Textless NLP
towards language processing from raw audio

Emmanuel Dupoux

MVA 2023

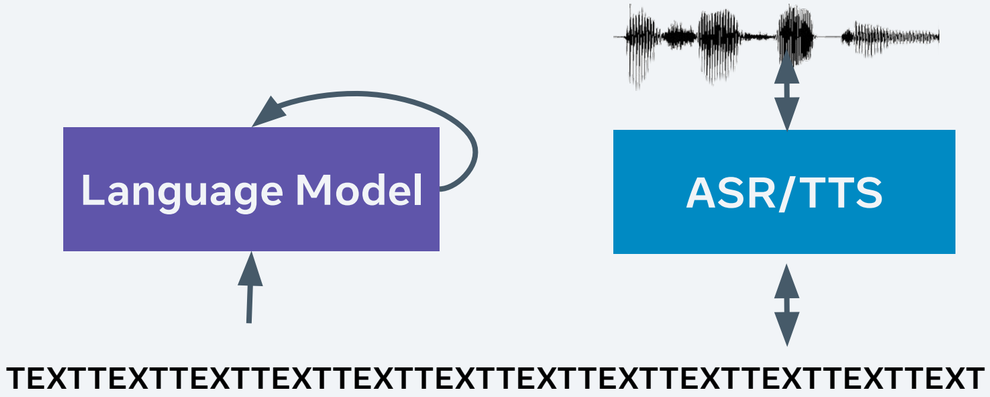
What

Textless NLP

Spoken language generation

Training AI models directly from raw audio recordings - no text or labels

Standard NLP



1. Fisher dataset
2. Nguyen et al. (2022)

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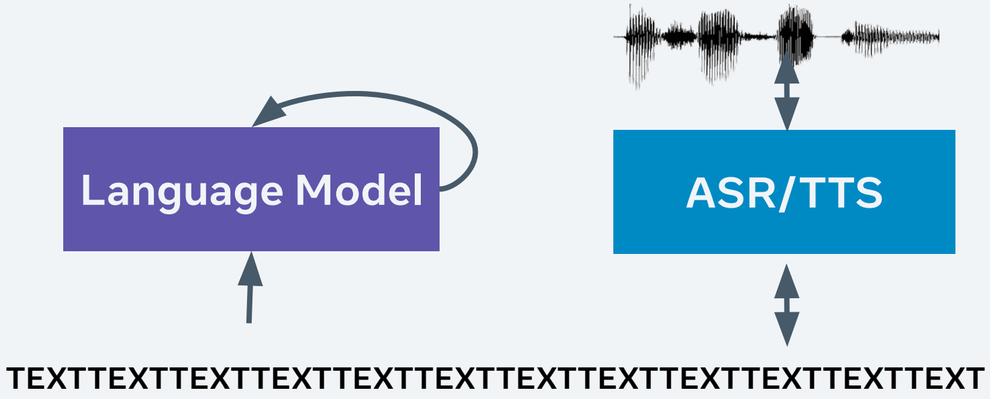
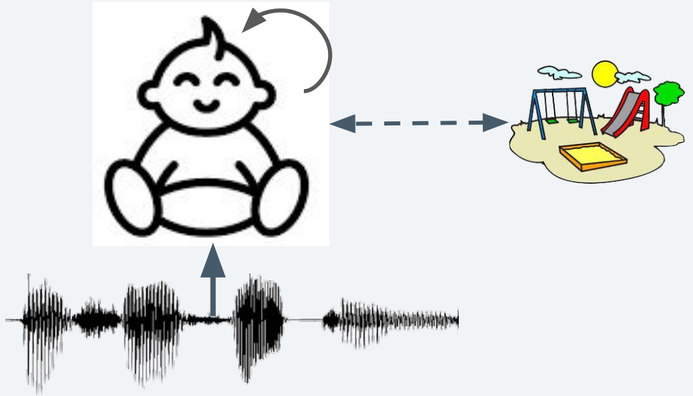
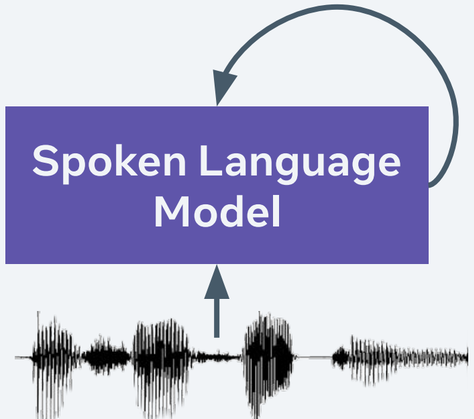


Human infants



Textless NLP



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Textless NLP

Spoken language generation

Training AI models directly from raw audio recordings - no text or labels

Spoken language is the primary means of human communication[1]

Yet, internet services are text based and struggle to capture nuances and richness of the oral modality.

1. Fisher dataset
2. Nguyen et al. (2022)

Textless NLP

Spoken language generation

Training AI models directly from raw audio recordings - no text or labels

Spoken language is the primary means of human communication[1]

Yet, internet services are text based and struggle to capture nuances and richness of the oral modality.

A simple solution? ASR+LM+TTS

Reproduce semantic aspect of the dialogue, but the expressivity and timing is wrong

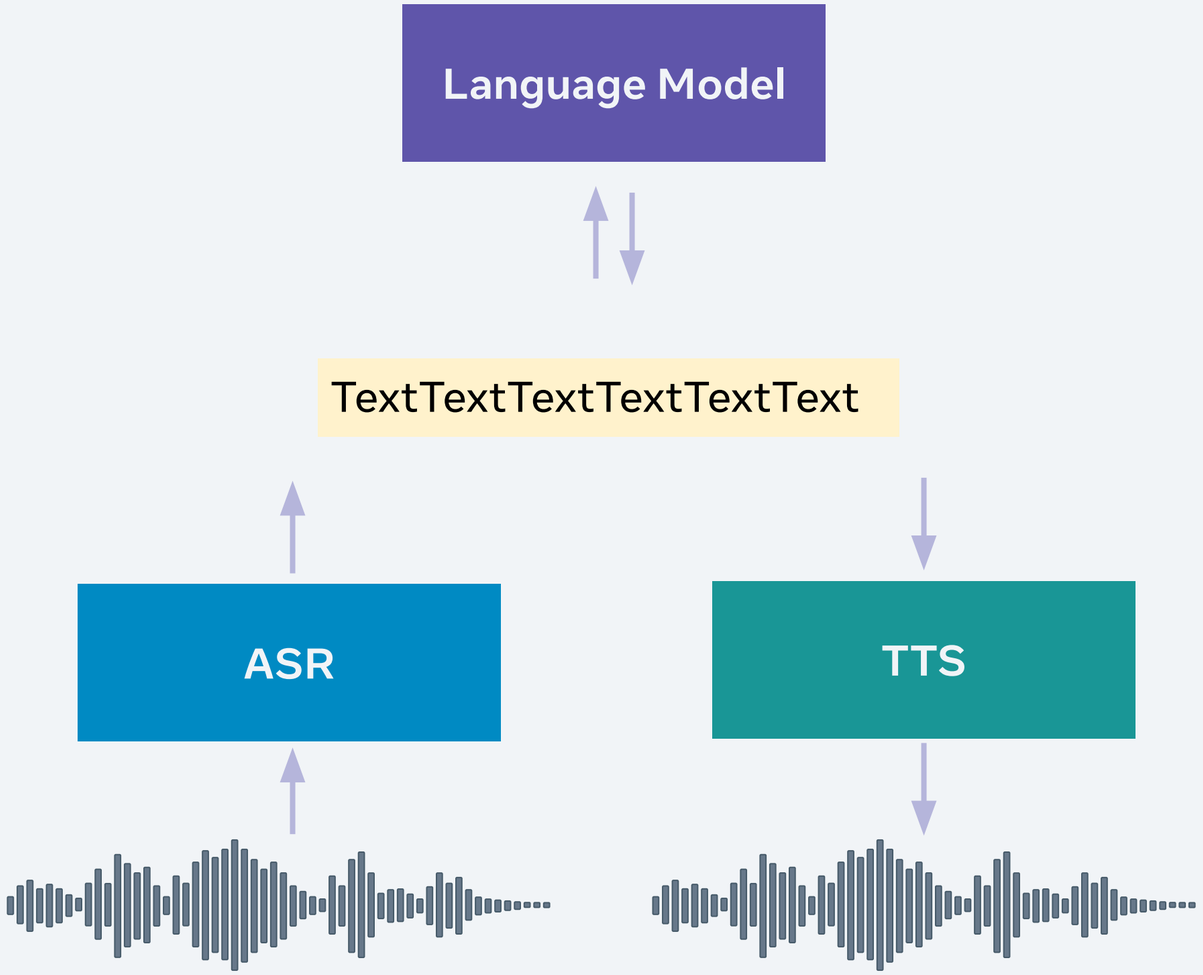
Generating spoken dialogues with gSLM[2]

The model reproduces naturalistic turn taking behavior including laughter and backchanneling, which is important for smooth human/agents interactions.

1. Fisher dataset
2. Nguyen et al. (2022)

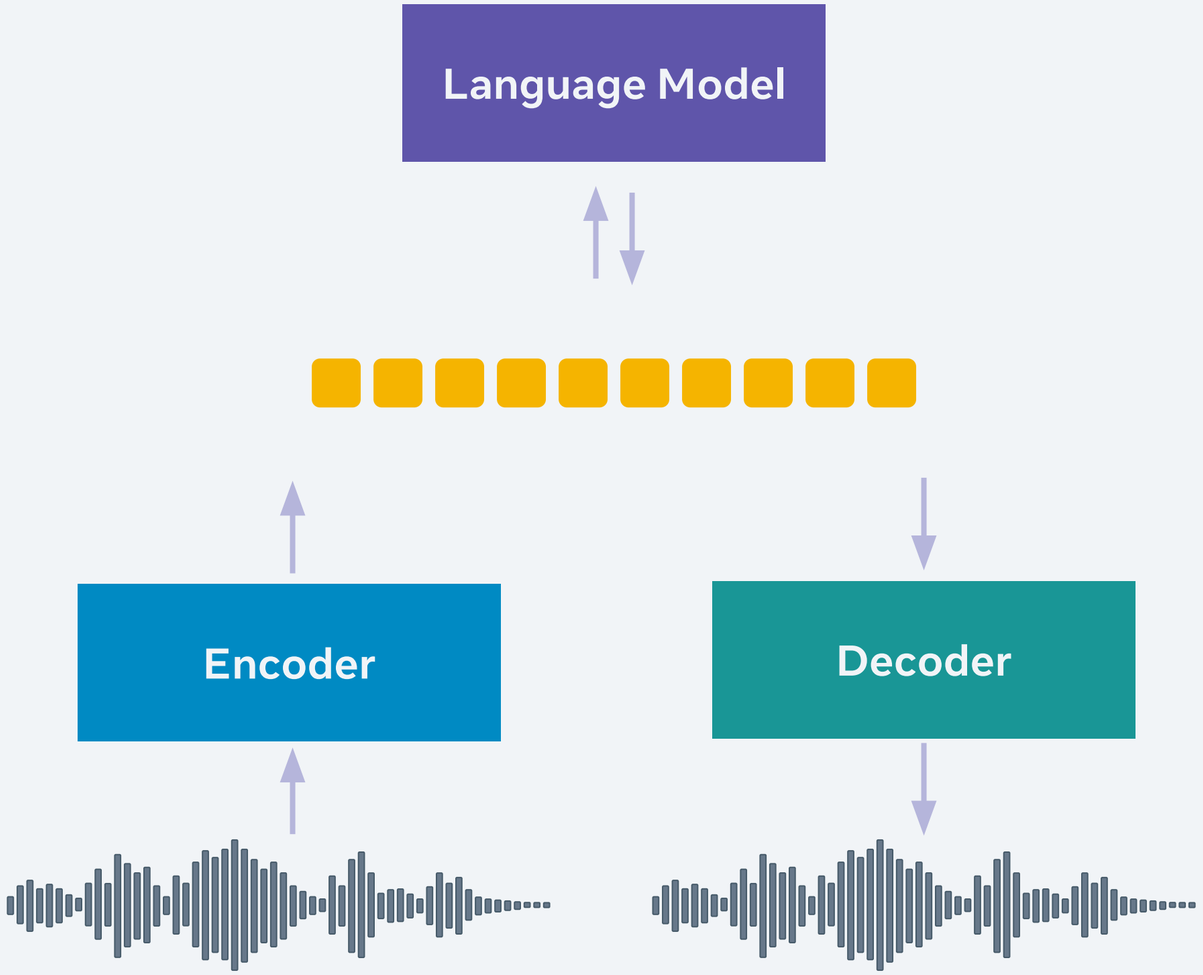
How

ASR+LM+TTS



Generative spoken language modeling

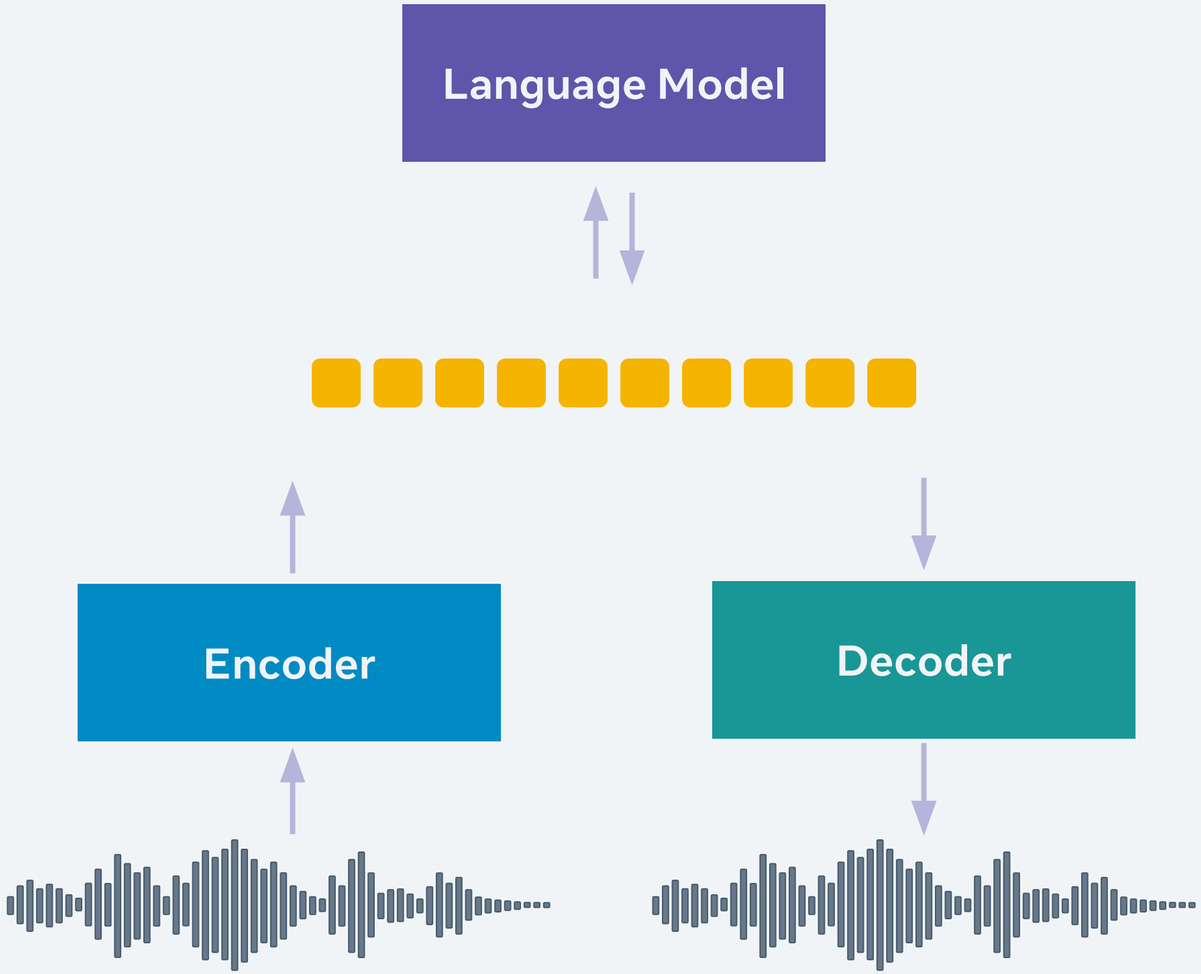
Self-supervised learning!



Generative spoken language modeling

Evaluation

Zero Resource Speech Challenge (ZRC) series



https://www.zerospeech.com

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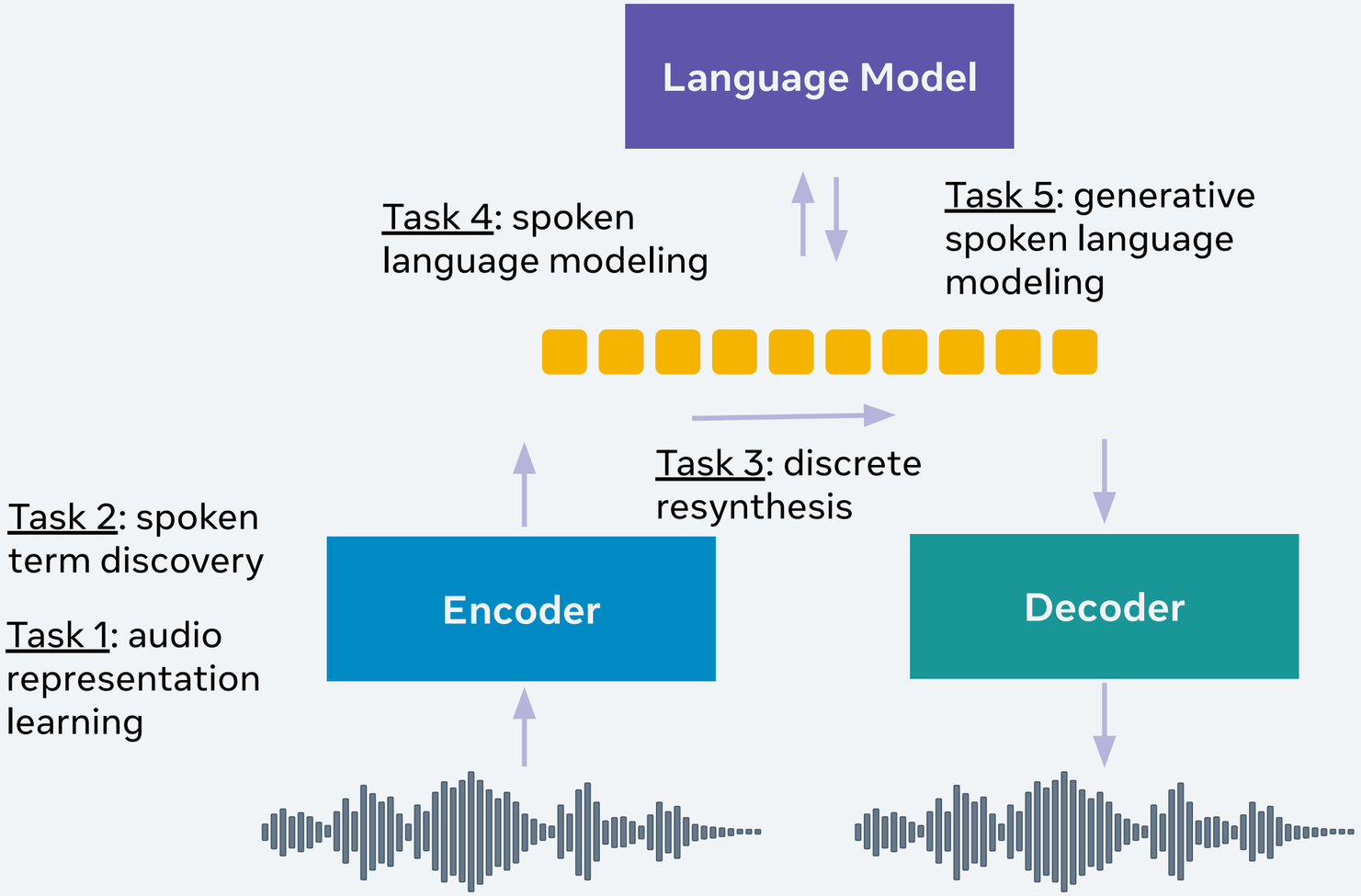

