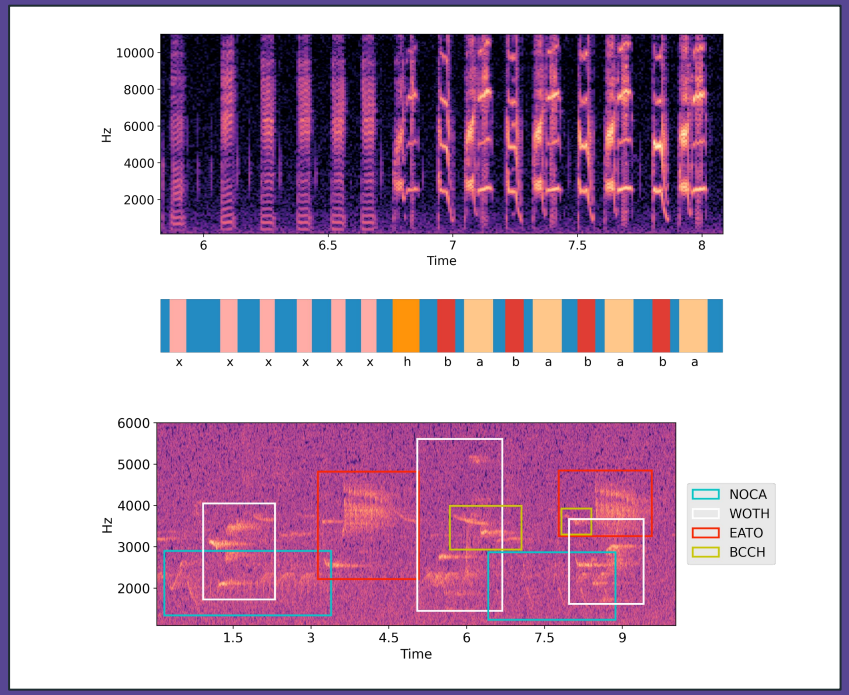
vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Works with a wide array of data formats

- vak parses annotation formats with crowsetta
- now a pyOpenSci package
  - https://www.pyopensci.org
  - published in Journal of Open Source Software
- PyCon 2023 lightning talk: https://youtu.be/54q_cPCNNS8?list=PL2Uw4_HvXqvY2zhJ9AMUa_Z6dtMGF3gtb&t=1082



https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Works with a wide array of data formats

- audio formats
  - pysoundfile
- array formats
  - npz files for spectrograms
  - scipy.io.loadmat

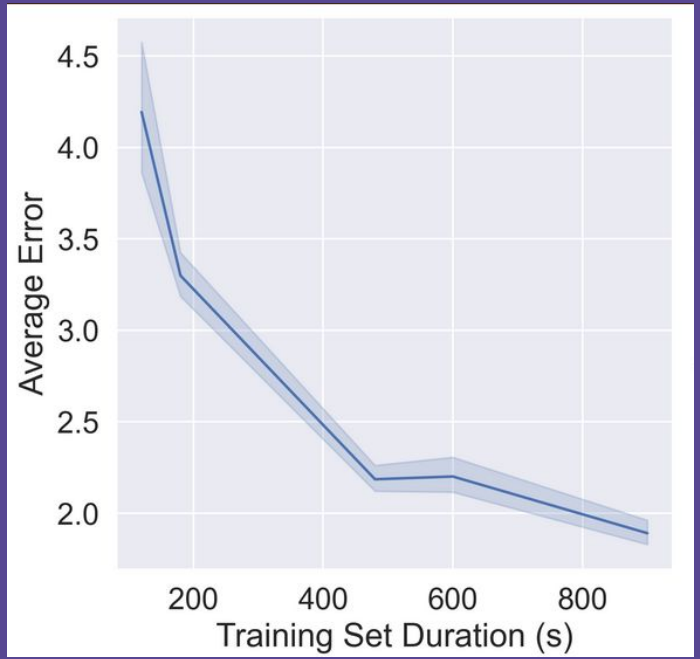
vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

Easily understand how much training data you need for your task

```
[LEARNCURVE]
models = "TweetyNet"
train_set_durs = [ 30, 45, 75, 120, 180, 480, 600]
num_replicates = 10
```



vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

- Built on the scientific Python stack
  - numpy
  - scipy
  - matplotlib
  - pandas
  - dask
- Version 1.0
  - Lightning backend
  - Better abstractions for models, tasks, and datasets

vak

https://github.com/vocalpy/vak

A neural network framework for acoustic behavior

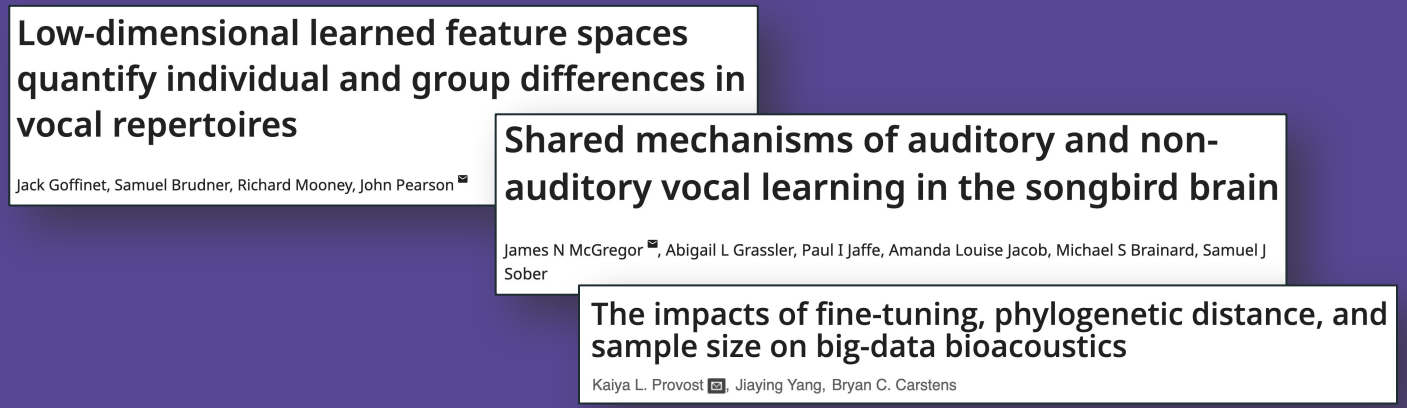
Design / API

- like other torch libraries for domain models
  - `models` module
    - family
  - `transforms` module
    - frame labels
  - `nn` module
    - `loss` module

https://github.com/vocalpy/vak

Publications using vak

- vak has been used by at least ~20 labs we have worked with directly, and are basis for several papers since.
- https://vak.readthedocs.io/en/latest/reference/about.html#publications-using-vak



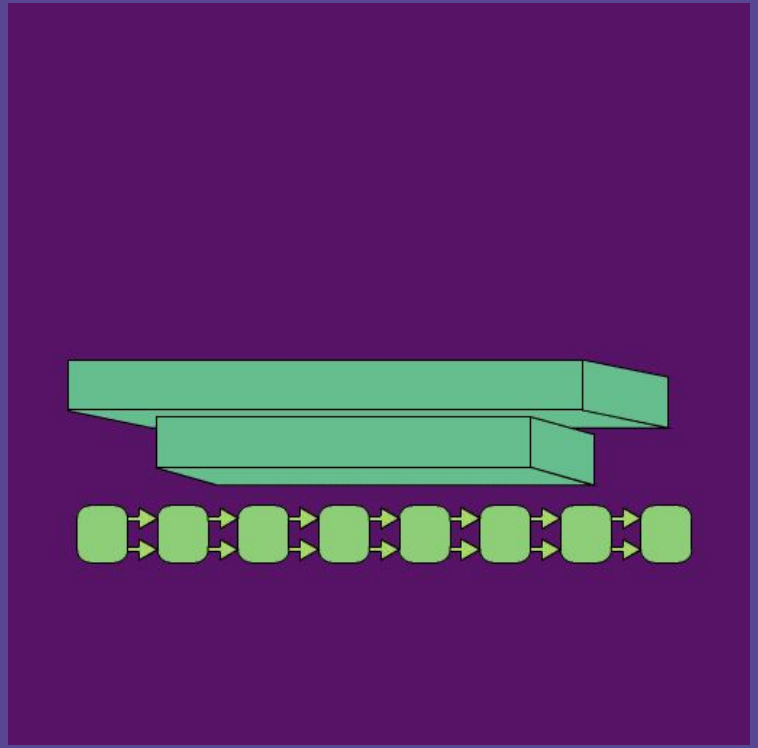
https://github.com/vocalpy/vak

Results: vak o.x

TweetyNet

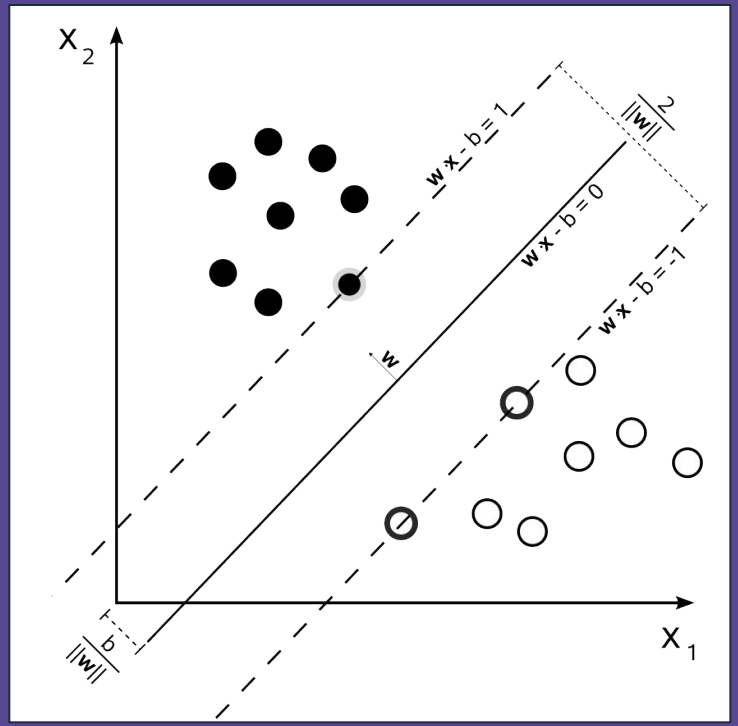
vak was developed for: "Automated annotation of birdsong with a neural network that segments spectrograms", Cohen et al., 2021

- https://elifesciences.org/articles/63853
- https://github.com/yardencsGitHub/tweetynet



How to automate annotation?

- Machine learning methods with engineered features?
  - e.g. Support Vector Machine (SVM), as in Tachibana et al. 2014
- Problem:
  - **Methods that use features extracted from segments can fail when segmentation is noisy**



https://en.wikipedia.org/wiki/Support_vector_machine#/media/File:Svm_max_sep_hyperplane_with_margin.png

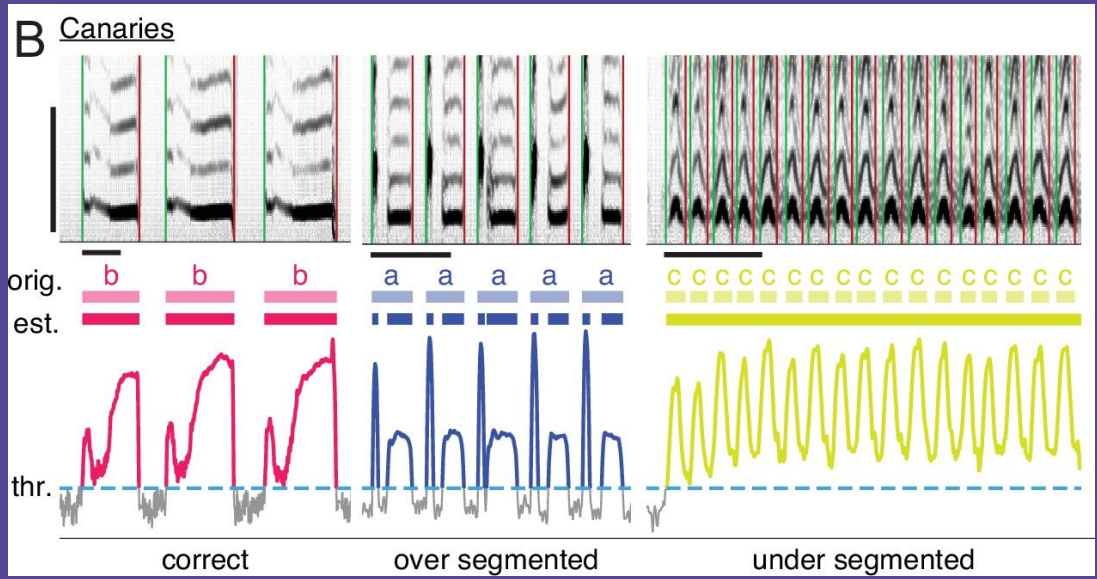
SciPy2016 https://bit.ly/43fSFzT

SciPy2017 https://youtu.be/BwNeVNou9-s

How to automate annotation?