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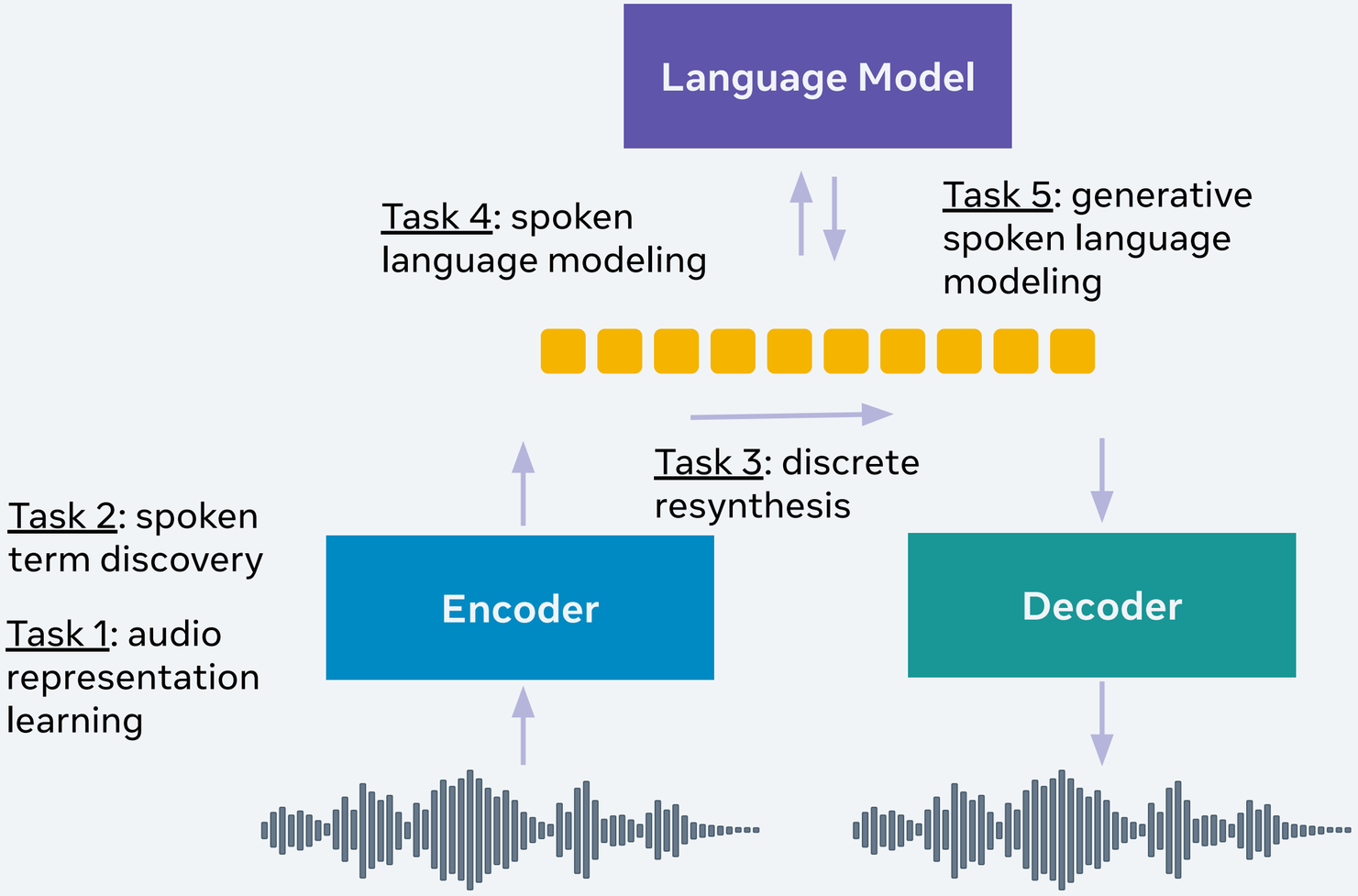
Generative spoken language modeling

Evaluation

Chall.	Tasks	Train Data
2015 [9]	T1, T2	English (Buckeye 5h), Xitsonga (2h30)
2017	T1, T2	English (45h), French (24h), Mandarin (2h30), German (25h), Wolof (10h)
2019	T3.	English (15h+4h40), Indonesian (15h+1h30)
2020	T1,T2,T3	reboot of ZR17, ZR19
2021a	T1,T4	English (Librispeech 960 or 100)
2021b	T1,T4	idem plus speech coco

Zero Resource Speech Challenge (ZRC) series



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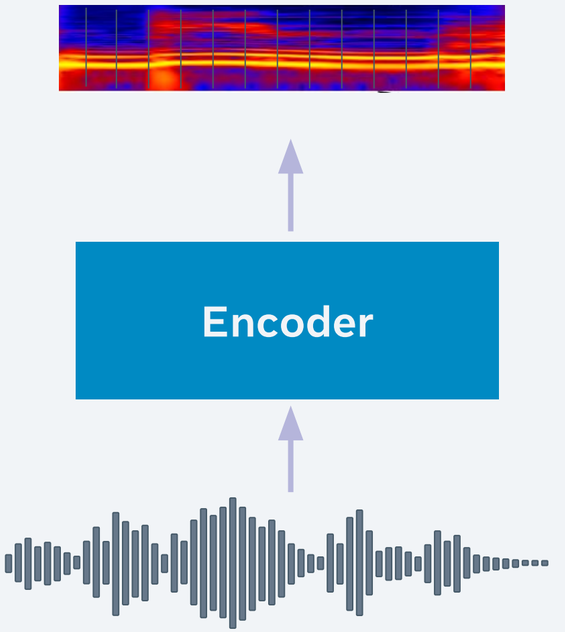
The encoder

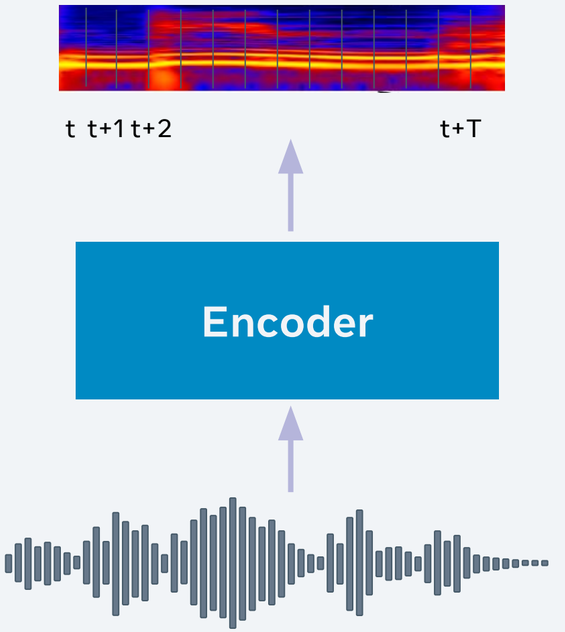
Audio Representation Learning



ZRC TASK 1:
Learning representations that encode linguistic information, and disregard non linguistic ones

The encoder

Audio Representation Learning



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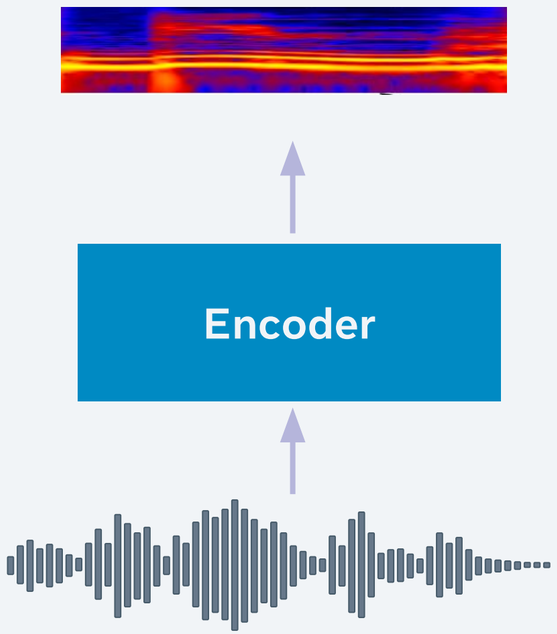


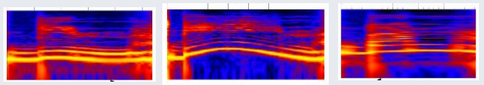
ZRC TASK 1:

Learning representations that encode linguistic information, and disregard non linguistic ones

Evaluation: *ABX discrimination*

a b x

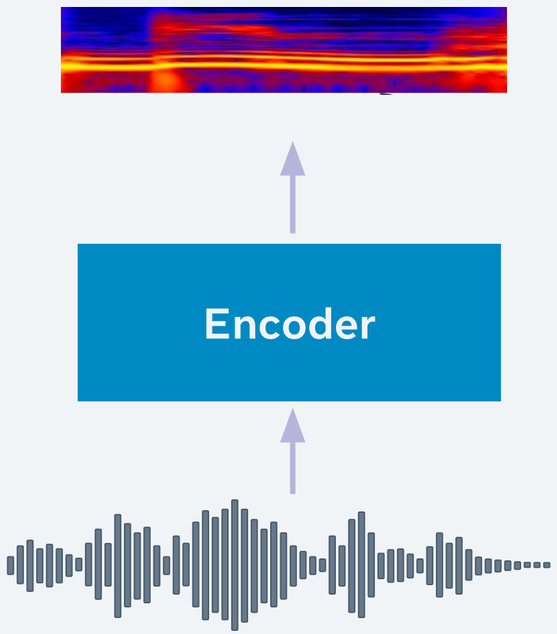
bit_{T1} bet_{T1} bit_{T2}



d(a,x) < d(b,x) ?

The encoder

Audio Representation Learning



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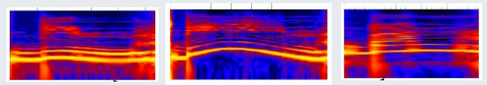


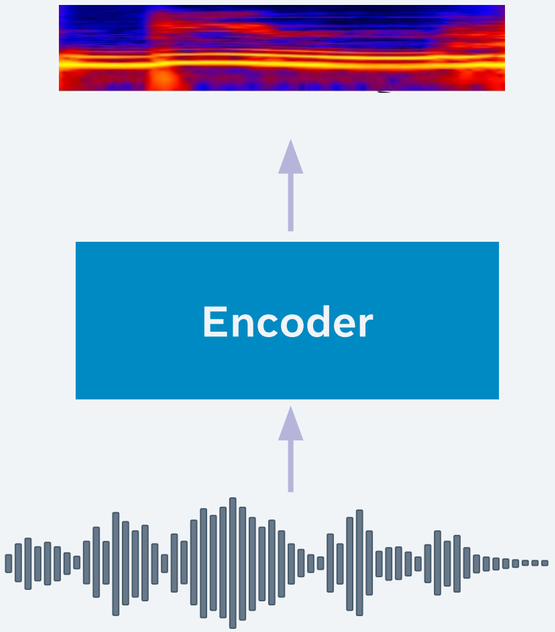
d(a,x) < d(b,x) ?

Main idea: *information compression*

- Spectral information (MFCC):
  20kbit/sec
- Telephone, speech codec:
  8kbit/sec (2.5x reduction)
- Text (phonemes):
  40bits/sec (***200x reduction !)***

The encoder

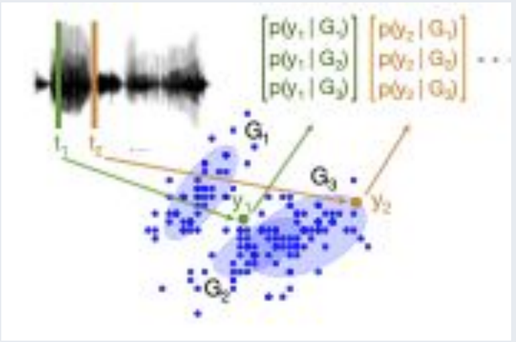
Audio Representation Learning



Best models

Compressive

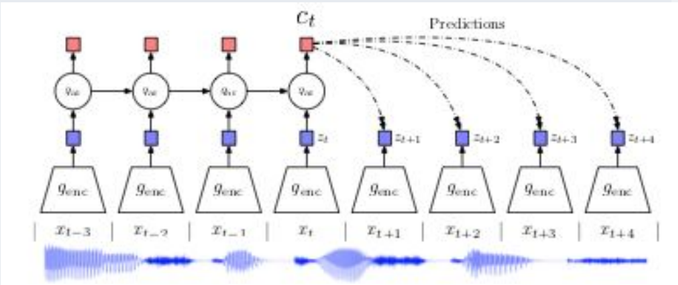
DPGMM[1]



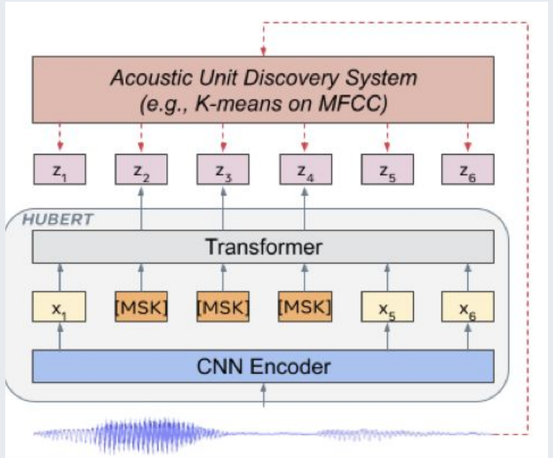
Wavenet autoencoder[2]

Predictive

CPC[3]



HuBERT[4]

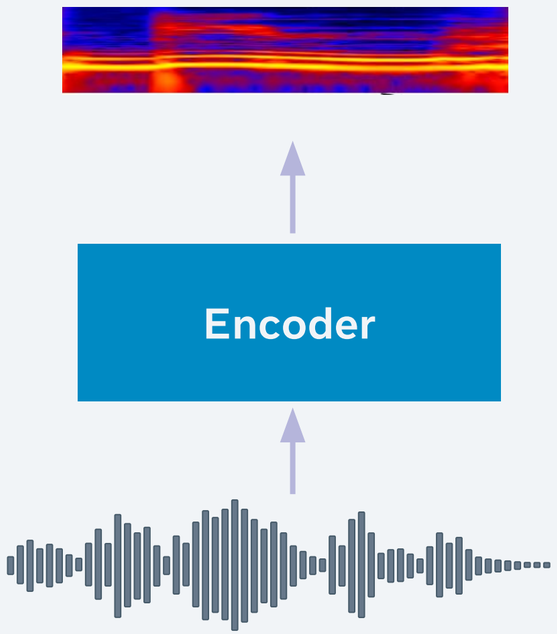


Wav2VEC[5]**, etc**

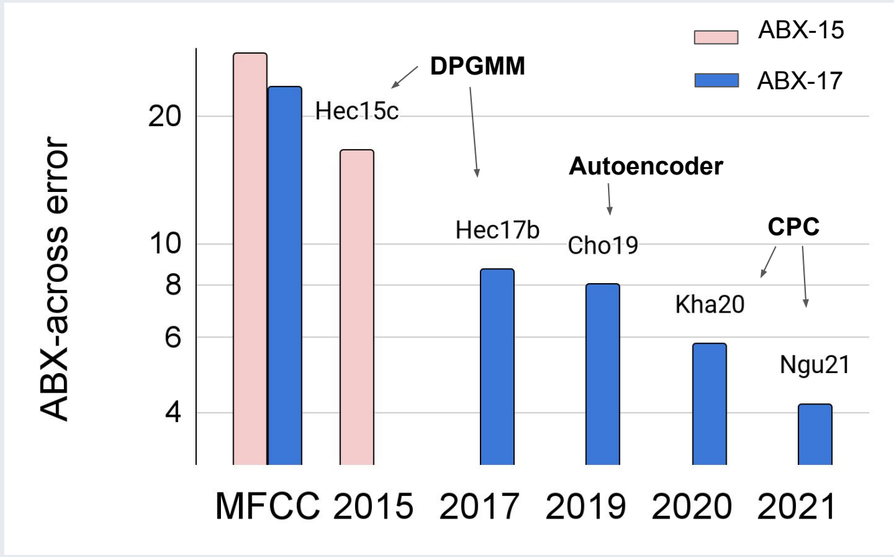
1. Heck et al, 2015, 2017
2. Chorowski et al. 2019
3. Van den Oord, 2018; Kharitonov et al. 2020;
4. Hsu et al, 2021
5. Baevsky et al, 2020

The encoder

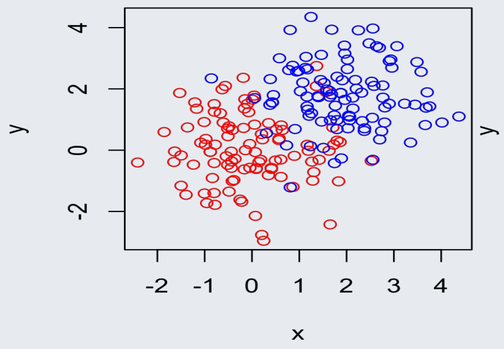
Audio Representation Learning



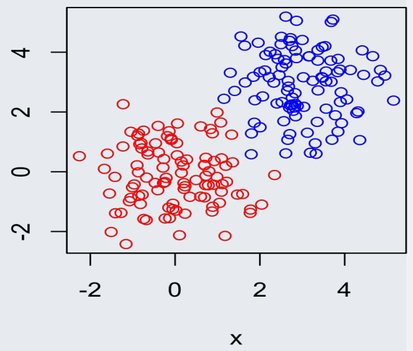
Leaderboard



Dunbar, Hamilakis, Dupoux (submitted)



ABX=20%
(2σ)