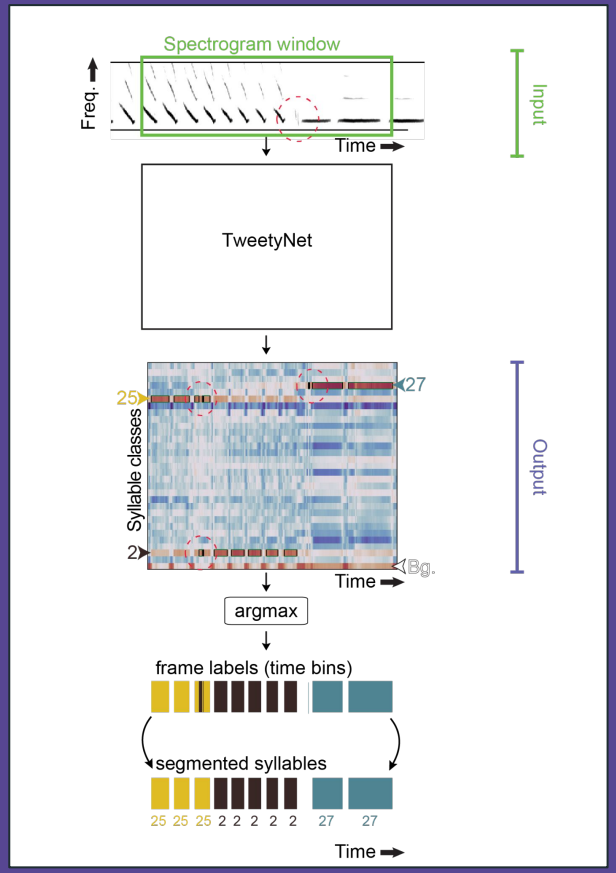
Problem:

- **Methods that use features extracted from segments can fail when segmentation is noisy**



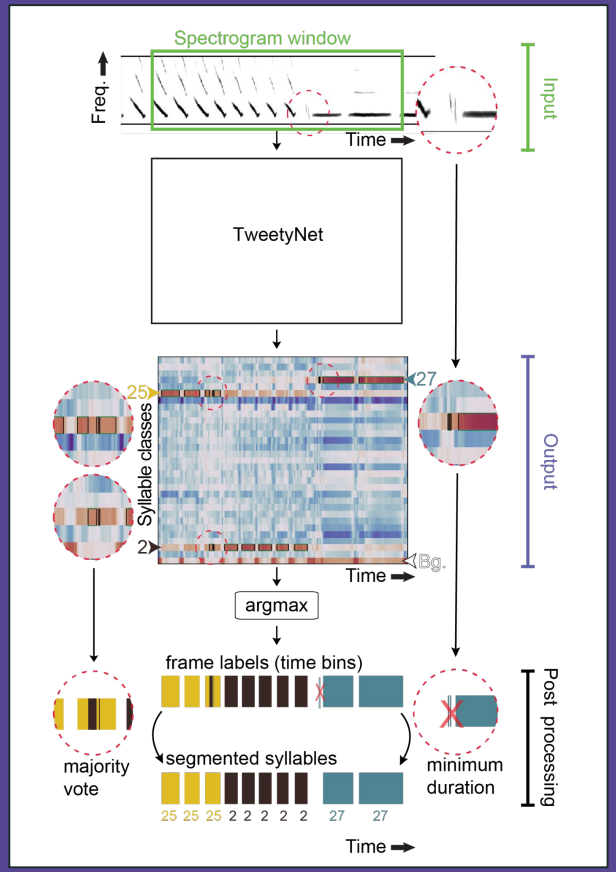
TweetyNet

A way to automate annotation without needing cleanly segmented audio



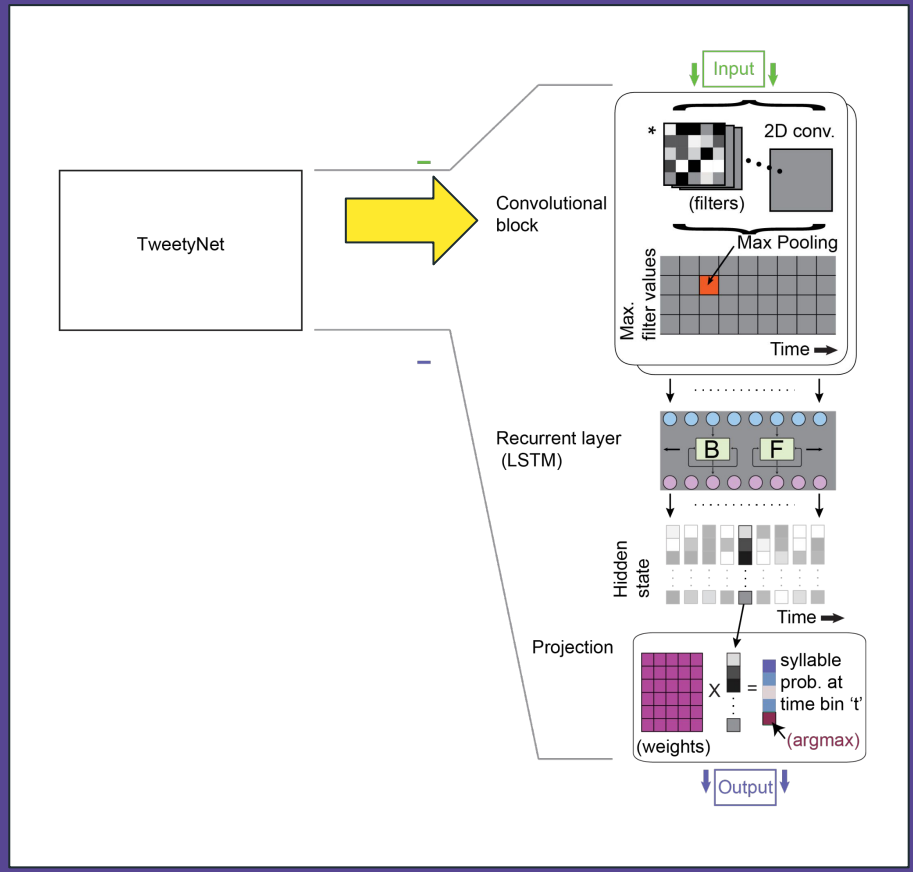
TweetyNet

A way to automate annotation without needing cleanly segmented audio



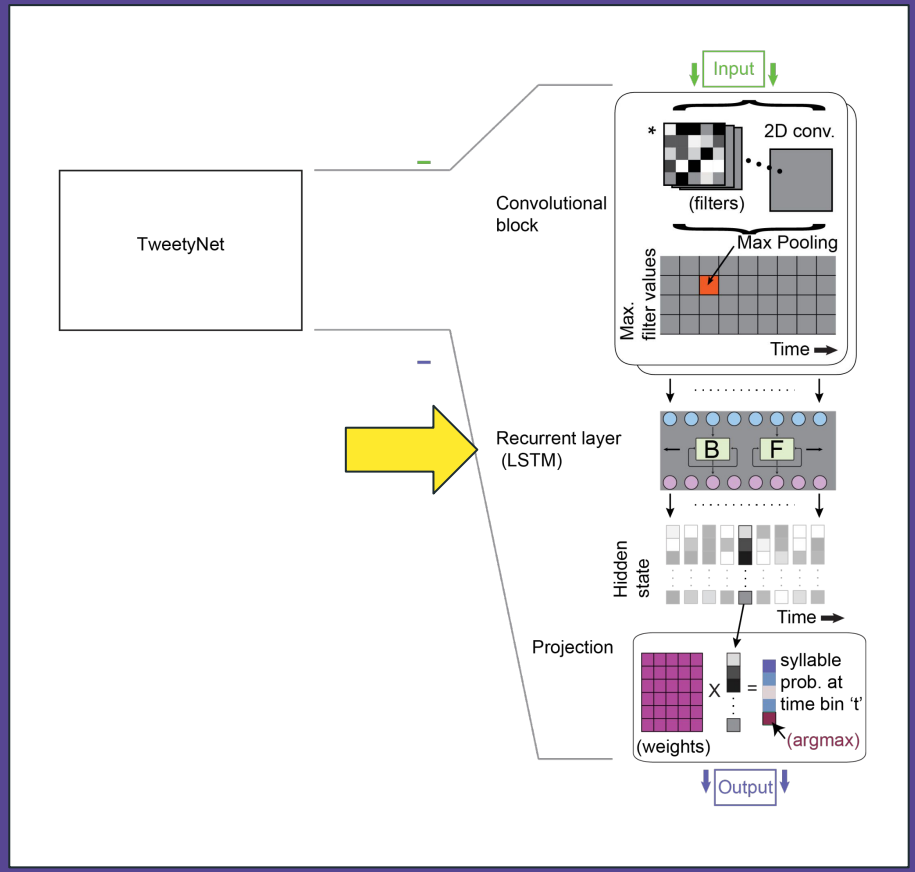
TweetyNet

A way to automate annotation without needing cleanly segmented audio



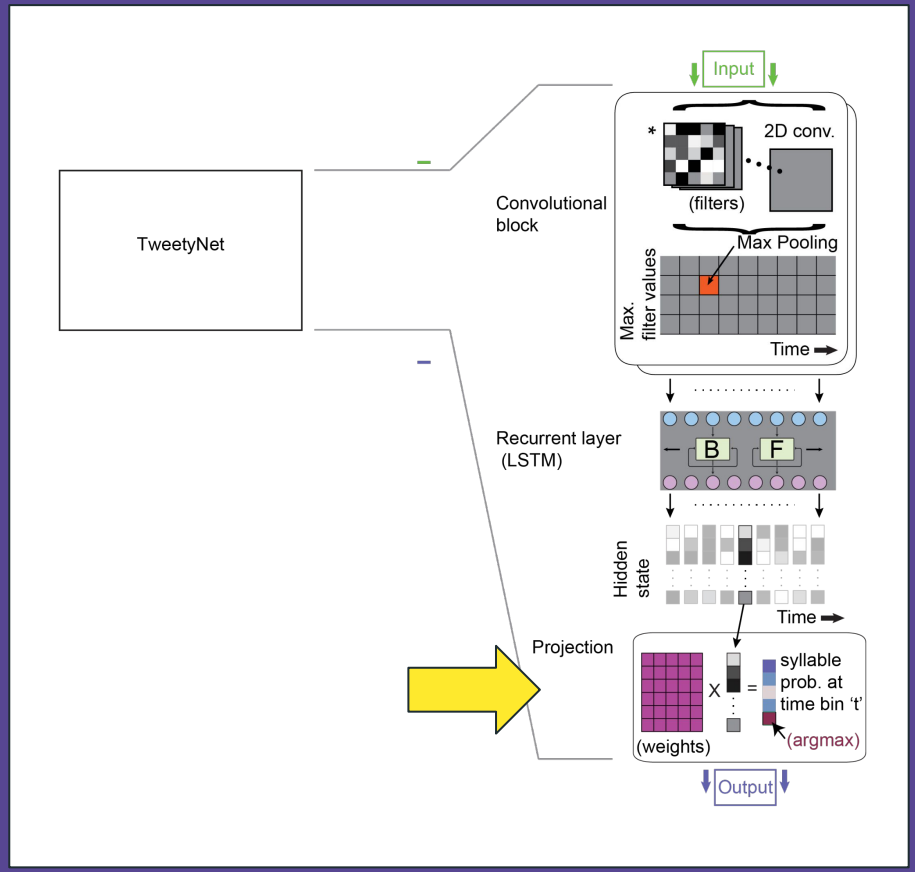
TweetyNet

A way to automate annotation without needing cleanly segmented audio



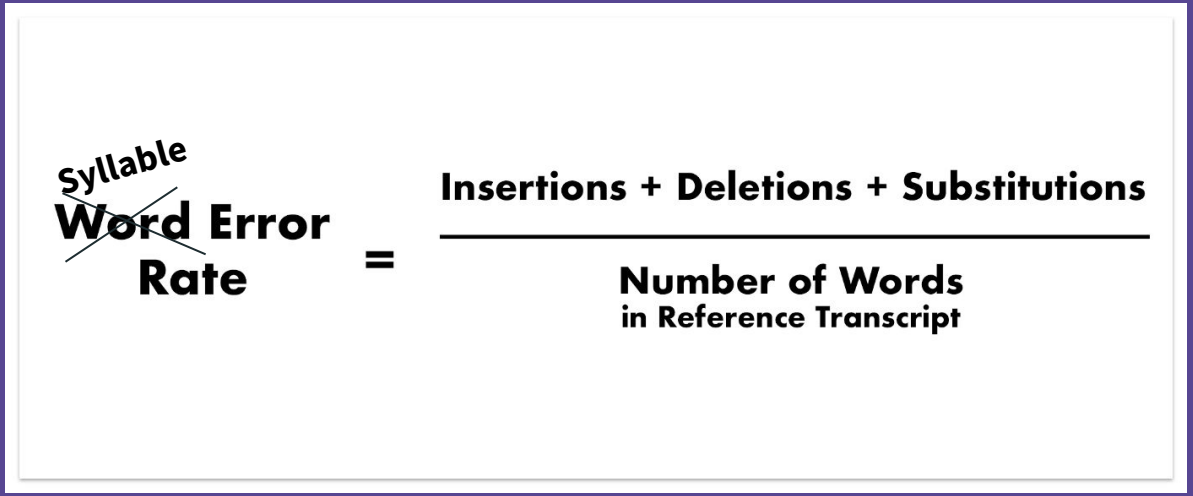
TweetyNet