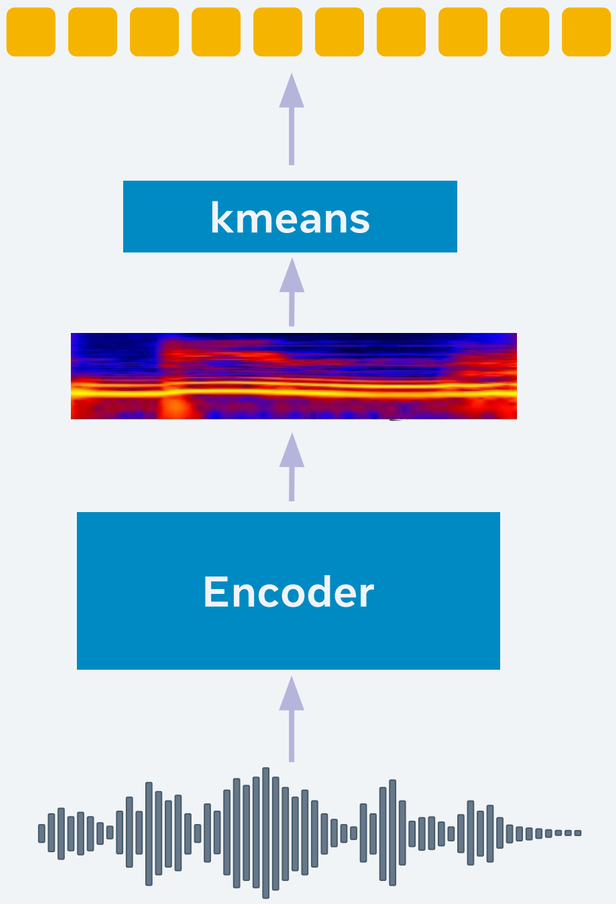


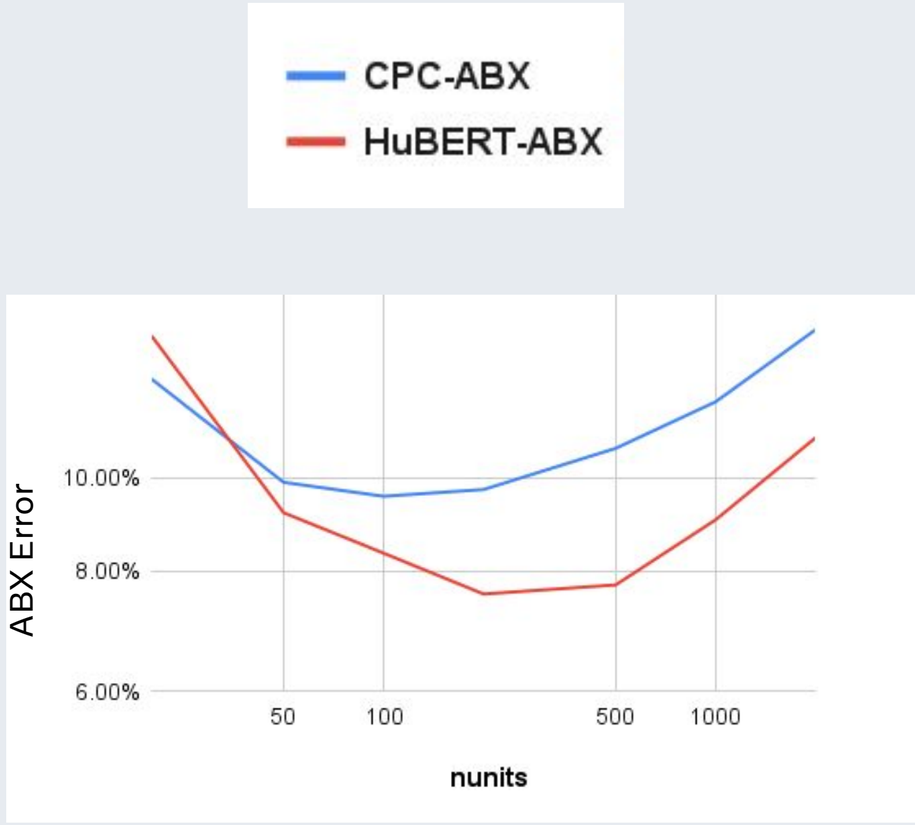
ABX=5%
(2.4σ)

Dunba, Hamilakis, Dupoux (2022)

The encoder

Acoustic Unit Discovery
(discrete representation learning)





Nguyen et al (2022)

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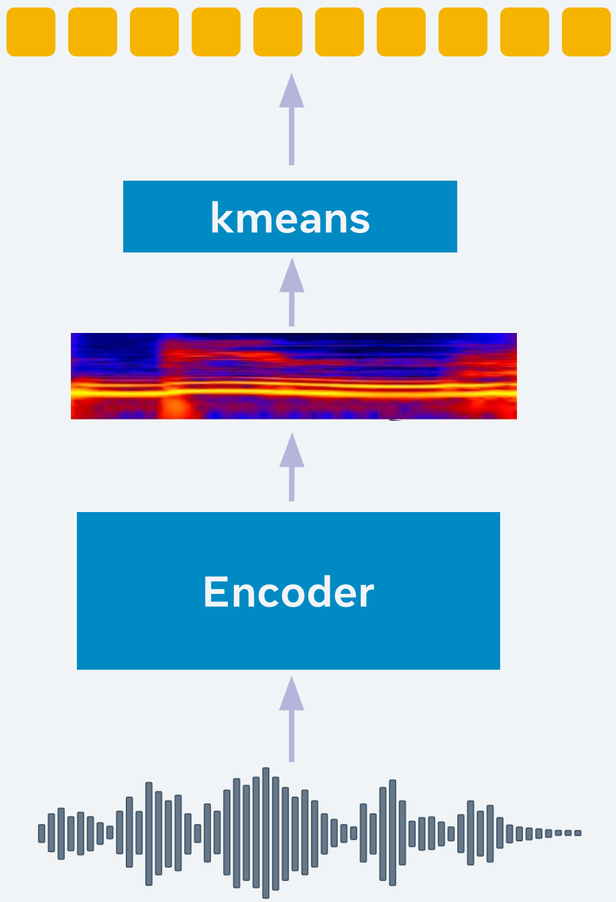
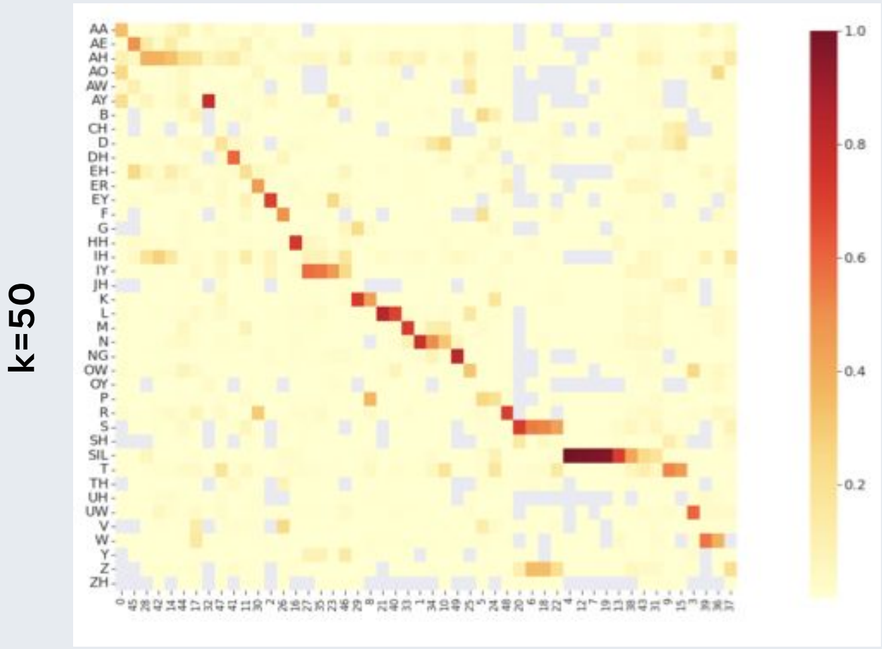
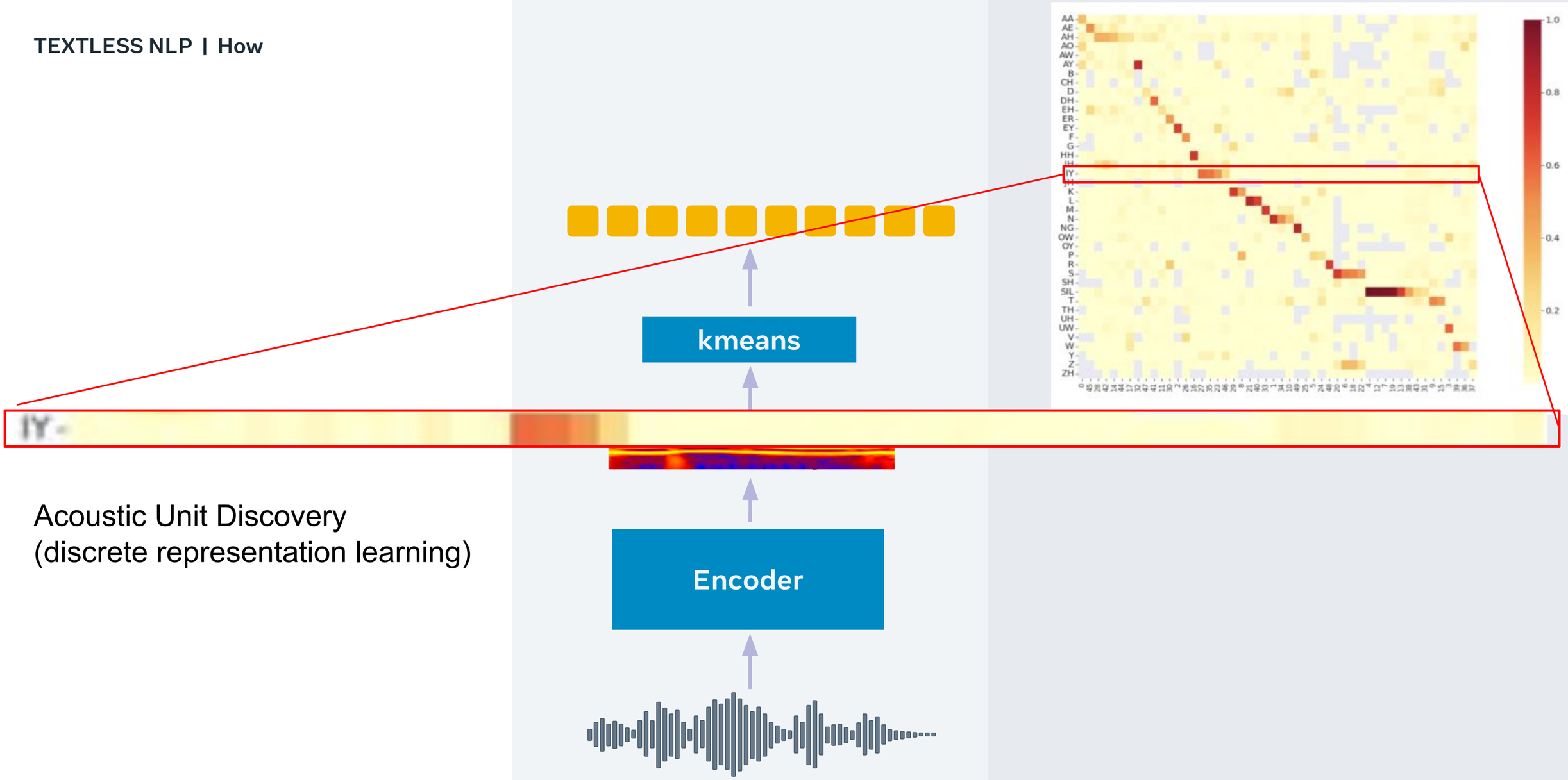




Nguyen et al (2022)



Acoustic Unit Discovery
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Nguyen et al (2022)

The encoder

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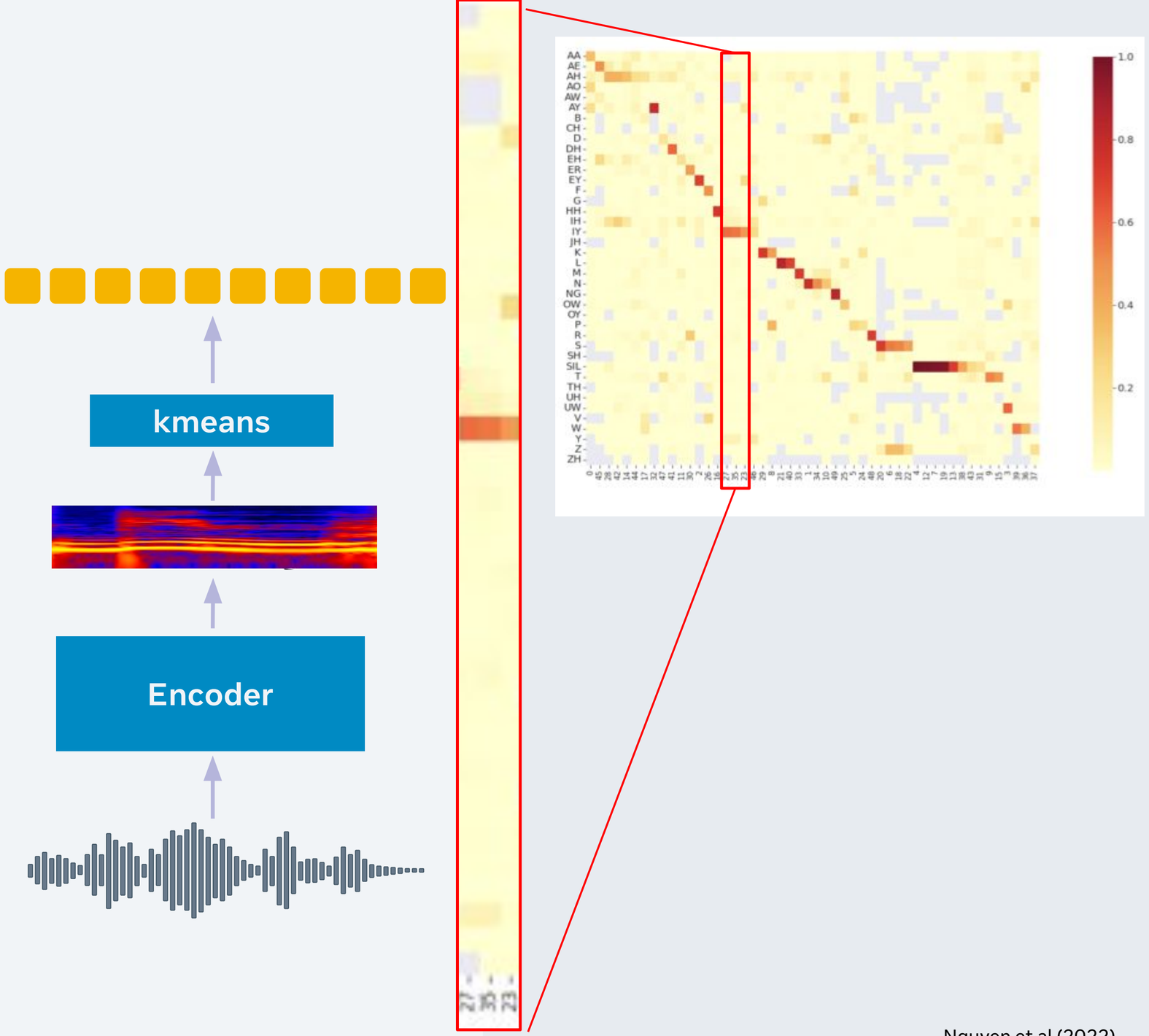

Nguyen et al (2022)

The encoder

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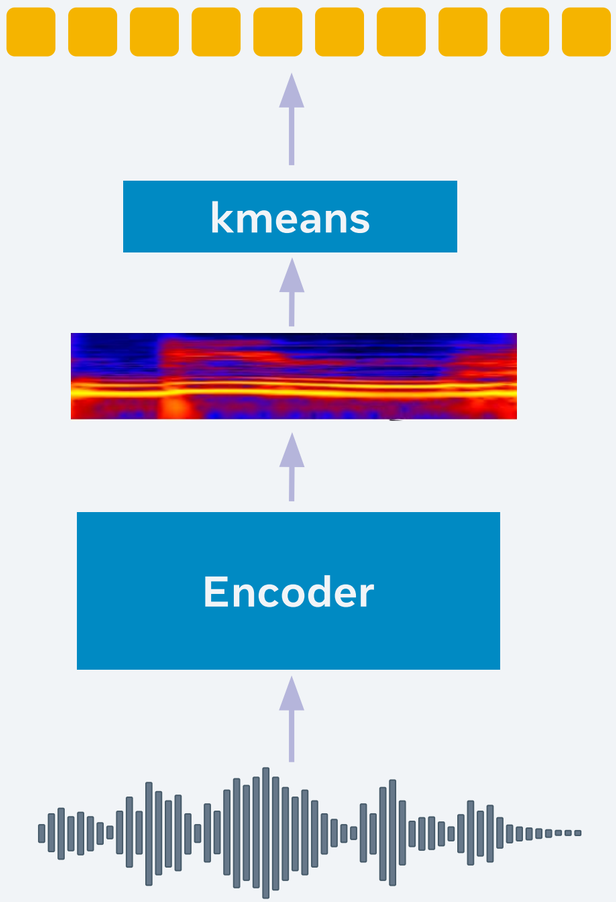

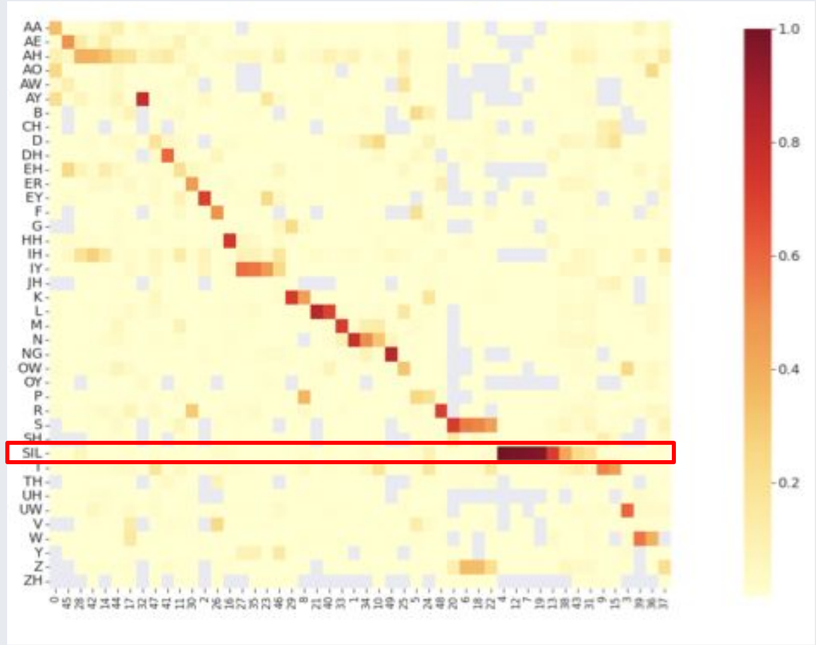

Nguyen et al (2022)

The encoder

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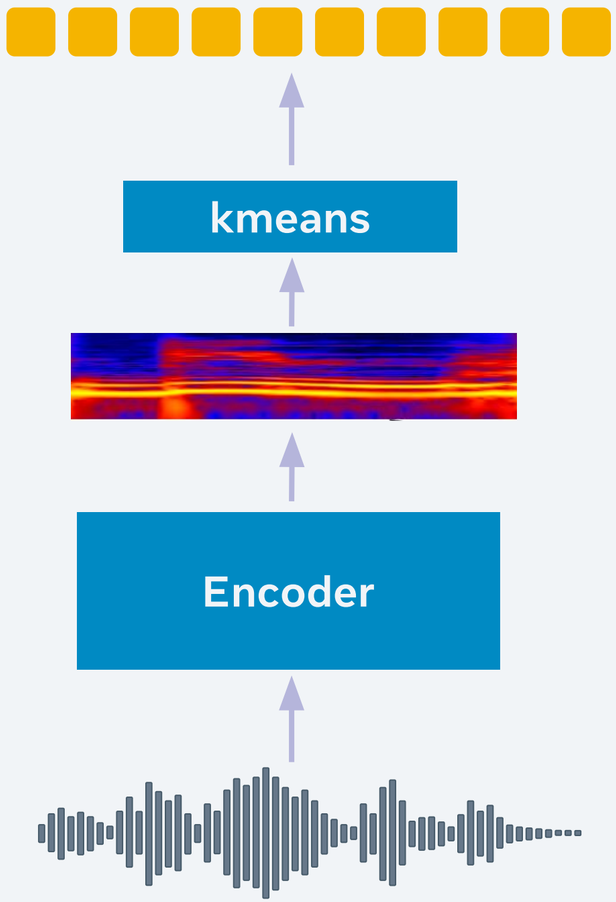

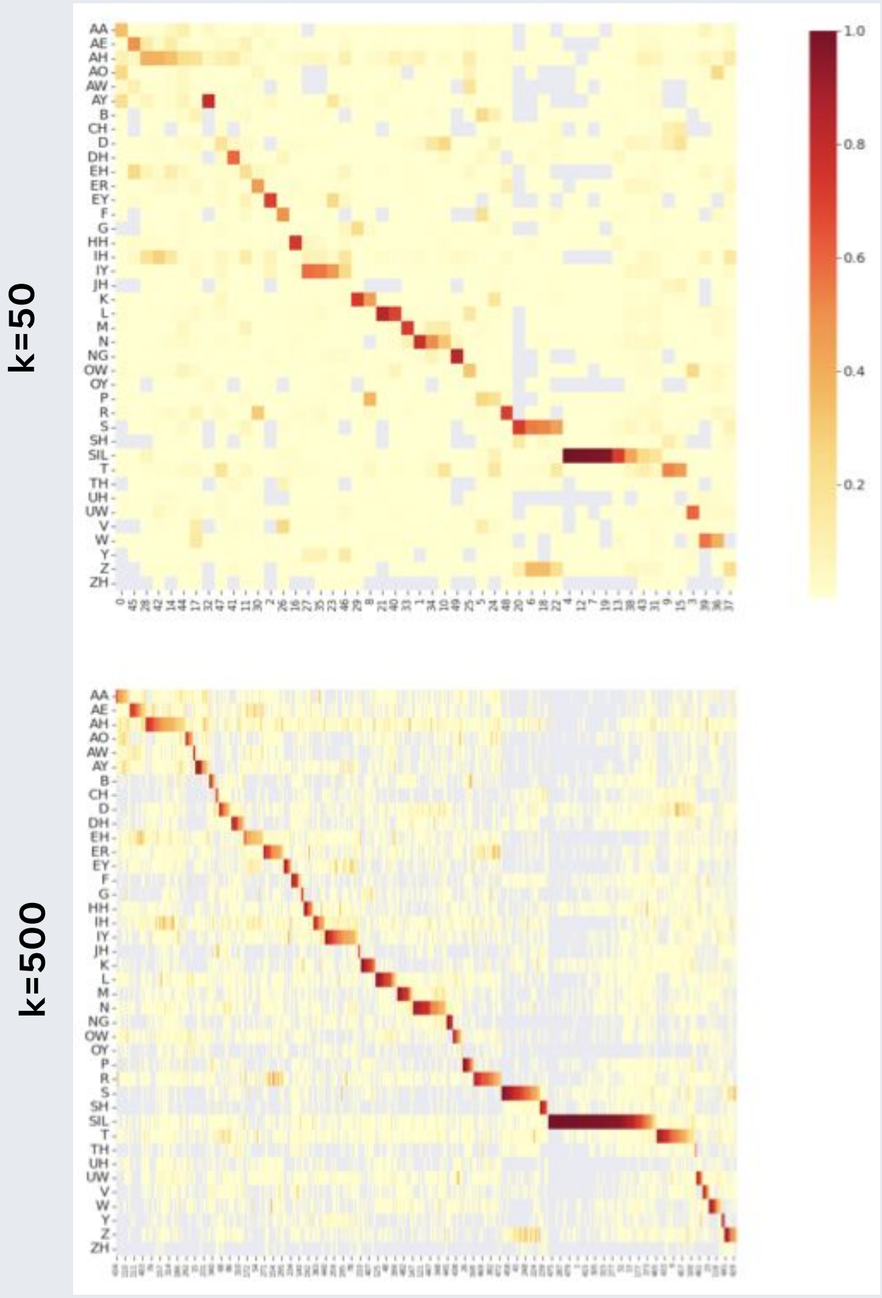

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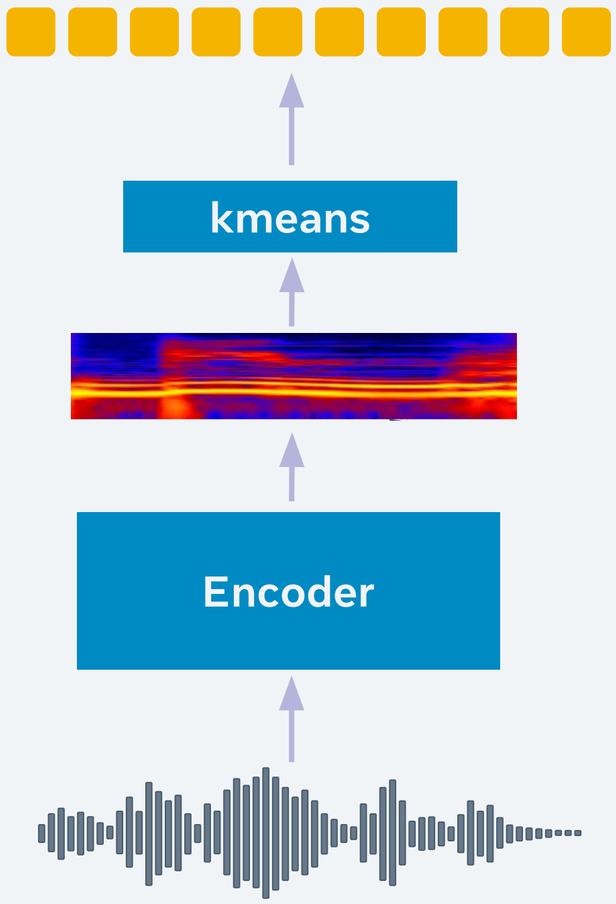
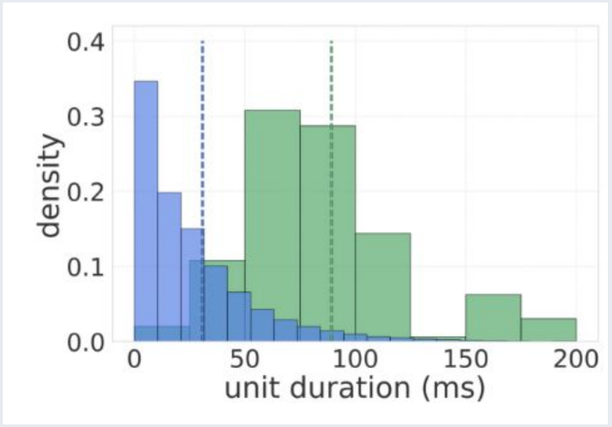
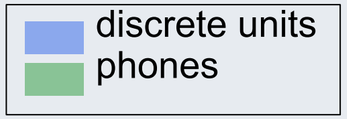
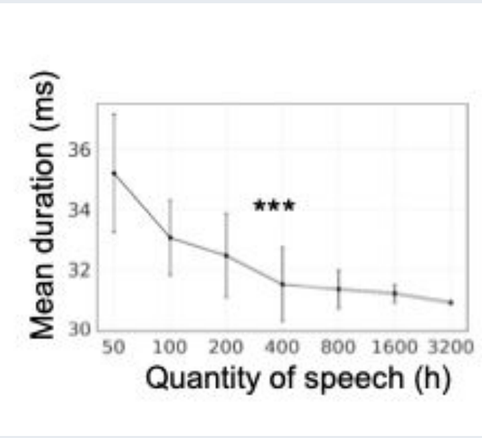


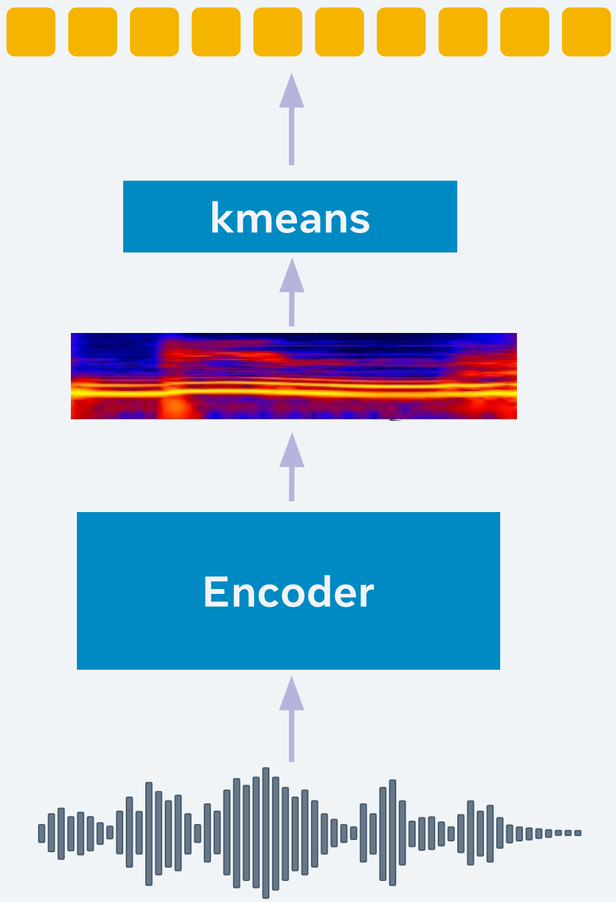


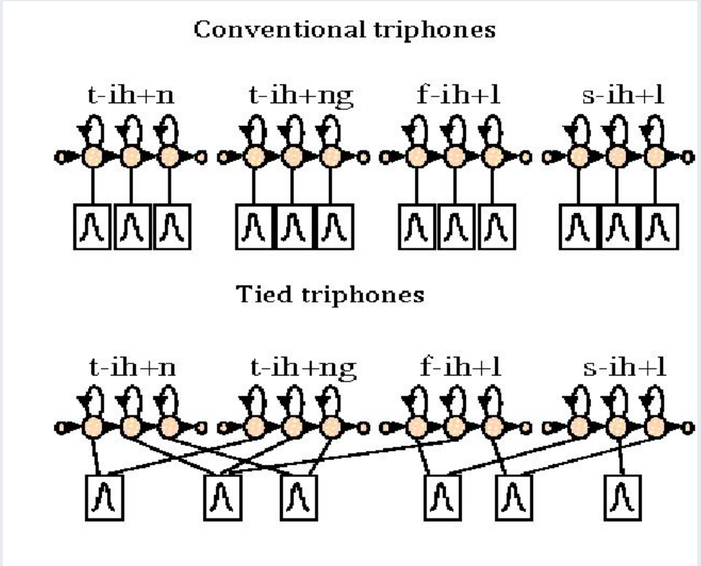




Lavechin et al (2022)

Acoustic Unit Discovery
(discrete representation learning)



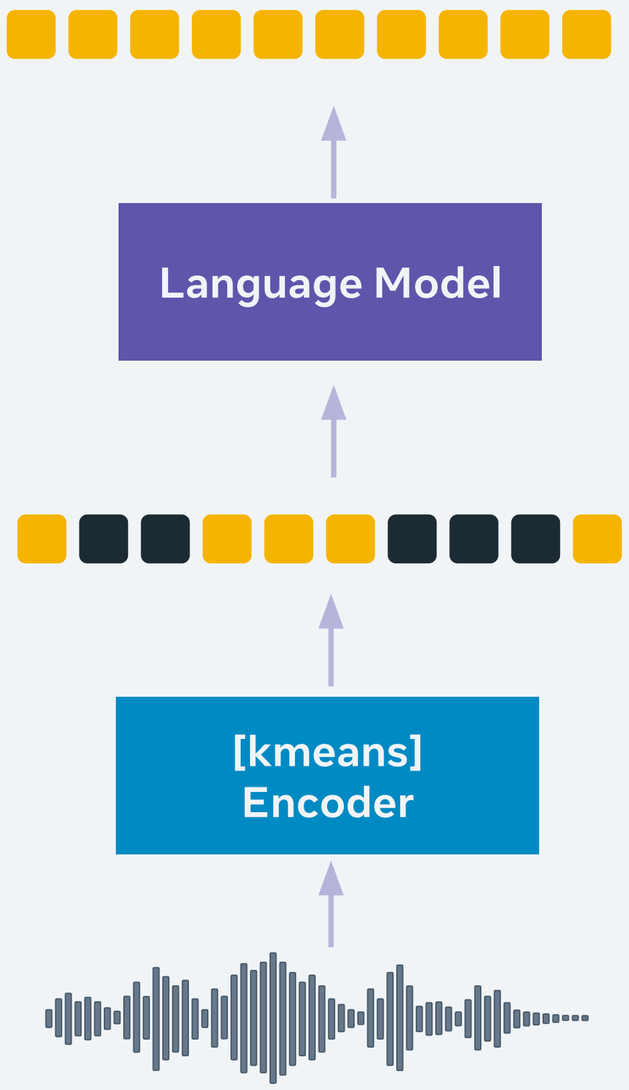


Tied phone states?

Lavechin et al (2022)

The language model

Spoken Language Modeling



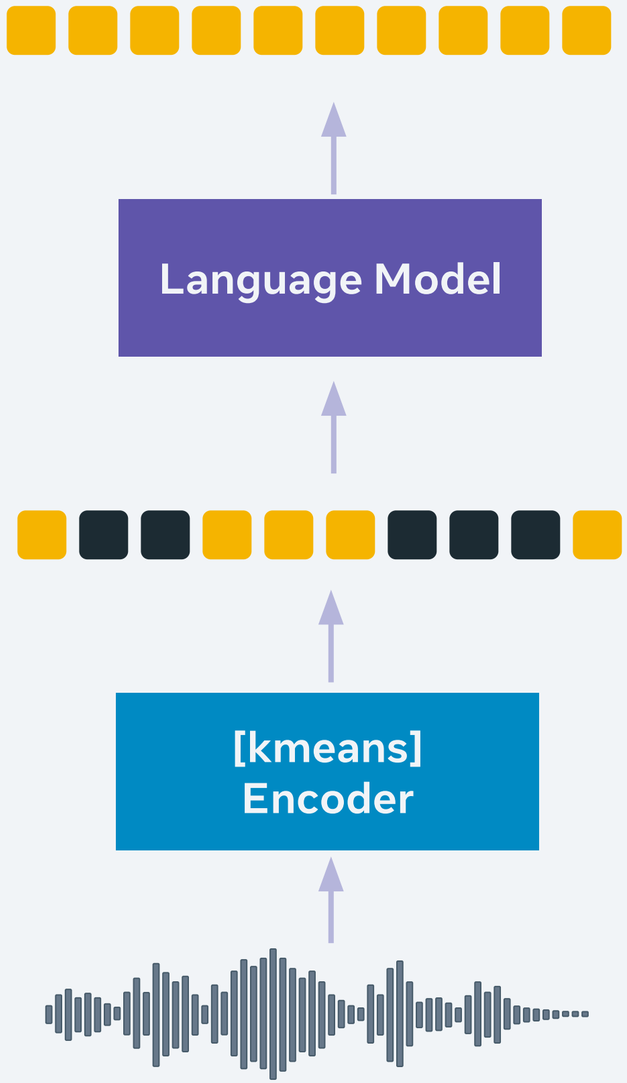
ZRC Task 4
Learn the probabilistic distribution of speech

Evaluation:

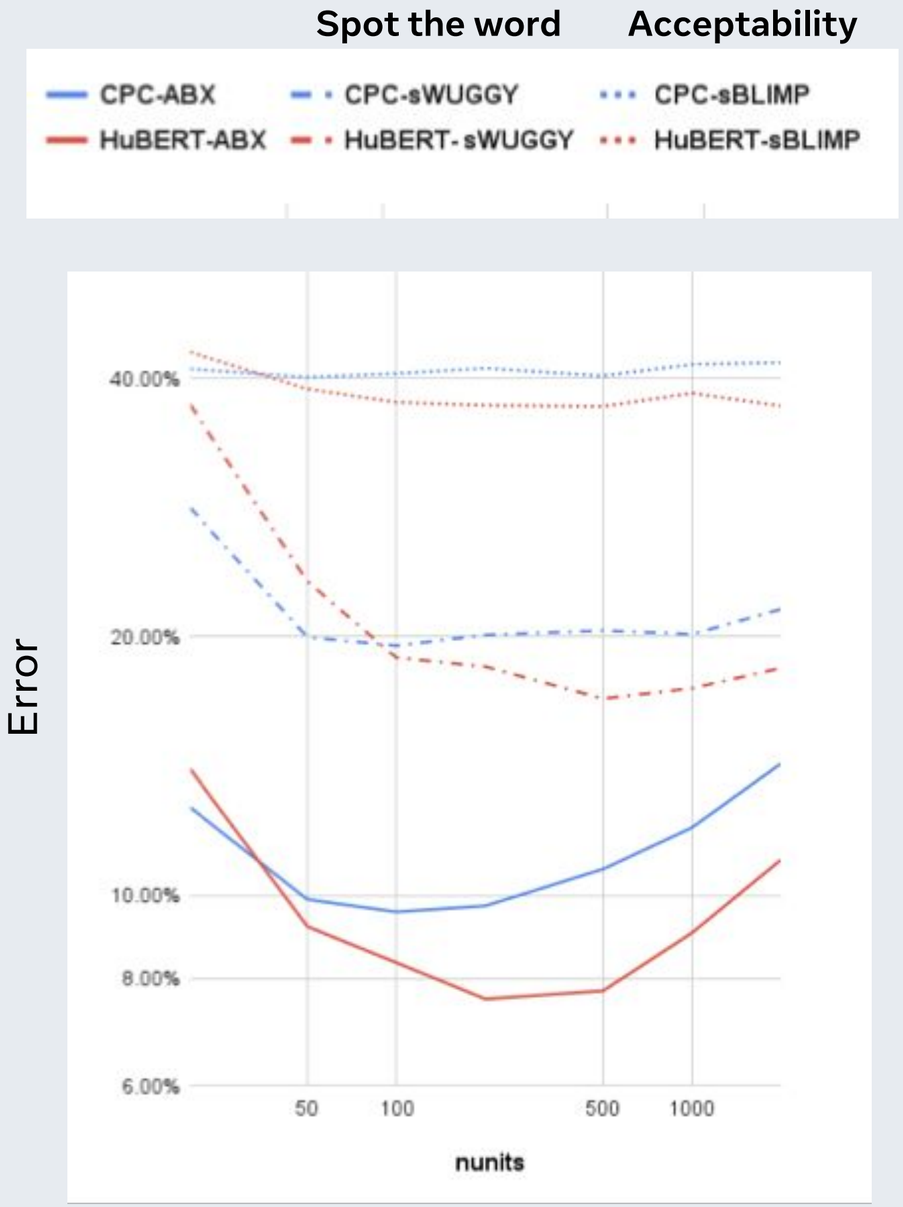
Levels	Tasks
Syntactic	**accept . judgment** *“they like” vs “they likes”*
Lexical	**spot-the-word** *“blick” vs “brick”*

The language model

Spoken Language Modeling



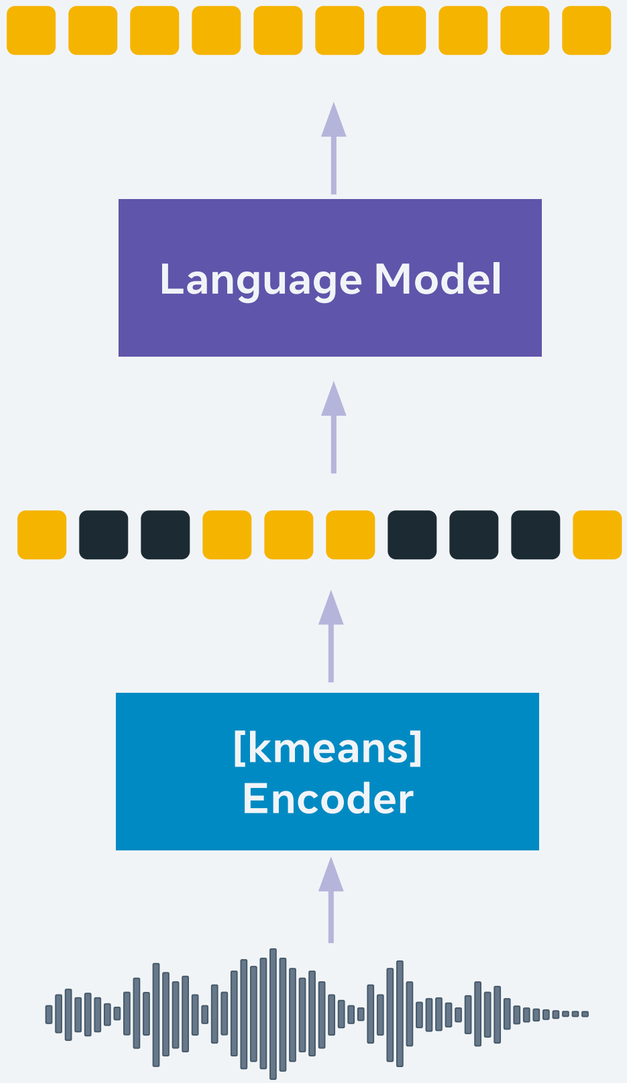
Leaderboard



Nguyen et al (2022)