A way to automate annotation without needing cleanly segmented audio



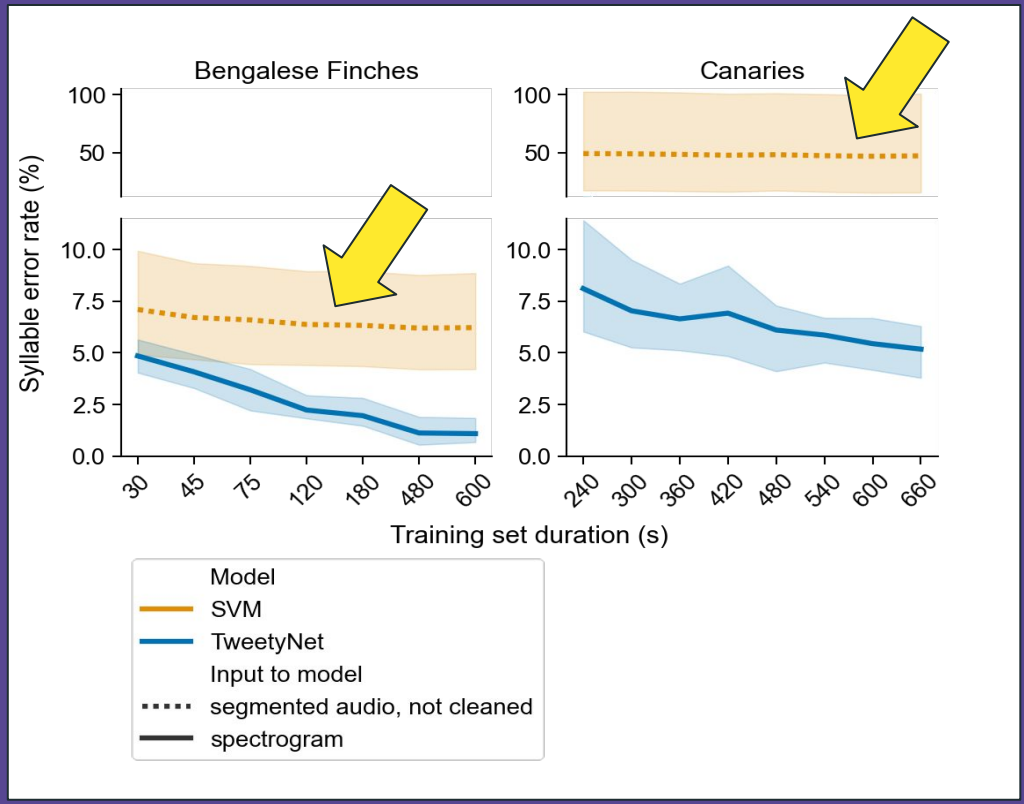
Metrics

- Frame error
- Syllable error rate
  - an edit distance
  - normalized



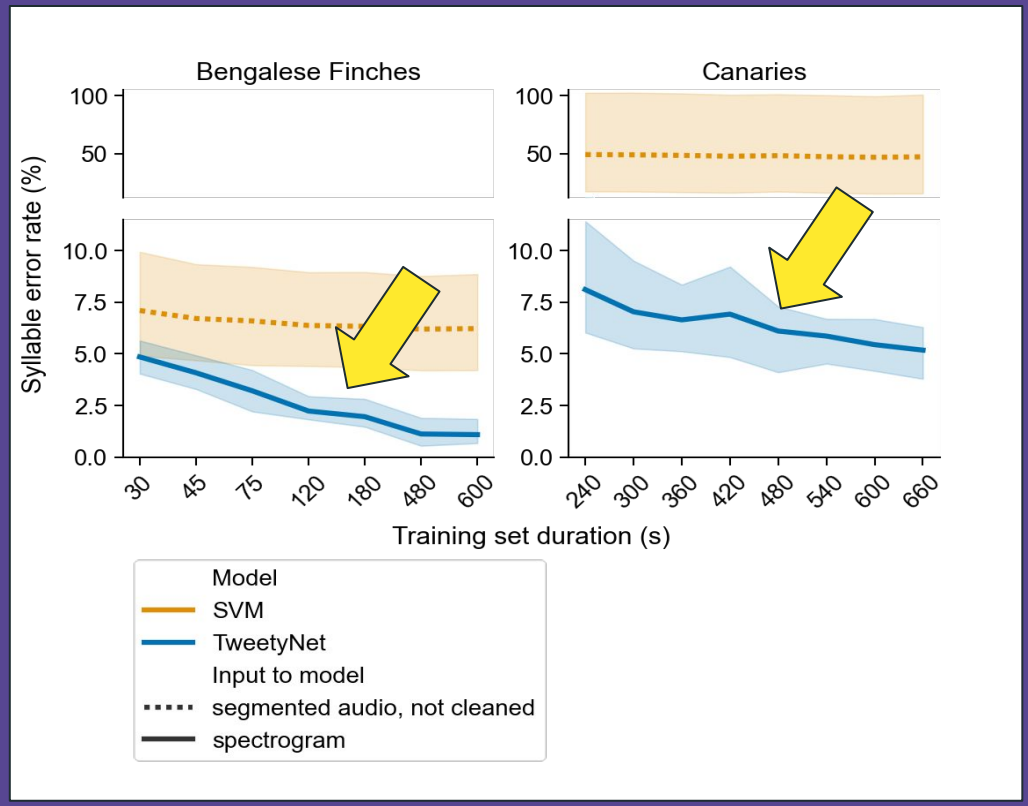
TweetyNet v. Support Vector Machine

Support Vector Machine applied to "raw" segmented audio = very high syllable error rate



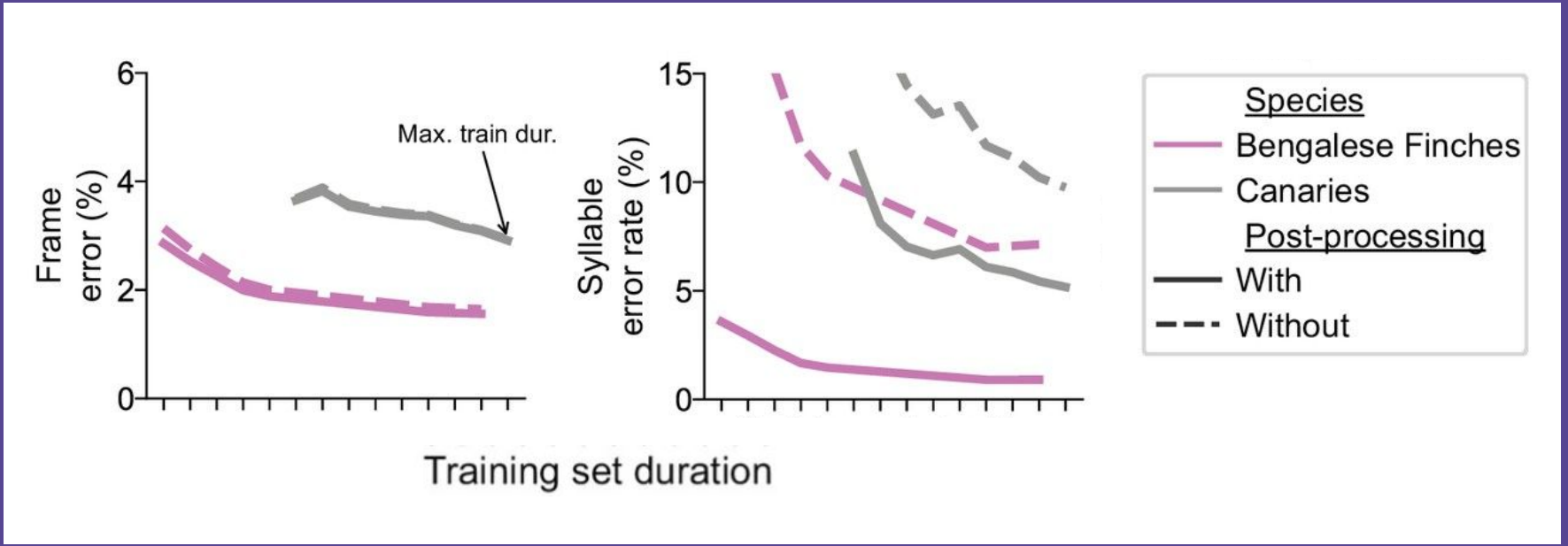
TweetyNet v. Support Vector Machine

TweetyNet applied to spectrogram, without needing to segment audio: much lower syllable error rate