The language model

Spoken Language Modeling



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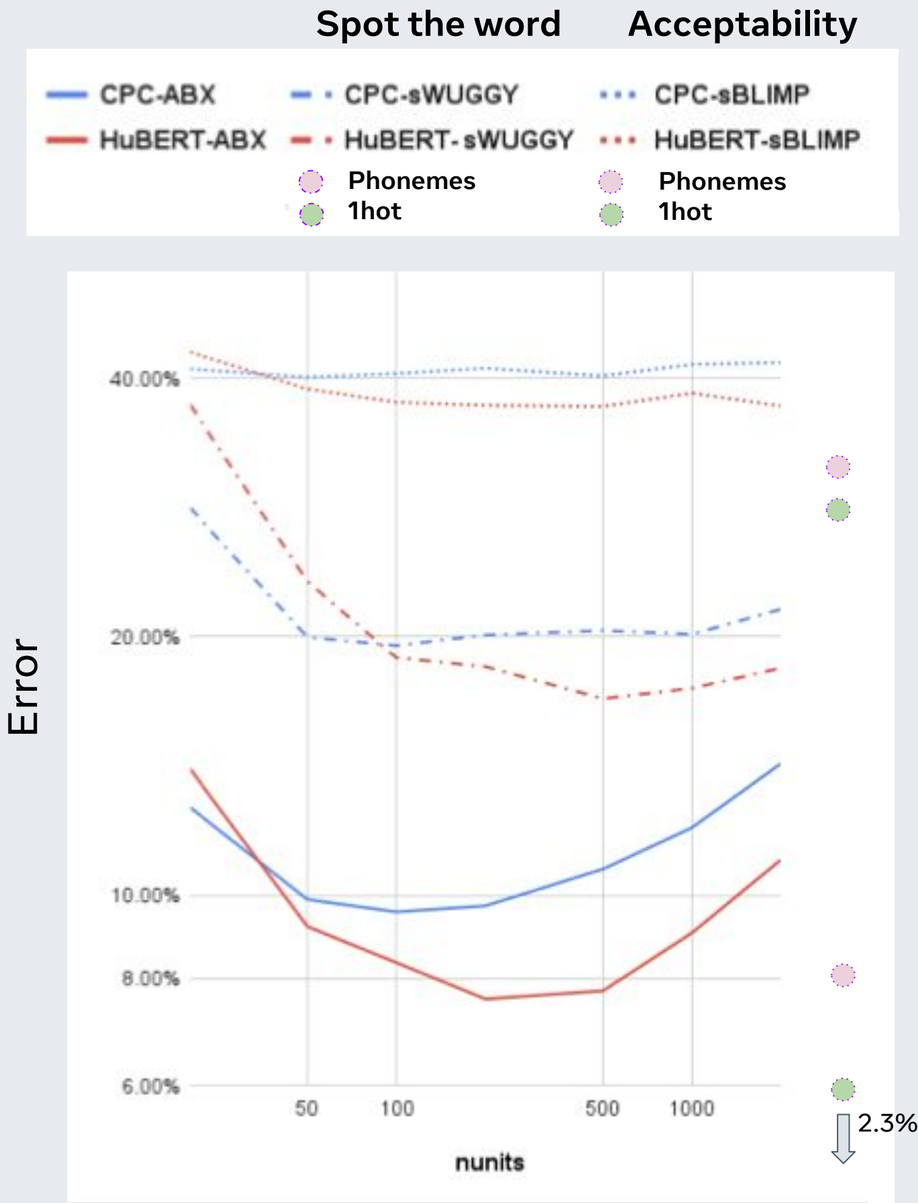
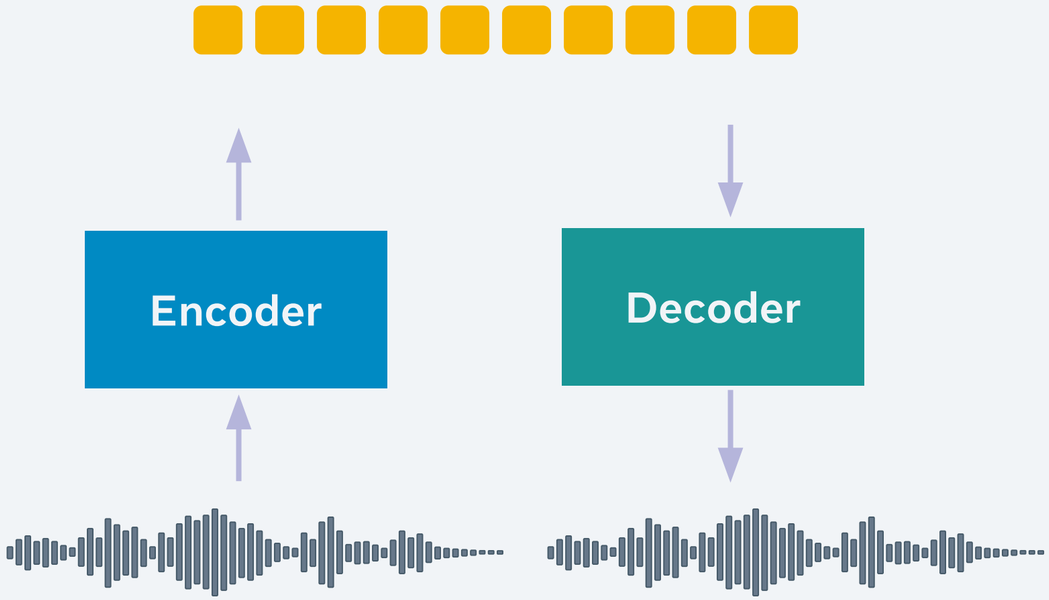


Nguyen et al (2022)

The decoder

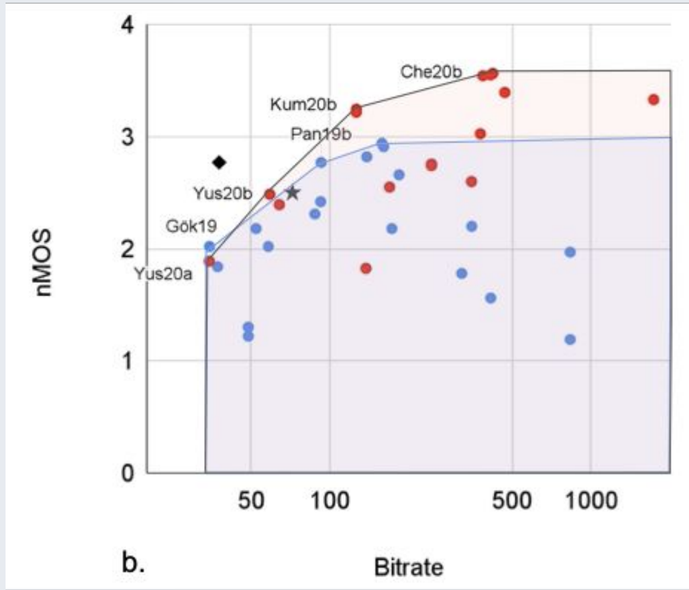
Discrete resynthesis



ZRC Task 3
Resynthetize speech from a discrete code

Evaluation:

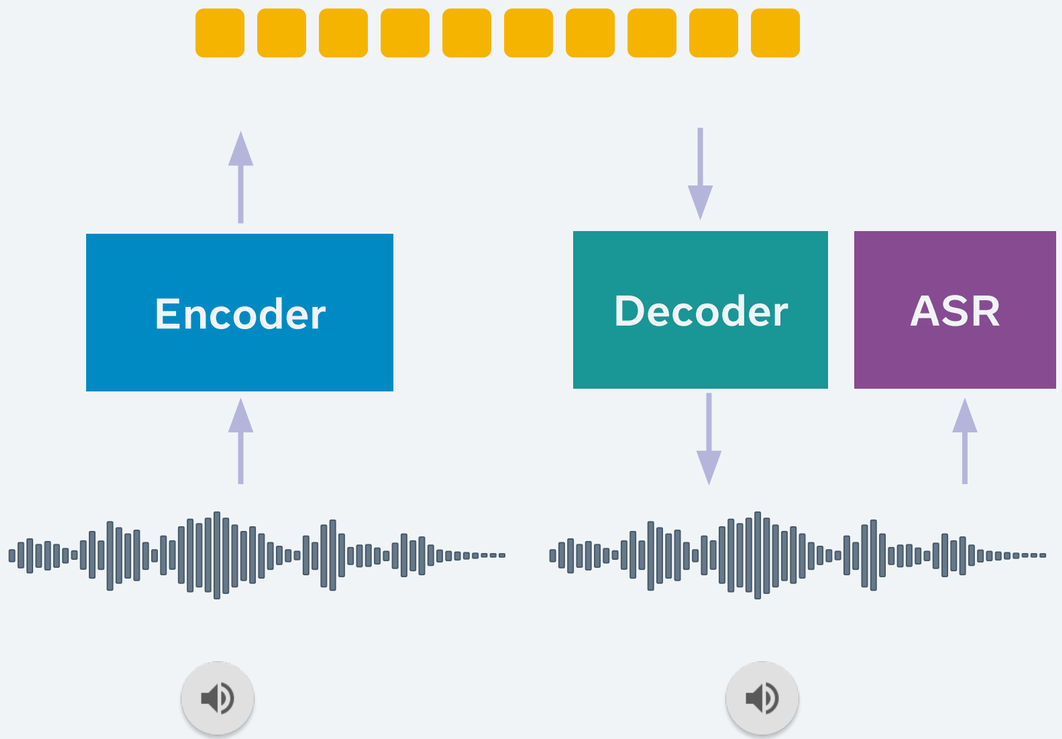
- Human (MOS)



Dunbar, Hamilakis, Dupoux (2022)

The decoder

Discrete resynthesis

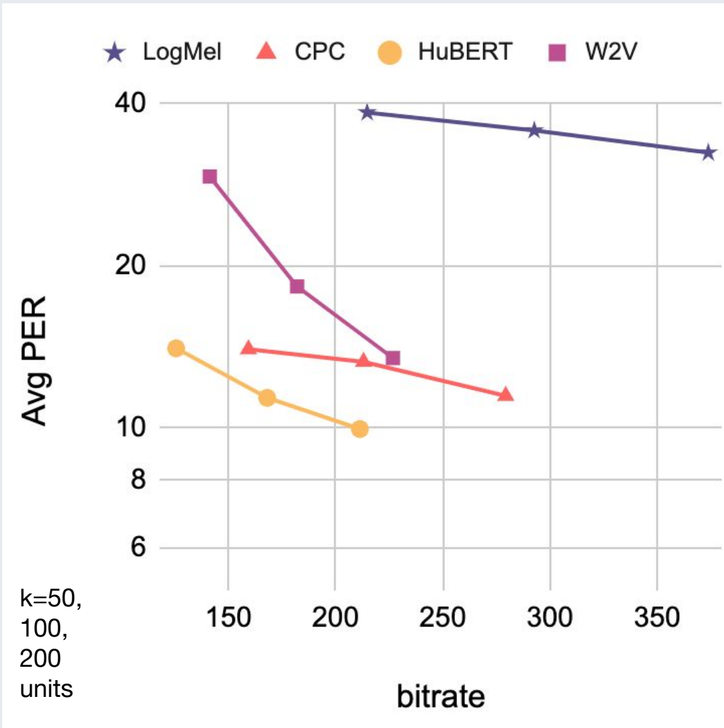


ZRC Task 3

Resynthetize speech from a discrete code

Evaluation:

- PER

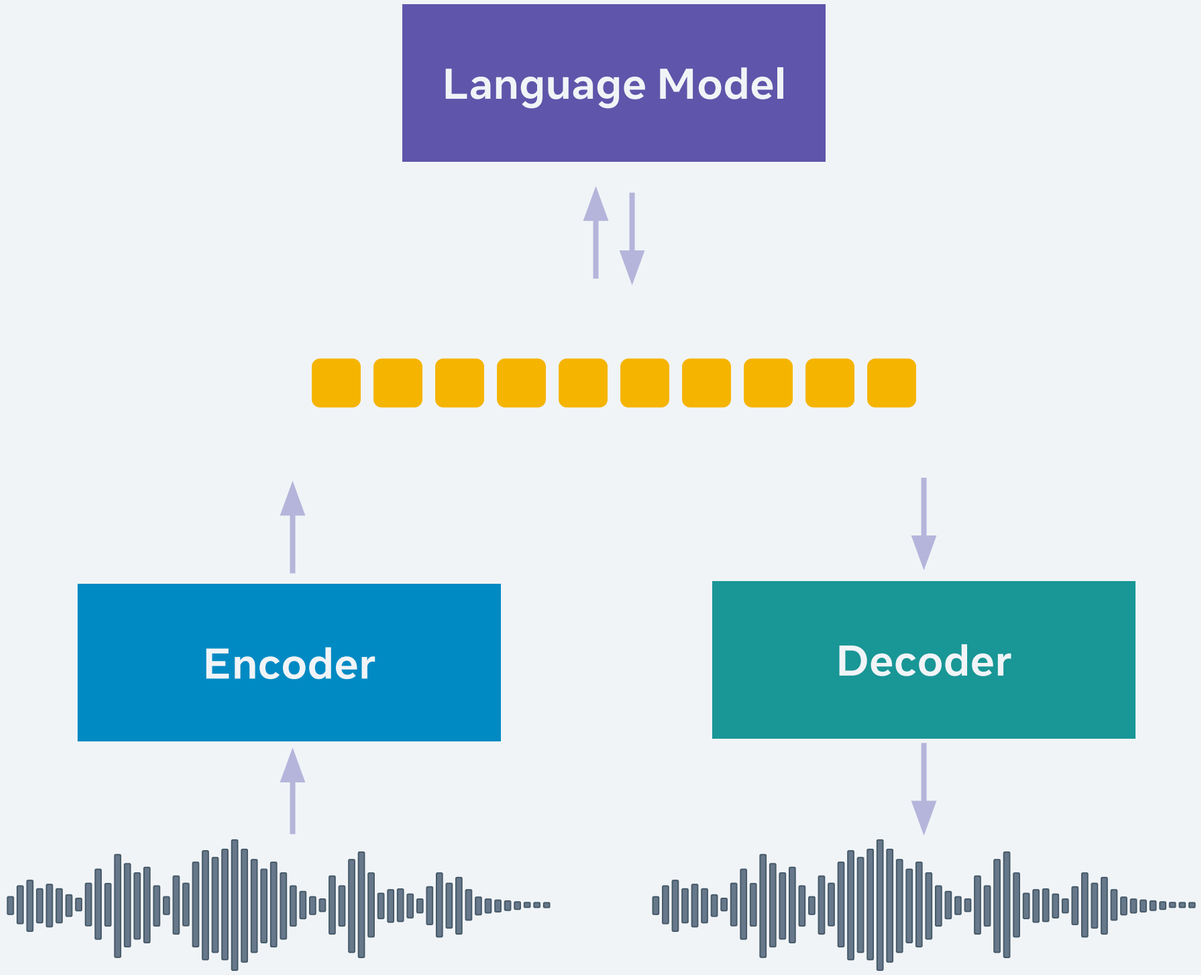


Correlation between PER and MOS, R= .90-.95

Lakhotia et al (2021). Generative spoken language modeling. TACL.