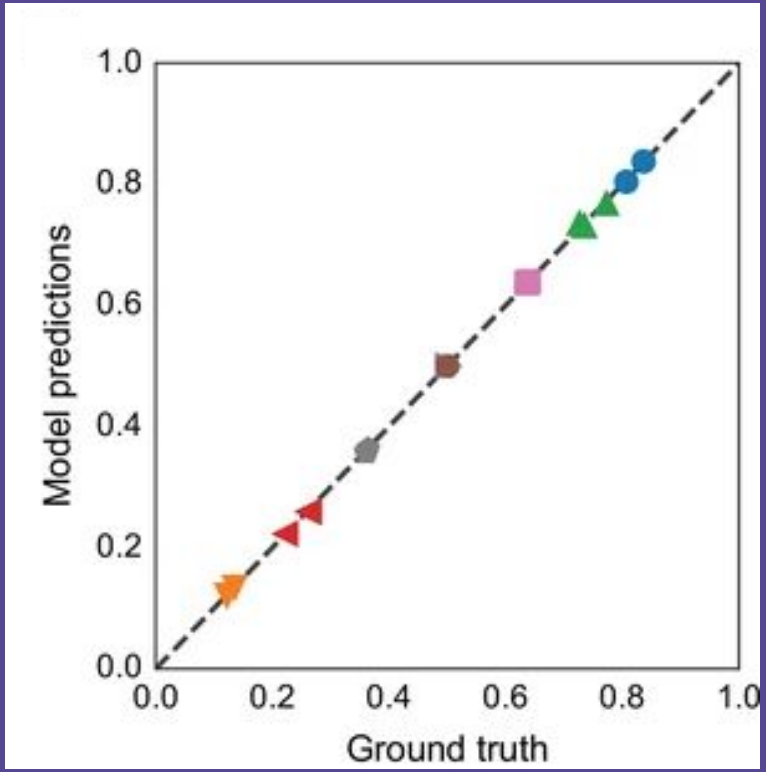
Post-processing

Reduces syllable error rate, not frame error



TweetyNet performance

TweetyNet predictions replicate key results about stability of *branch points* in Bengalese finch song



Results: Vak 1.0

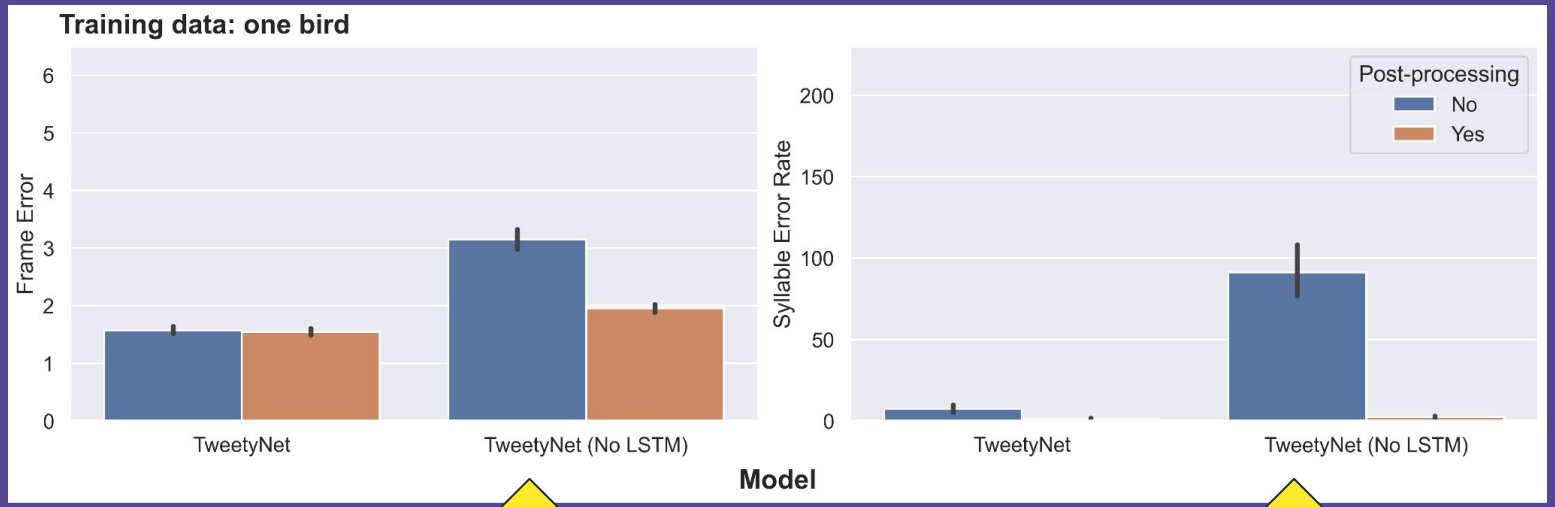
Ablation experiment

Ablation = remove recurrent Long Short Term Memory (LSTM) layer

```
@model(family=FrameClassificationModel)
class TweetyNoLSTMNet:
    """TweetyNet model without LSTM layer"""
    network = TweetyNetNoLSTM
    loss = torch.nn.CrossEntropyLoss
    optimizer = torch.optim.Adam
    metrics = {'acc': metrics.Accuracy,
               'levenshtein': metrics.Levenshtein,*
               'segment_error_rate': metrics.SegmentErrorRate,
               'loss': torch.nn.CrossEntropyLoss}
    default_config = {
        'optimizer':
            {'lr': 0.003}
    }
```

Ablation experiment

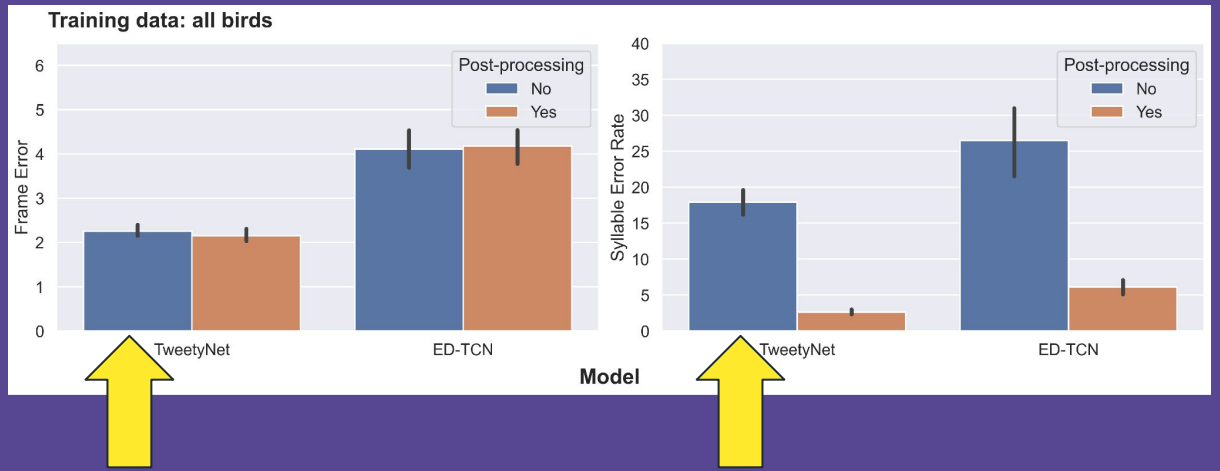
TweetyNet without LSTM has higher frame rate and syllable error rate



Comparing architectures

On this task, TweetyNet achieves a lower segment error rate than ED-TCN (Lea et al. 2017)

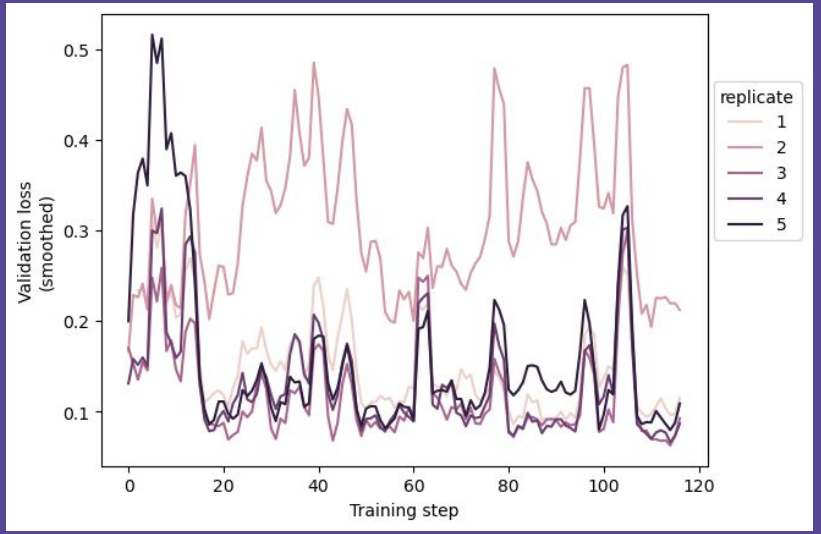
- Lea et al. report that ED-TCN reduces oversegmenting compared to a CNN-LSTM model



Inspecting loss plots

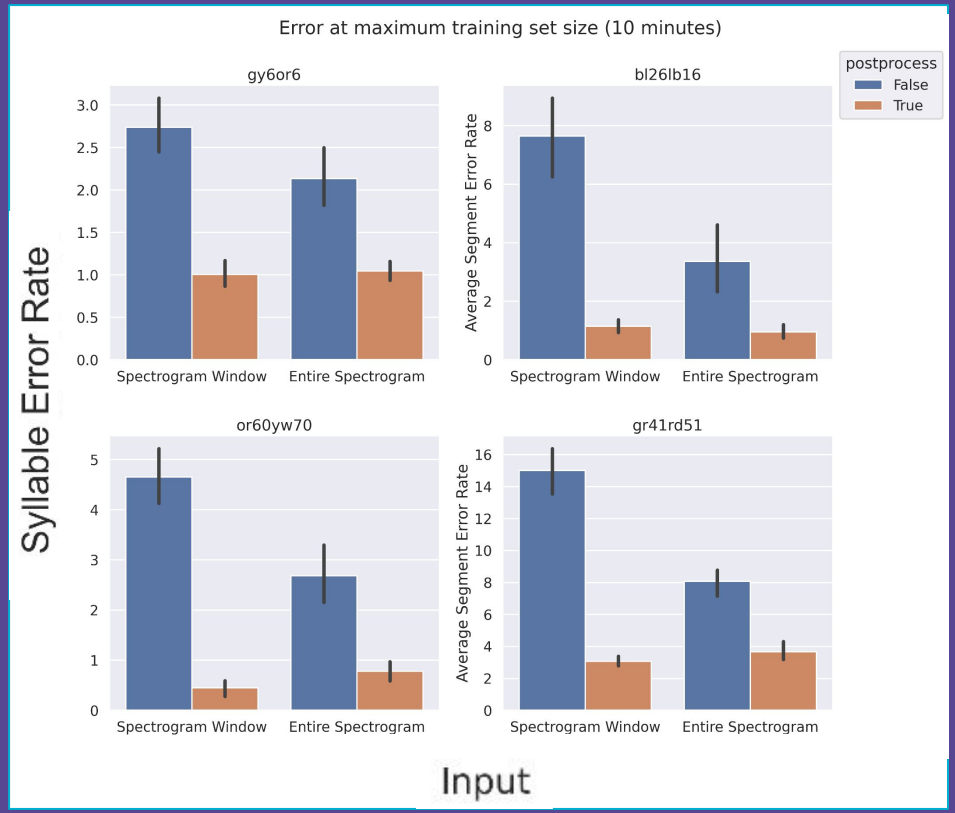
Can convert Tensorboard events files to pandas Dataframes with `vak.common.tensorboard.events2df`