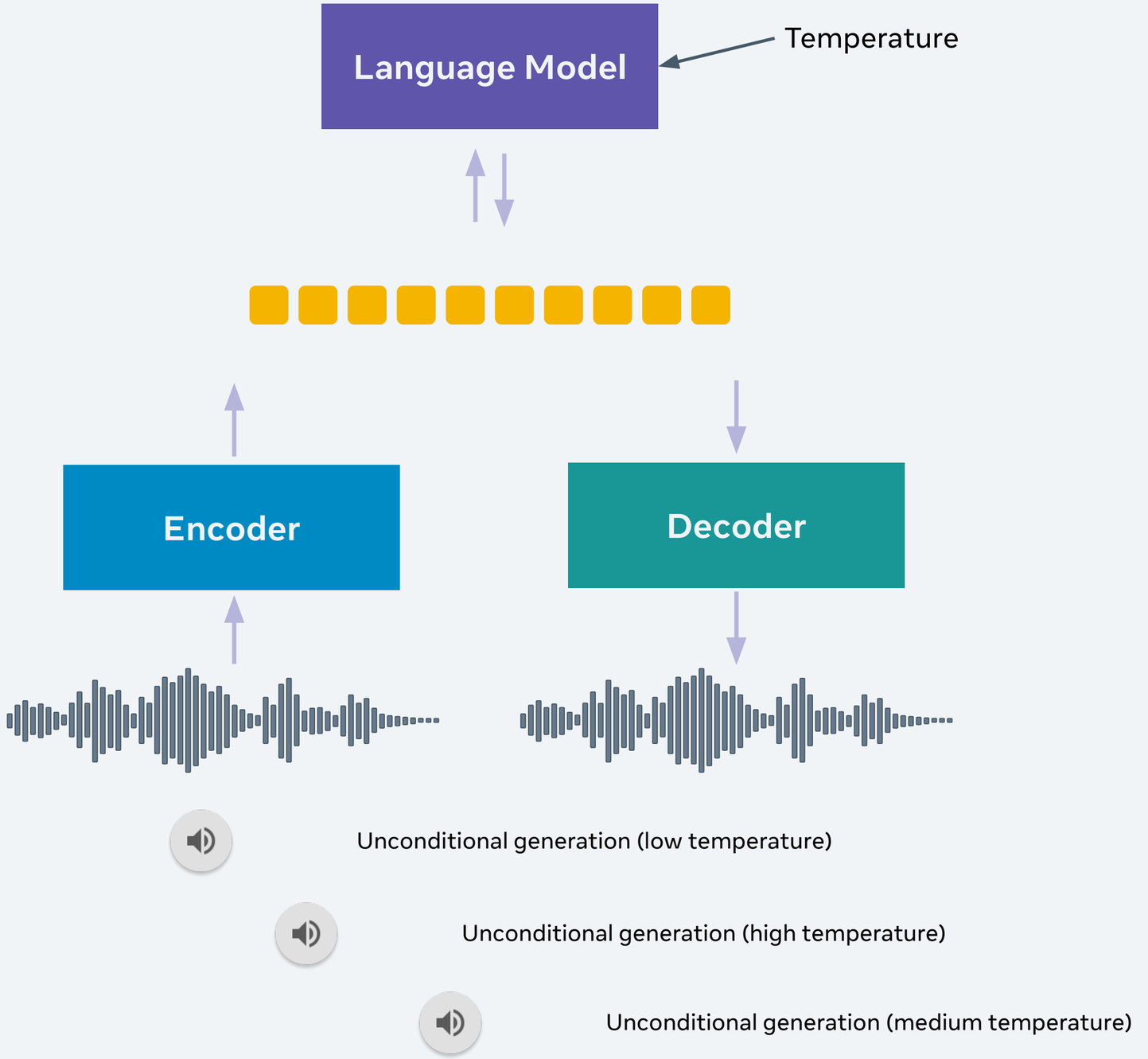
Generative Spoken Language Modeling

Putting all together



Generative Spoken Language Modeling

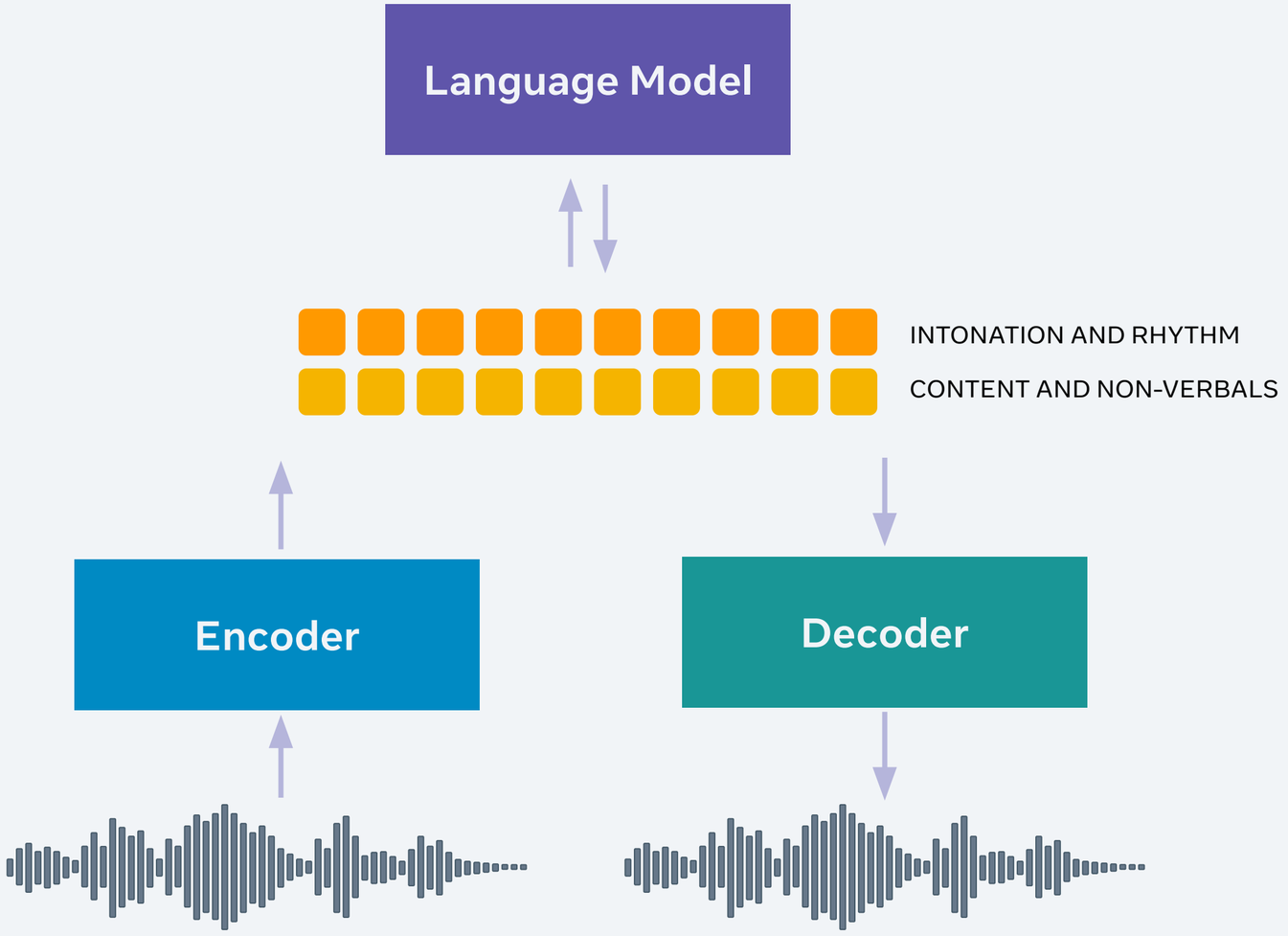
Putting all together



Lakhotia et al (2021). Generative spoken language modeling. TACL.

Prosodic Generative Spoken Language Modeling

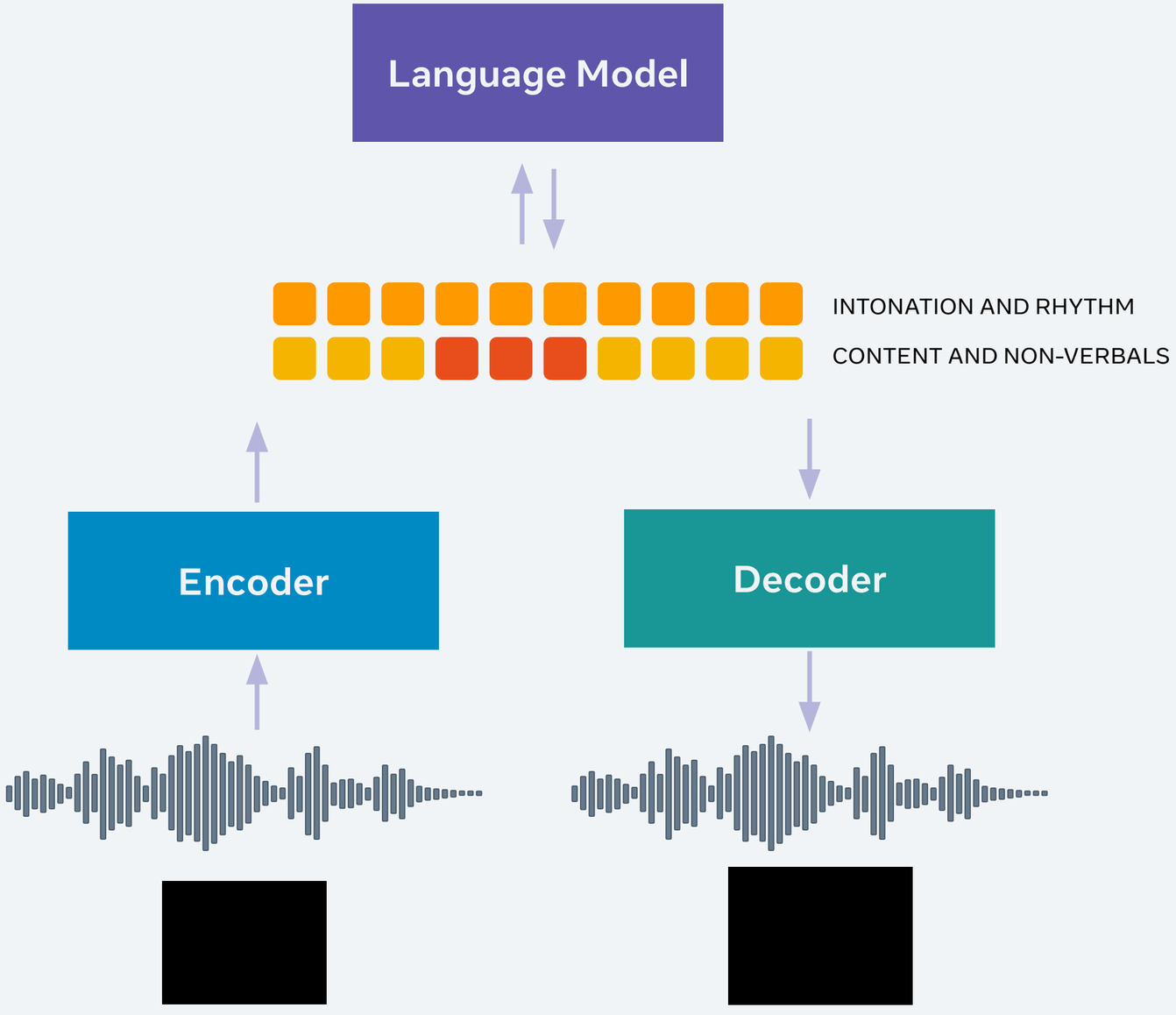
Expressive language modeling



Kharitonov et al (2021). Text-Free Prosody-Aware Generative Spoken Language Modeling; ACL

Speech-to-speech applications

Emotion conversion



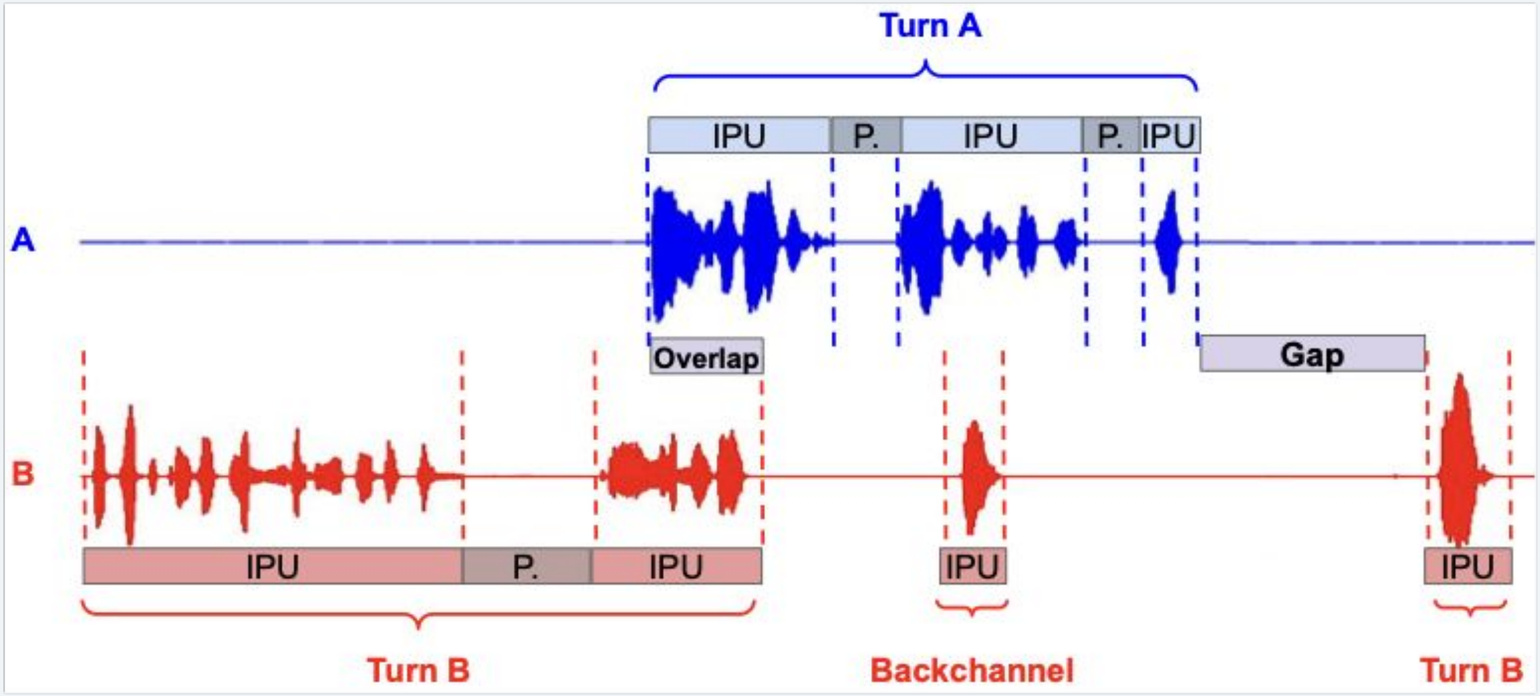
Kreuk et akl (2021).

Conditional samples

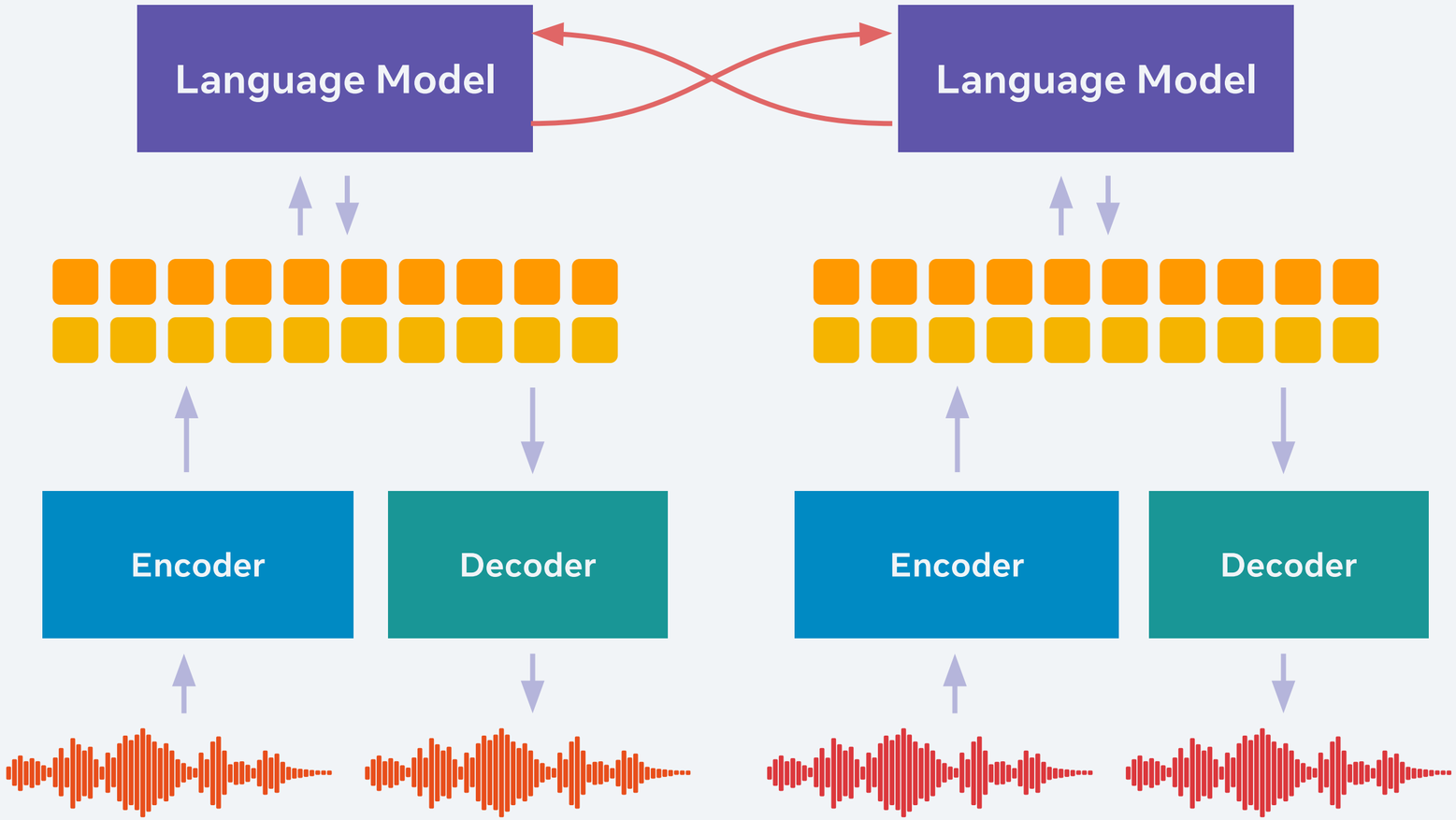
Kharitonov et al (2021). Text-Free Prosody-Aware Generative Spoken Language Modeling. ACL

More samples: https://speechbot.github.io/pgslm

Dialogue modeling

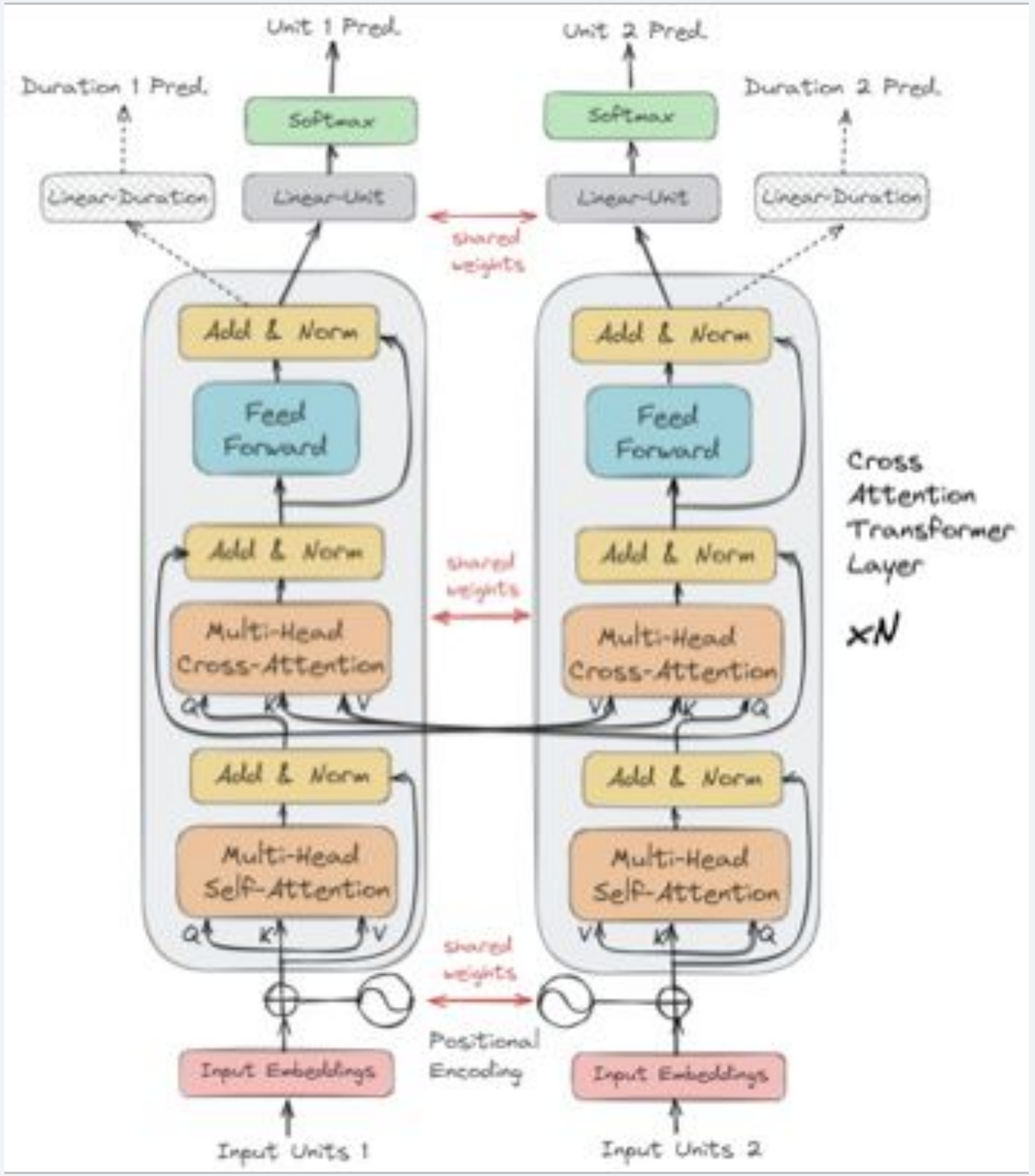


Dialogue modeling



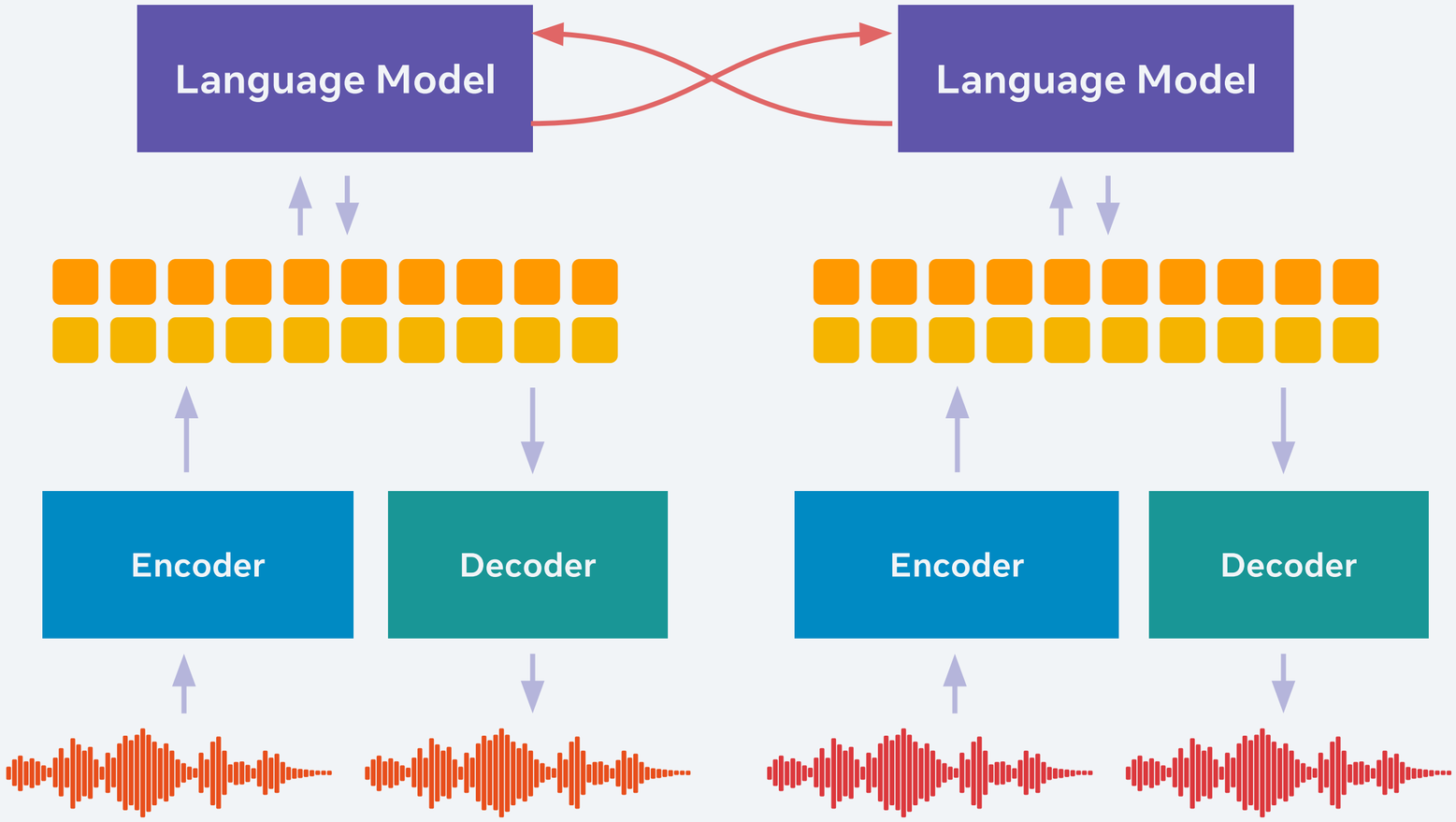
Nguyen et al (2022) Generative Spoken Dialogue Modeling

Dialogue modeling



Nguyen et al (2022) Generative Spoken Dialogue Modeling

Dialogue modeling

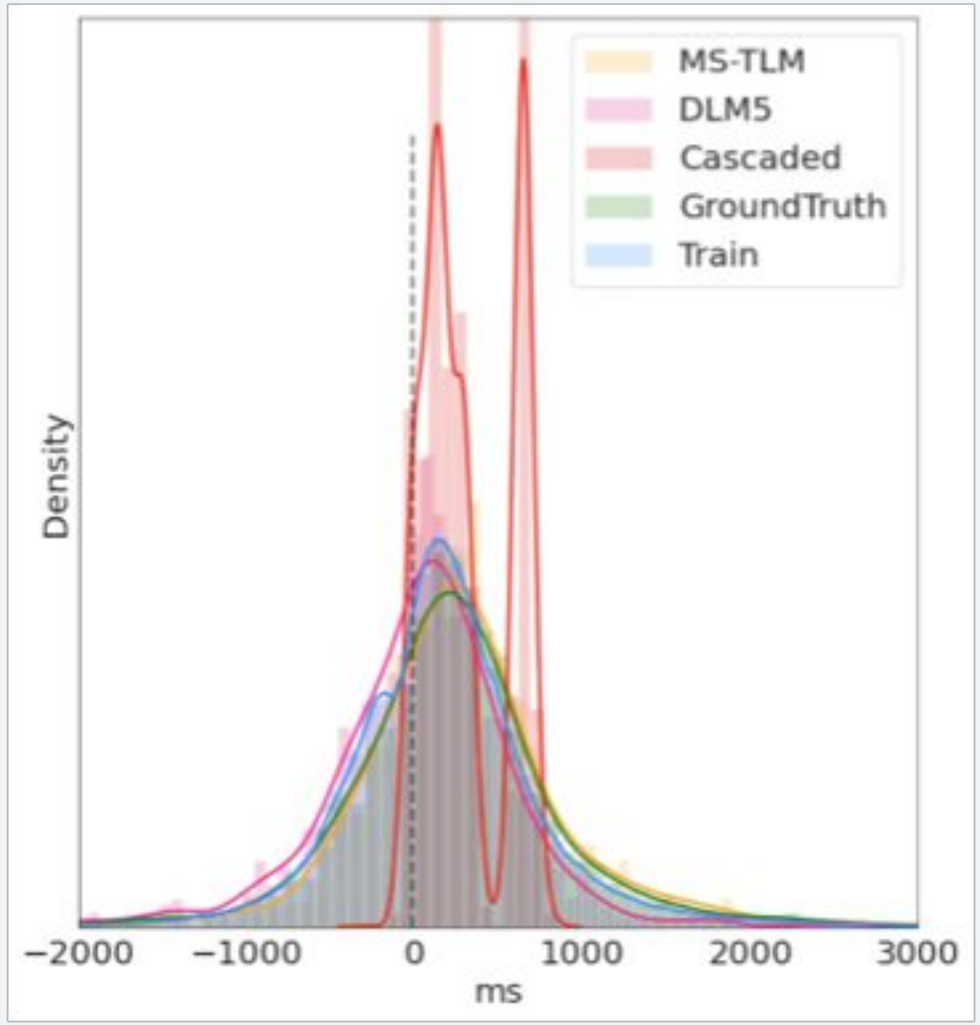


4 second prompt with real humans

Automatic continuation

Nguyen et al (2022) Generative Spoken Dialogue Modeling

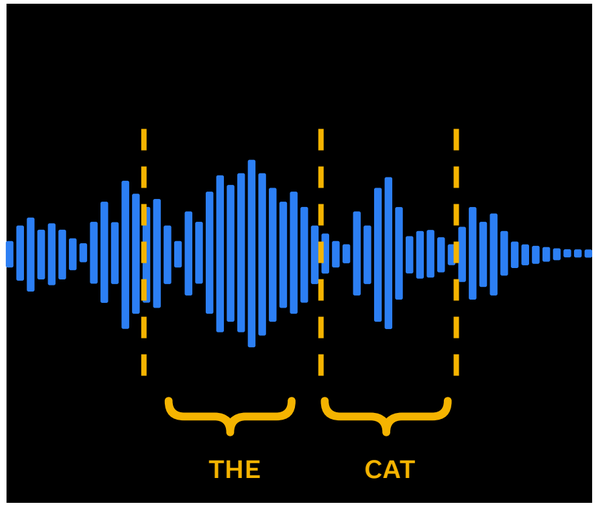
Dialogue modeling



Nguyen et al (2022) Generative Spoken Dialogue Modeling

Challenges

Noise and variability of real-world audio[1]

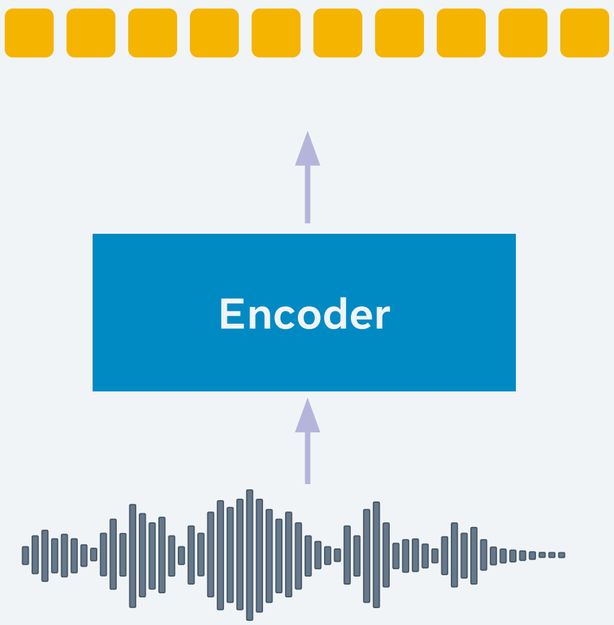


Meaningful segment discovery

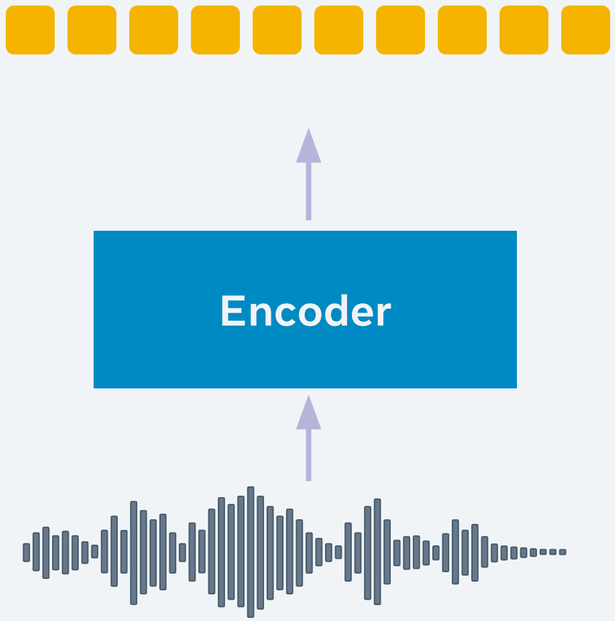
Data collection & curation

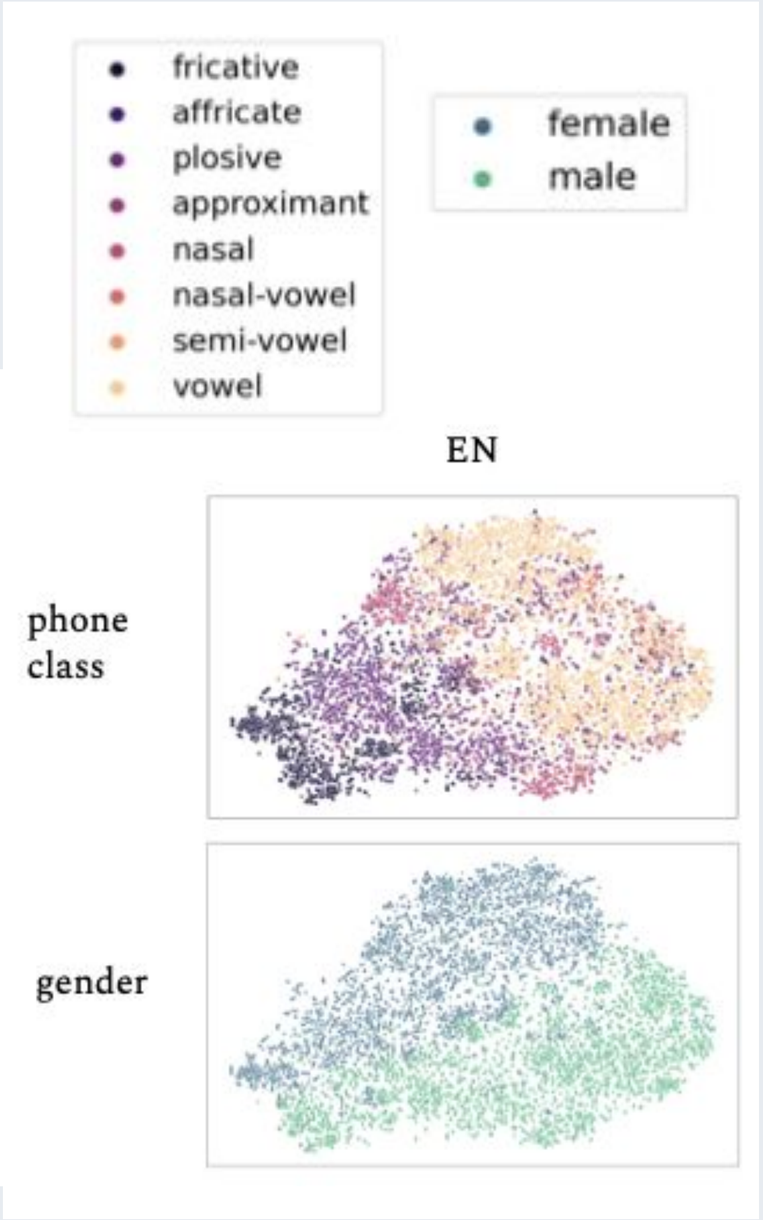
1. CHIMES5. Trmal, Vincent, Watanabe , Barker (2018), Interspeech

Noise robust invariant representations



Noise robust invariant representations





De Seyssel et al (2022). Interspeech

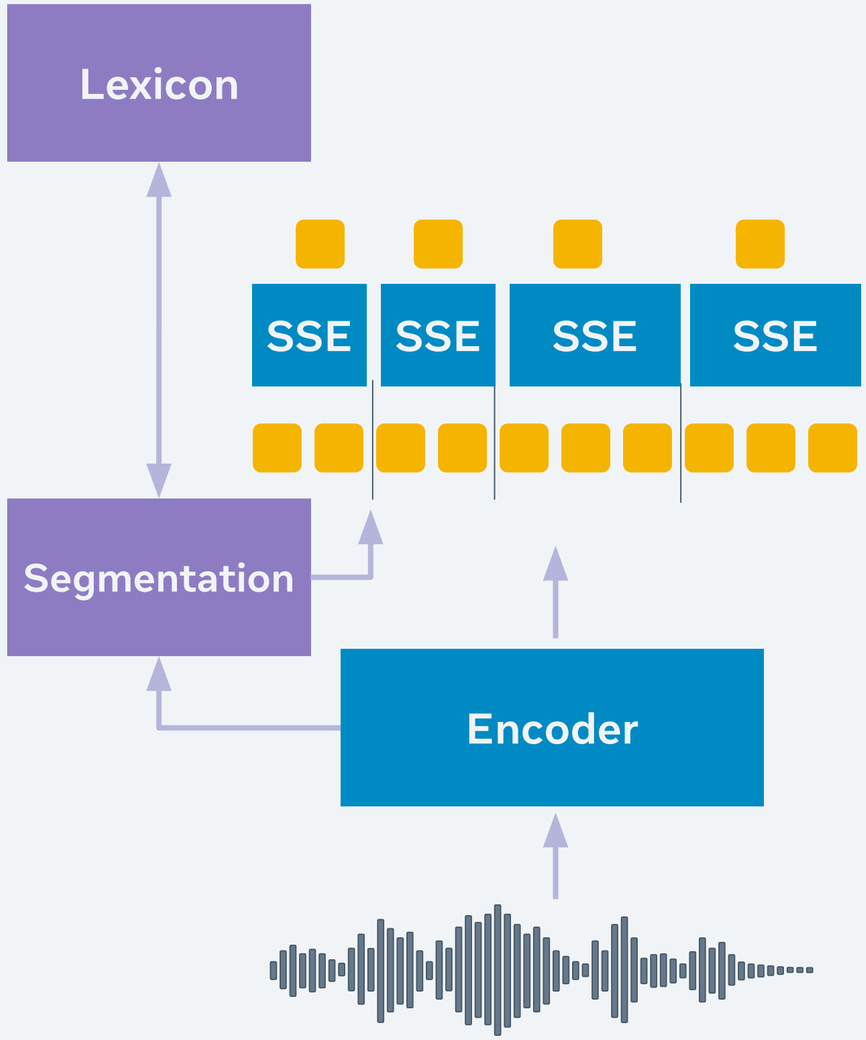
Word discovery

Something is wrong with frame based units!

System	sWUGGY	sBLIMP	sSIMI	
			synth.	libri.
CPC-big+km50+BERT-small	65.81	52.91	3.88	5.56
	65.94	53.02	3.02	0.06
CPC-big+km50+LSTM	66.13	53.32	4.42	7.56
	66.22	52.89	7.35	6.66
CPC-small+km50+BERT	70.69	54.26	2.99	6.68
	70.50	54.61	8.96	-1.55
CPC-big+km50+BERT	75.56	56.14	6.25	8.72
	75.51	56.16	5.17	1.75
Forced align BERT	92.19	63.72	7.92	4.54
	91.88	63.16	8.52	2.41
Phone BERT	97.90	66.78	9.86	16.11
	97.67	66.91	12.23	20.16
RoBERTa large	96.58	81.56	32.28	28.96
	96.25	82.11	33.16	27.82

Nguyen et al (2021) The Zero Resource Speech Benchmark 2021: Metrics and baselines for unsupervised spoken language modeling