No clear evidence of overfitting



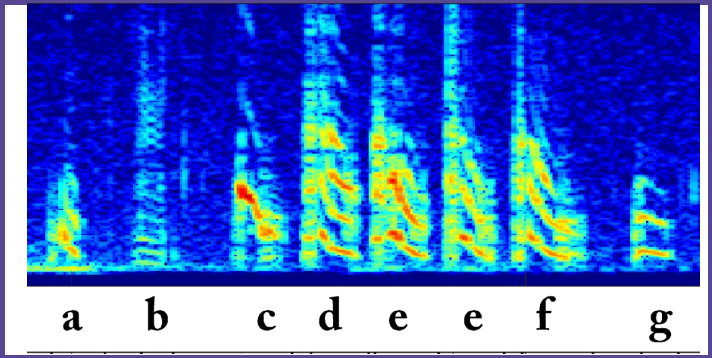
Training TweetyNet on entire song bouts

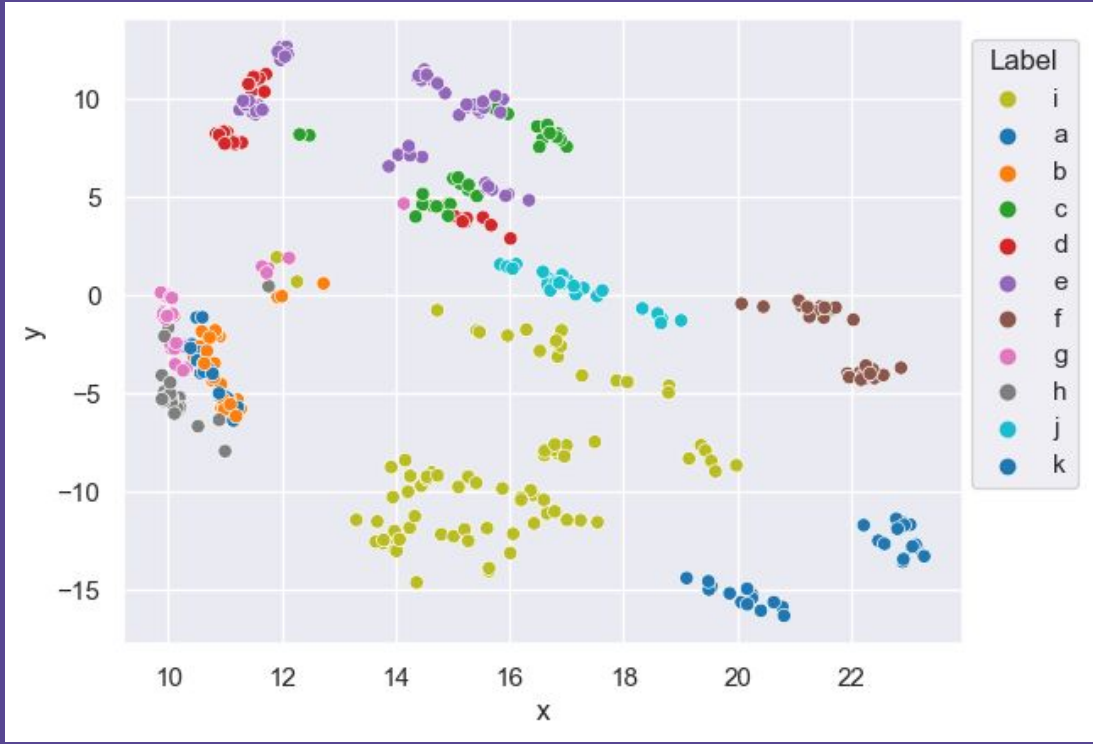
Improves syllable error rate **without** post-processing



Other model families: Parametric UMAP

Embedding by a fit Parametric UMAP model that uses a convolutional encoder





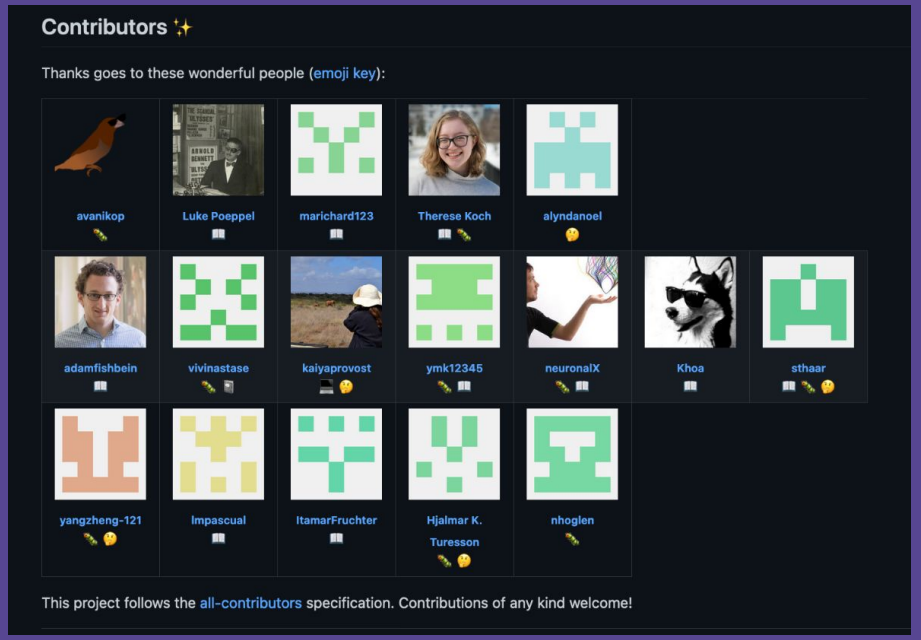
vak development roadmap

In progress as part of version 1.0: https://github.com/vocalpy/vak/issues/614

- Additional model families
  - Object detection
  - Sequence-to-sequence
- Pre-trained models
- Built-in benchmark datasets
- VocalPy as backend for `prep` step
  - https://github.com/vocalpy/vocalpy
  - Proceedings paper in Forum Acusticum 2023

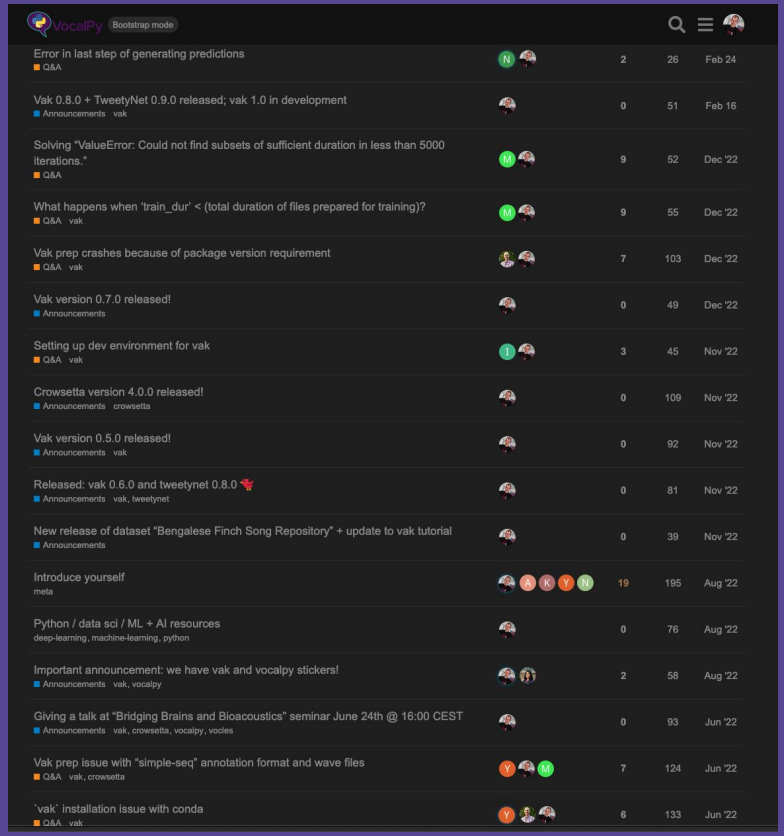
Acknowledgements (part 2)

- **Thank you contributors!**



VocalPy community

- **We already have a growing forum: https://forum.vocalpy.org/**



Ways you can contribute

- Star our repositories on GitHub
- Join the forum
  - Ask questions
  - Answer questions!
  - Share examples
- Contribute code

Questions?

- VocalPy organization on GitHub: https://github.com/vocalpy
  - https://github.com/vocalpy/vak
  - https://github.com/vocalpy/crowsetta
  - https://github.com/vocalpy/vocalpy
- vak docs: https://vak.readthedocs.io/en/latest/
- crowsetta docs: https://crowsetta.readthedocs.io/en/latest/
- VocalPy forum: https://forum.vocalpy.org/