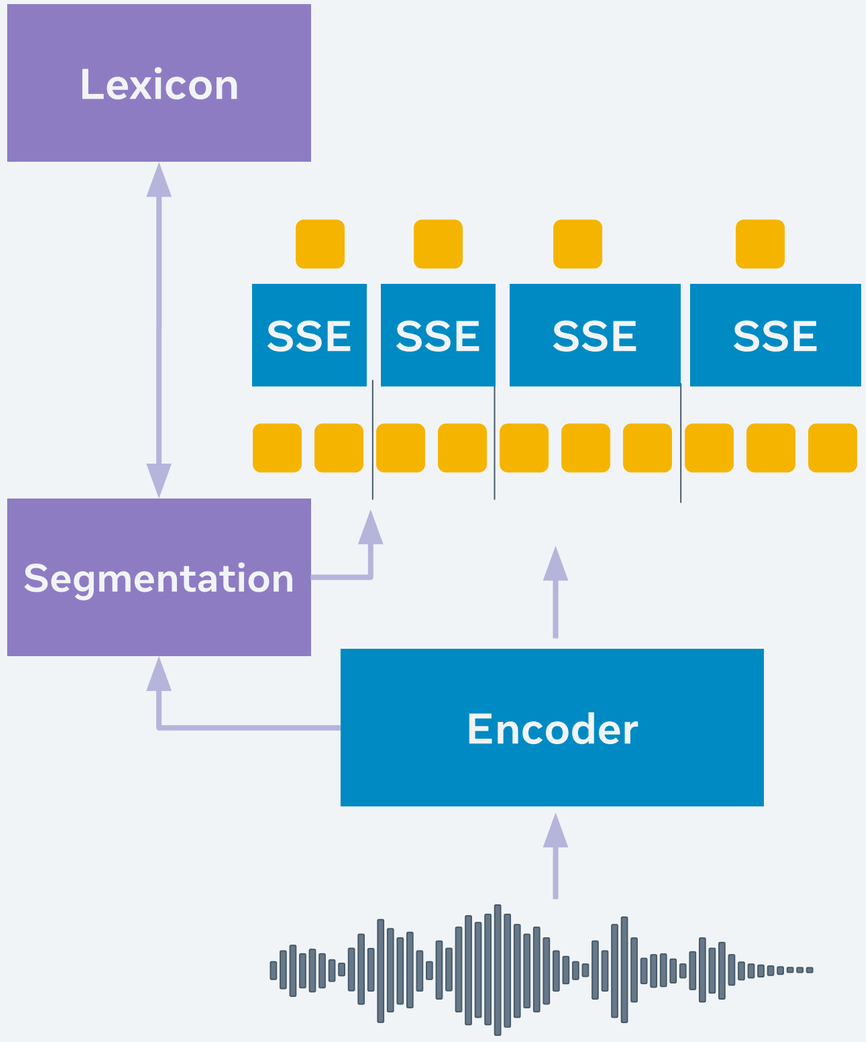
Word discovery



ZRC Task 2

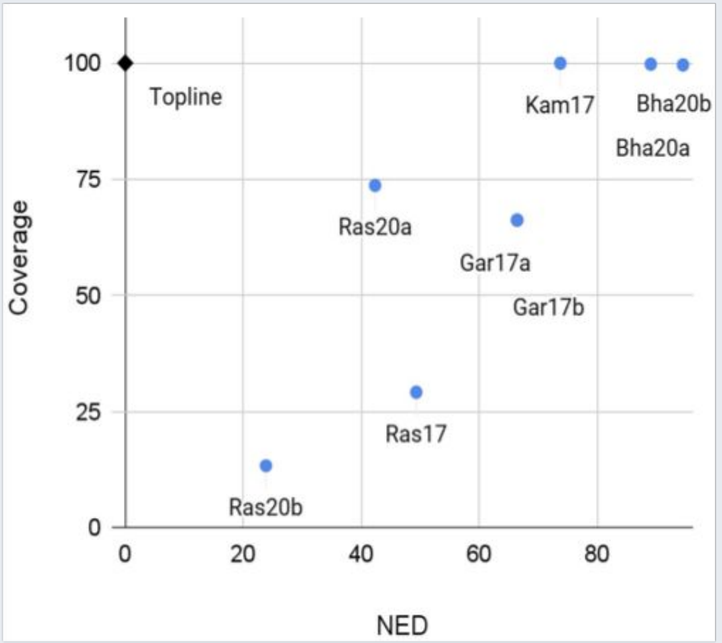
Discover spoken terms and segment with it

Word discovery



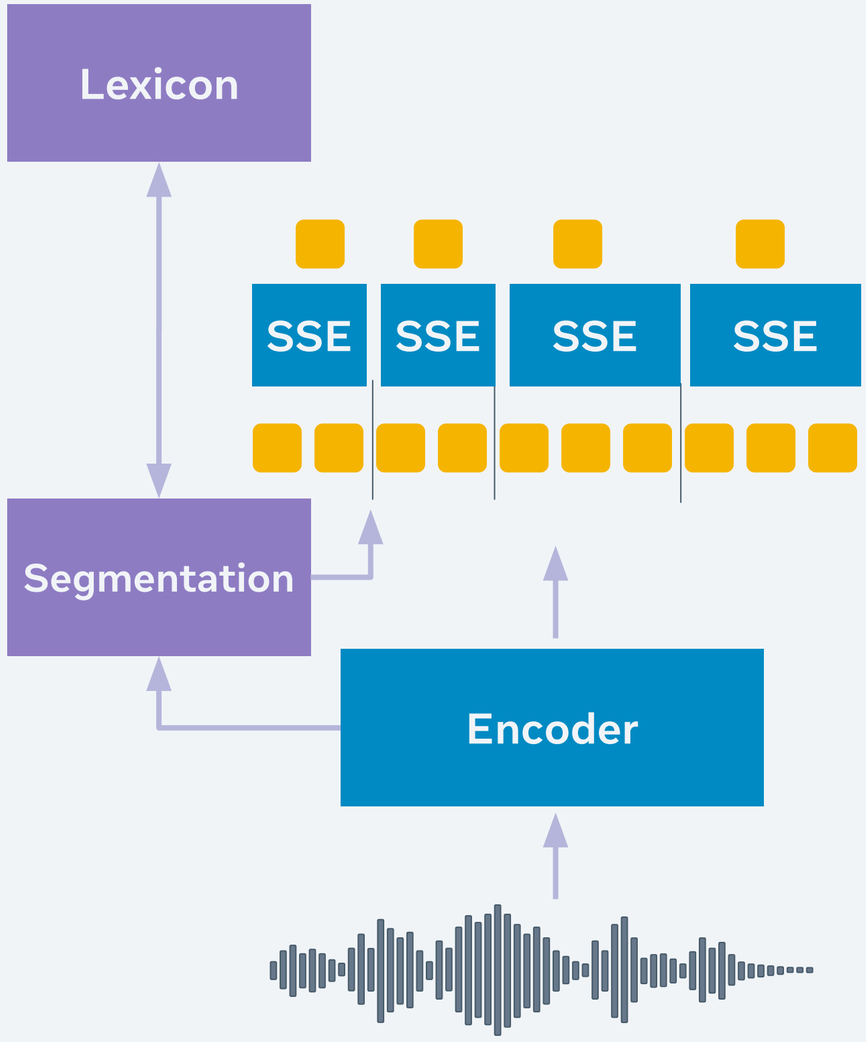
ZRC Task 2

Discover spoken terms and segment with it



Dunbar, Hamilakis & Dupoux (2022)

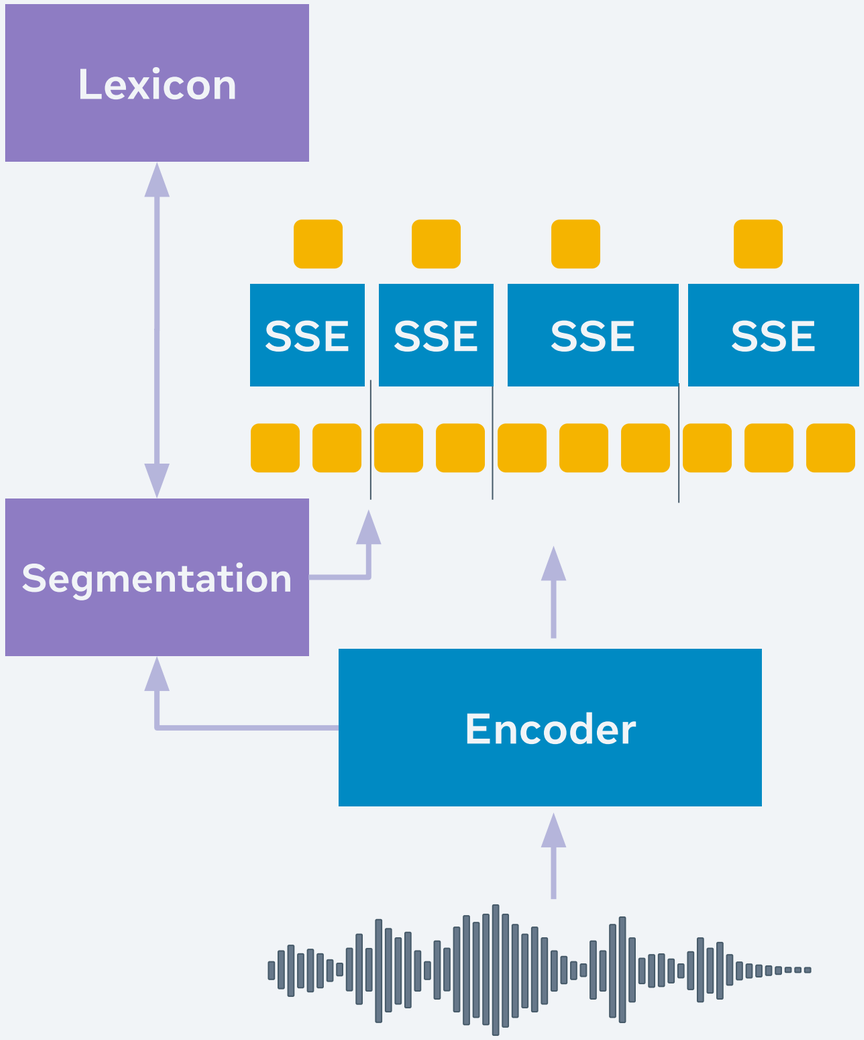
Word discovery



ZRC Task 2
Discover spoken terms and segment with it

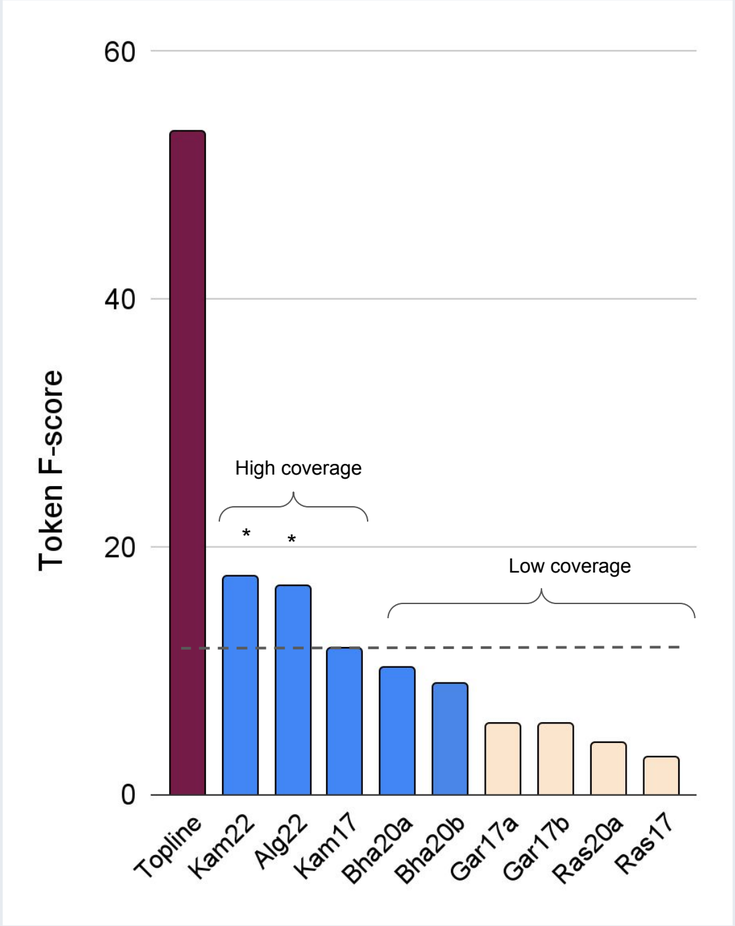
ɬˆlɛˀvə̆n
ɬˆlɛvə̆n
ɬˆɬɛvə̆n
əˈlɛˀvə̆n
ɬˆlɛvə̆n
əlɛvə̆n
əˈɬɛvn
əɬɛbm
ɬˆˈlɛvn
lɛvə̆n
əɬɛˬˀᵊvə̆n
ɬɛvɱ
əɬɛᵊvə̆n
ɬˈlɛvɱ

Word discovery



ZRC Task 2

Discover spoken terms and segment with it



Dunbar, Hamilakis & Dupoux (2022)

Data

Most of existing speech data is text-based
- Librispeech, common voice, Librilight (audiobooks)

Or formal speech
- VoxPopuli, Oyez

The internet has a lot of casual speech
- Podcasts, local radios, interactive video games

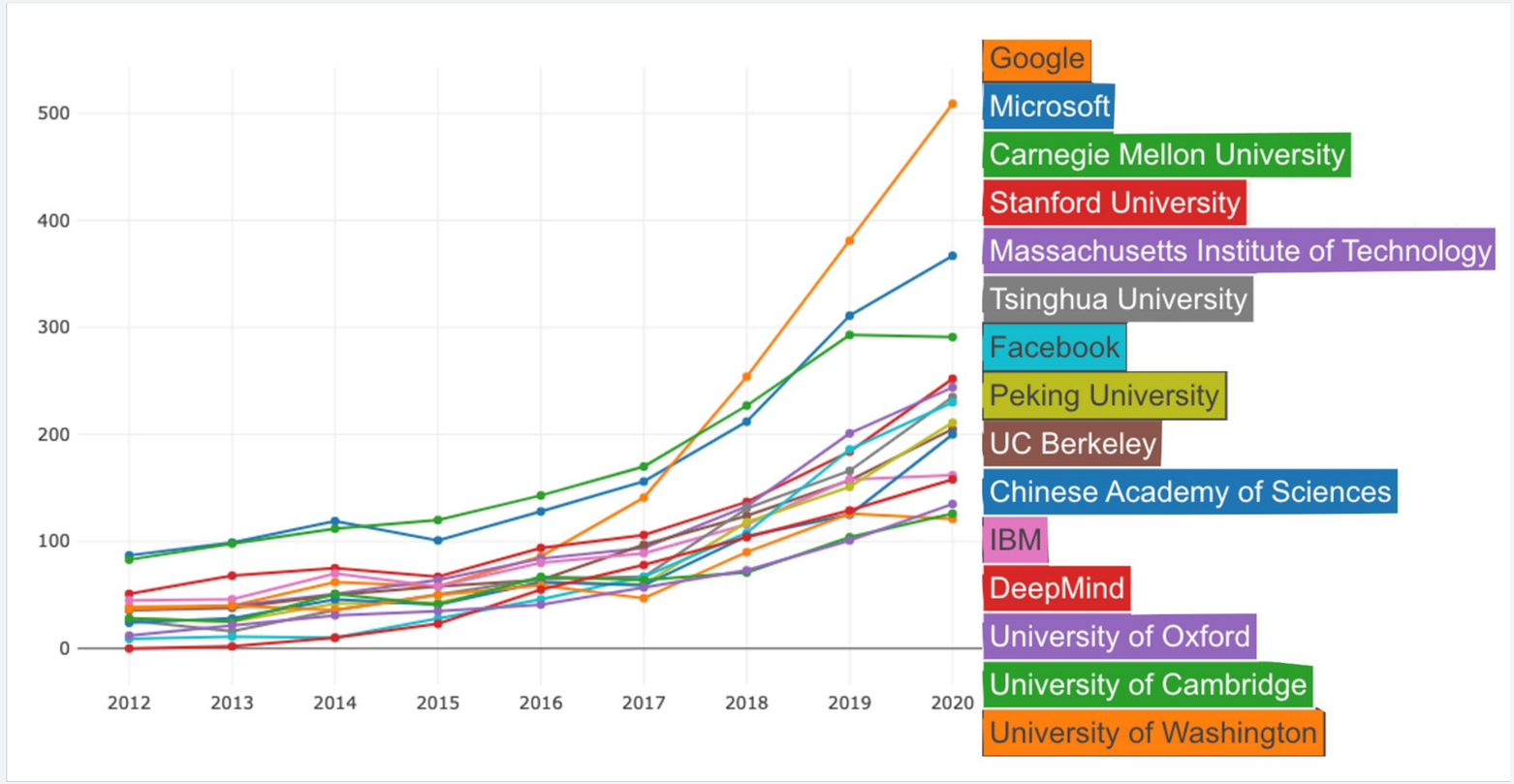
But large open source dataset have not yet been done

Why

Why it matters

TEXT-BASED SERVICES

- Search
- Translate
- Question & Answer
- Recommend
- Describe



Trend of research publications on text-based NLP

Why it matters

SPEECH TO SPEECH SERVICES

- Search
- Translate
- Question & Answer
- Recommend
- Describe

More inclusive

Most languages have no written presence on the web.

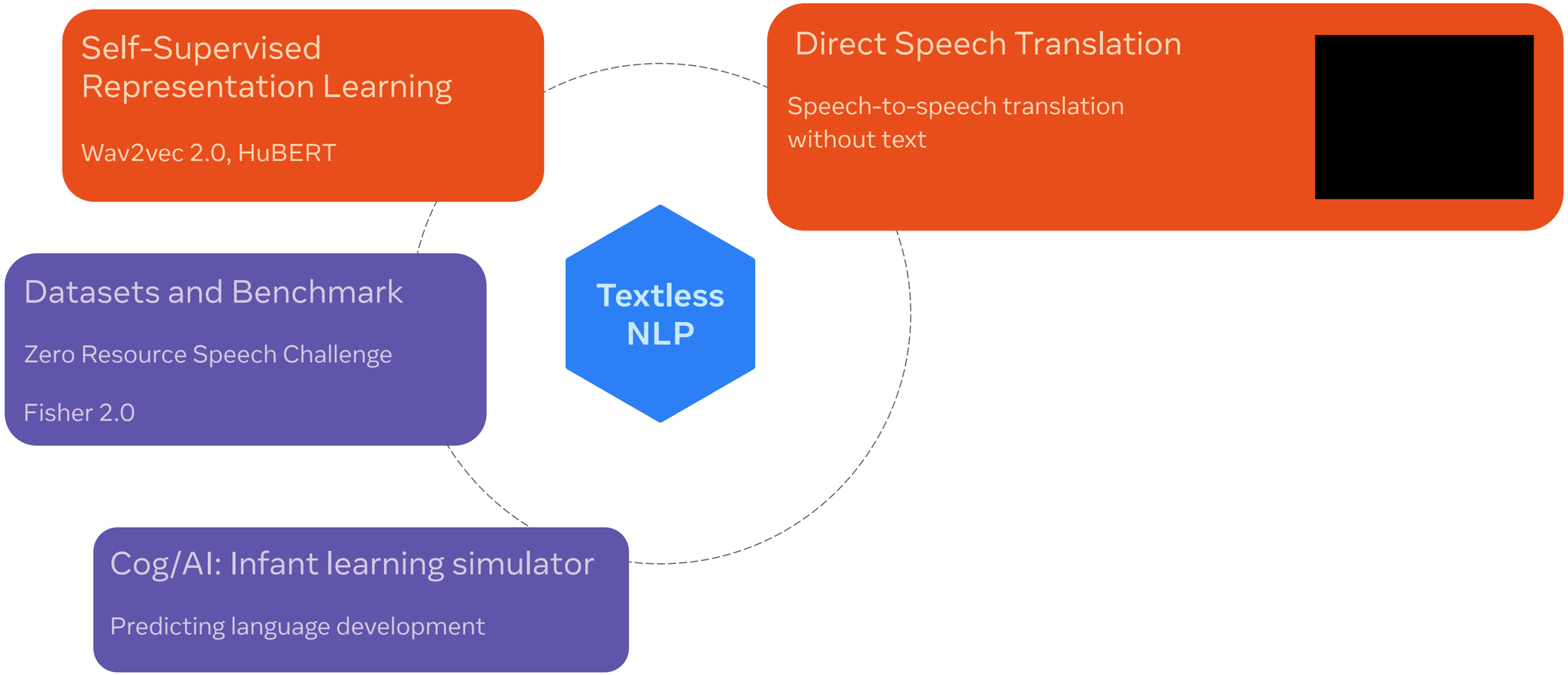
More expressive

Intonation, rhythm, sarcasms, laughters, yawning, etc.

More ubiquitous

Online games, local radios, podcasts, metaverse.

Related projects



References

Zero resource speech challenge: Now rolling submissions!

Review paper: Dunbar, Hamilakis & Dupoux (2022). Self-supervised language learning from raw audio: Lessons from the Zero Resource Speech Challenge. JSTSP.

WebSite: www.zerospeech.com

Textless project at Meta

Blog post: https://ai.facebook.com/blog/textless-nlp-generating-expressive-speech-from-raw-audio/ and https://ai.facebook.com/blog/generating-chit-chat-including-laughs-yawns-ums-and-other-nonverbal-cues-from-raw-audio/

Review paper. In progress!

Textless library: https://github.com/facebookresearch/textlesslib

Samples, papers and code: https://speechbot.github.io

Self supervised audio representations

Review paper: https://arxiv.org/abs/2205.10643

Speech to speech translation

Blog Post: https://ai.facebook.com/blog/advancing-direct-speech-to-speech-modeling-with-discrete-units/