☒☒☒☒☒☒☒☒☒☒☒☒☒☒☒☒

Sora Nagano

The University of Tokyo

2025-07-12

[illegible]

[illegible]

1. ☒☒☒☒☒☒☒☒

1.1 [illegible] vs [illegible]

[illegible]

[illegible] [illegible]

[illegible]

- [illegible]Chomsky & Halle 1968[illegible]
- [illegible]Prince & Smolensky 1993[illegible]
- [illegible]

[illegible][sakɯ͍ᵝa] ⟶ /sakura/

- [illegible]/s/, /a/, /k/, /u/, /r/, /a/[illegible]
- [illegible][+consonantal], [-voice], [+coronal]……[illegible]

1.1 [illegible] vs [illegible]

[illegible]

[illegible] [illegible]

[illegible] (Staples & Graves, 2020)

- word2vec, Skip-gram[illegible]Mikolov et al. 2013[illegible]
- [illegible]king - man + woman ≈ queen (Silfverberg et al., 2018)
- [illegible] (Kolachina & Magyar, 2019)

1.2 [illegible]

[illegible]

[illegible] [illegible]

GAN [illegible] (Begǔs, 2020)[illegible]

- [illegible]
- VOT[illegible]
- [illegible] (Chen & Elsner, 2023)

1.2 [illegible]

[illegible]

[illegible] [illegible]

Vector Quantization (VQ)[illegible]→[illegible] (Higy et al., 2021)

- k-means [illegible]→[illegible]
- Gumbel-Softmax[illegible]
- [illegible]128, 256, 512…[illegible]

[illegible] [illegible]

VQ [illegible]

[illegible]$[0.3, 0.8, -0.2] \longrightarrow$ [illegible]ID:47[illegible]

[illegible]

1.3 [illegible]

SSL [illegible]

[illegible] [illegible]

[illegible] (Venkateswaran et al., 2025)[illegible]

- [illegible]F0, formant[illegible]
- [illegible]
- [illegible]

1.3 [illegible]

[illegible]

[illegible] [illegible]

- [illegible]/p/-/p^h/[illegible] (Medin et al., 2024)
- [illegible] (Pasad et al., 2024)
- [illegible] (Pouw et al., 2024)
- [illegible] (Gosztolya et al., 2024)

1.4 [illegible]

[illegible]

[illegible]

[illegible]×[illegible] (Panchendrarajan & Zubiaga, 2024)[illegible]

- [illegible]+[illegible]
- [illegible]

[illegible]

[illegible]

[illegible]→[illegible]

[illegible]→[illegible]

[illegible]NN[illegible]→[illegible]→[illegible]

1.5 [illegible]

[illegible]

[illegible]

- [illegible] X [illegible] Y [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

- [illegible]VQ[illegible]
- [illegible]
- [illegible]

2. ☒☒☒☒☒

2.1 [illegible]

[illegible]

[illegible]

[illegible] (Cho et al., 2025)[illegible]vs [illegible]

- [illegible]
- [illegible] (Staples & Graves, 2020)

2.2 NLP [illegible]

[illegible] [illegible]

NLP = Natural Language Processing[illegible]
[illegible]Google [illegible]Siri[illegible]ChatGPT

NLP [illegible]

- **1950 [illegible]**[illegible]
- **1990 [illegible]**[illegible]
- **2010 [illegible]**[illegible]

[illegible] [illegible]

[illegible] =[illegible]

2.3 [illegible] NLP [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

NLP [illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible] [illegible]

[illegible]/p/[illegible]/b/[illegible][labial][illegible][± voice][illegible]⟶ NLP [illegible][0.2, −0.8, 1.3, …][illegible]

3. SSL☒☒☒☒☒☒☒☒☒☒

3.1 SSL[illegible]

[illegible] [illegible]

[illegible]Self-Supervised Learning, SSL[illegible] =[illegible]

[illegible]

[illegible]/a/[illegible]/k/[illegible]
⟹ SSL[illegible] (Mohamed et al., 2022)[illegible]

3.1 SSL[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

SSL [illegible]

- [illegible]
- [illegible] (Choi et al., 2024)
- [illegible]

3.2 wav2vec 2.0[illegible] SSL [illegible]

[illegible] [illegible]

wav2vec 2.0[illegible]Meta/Facebook [illegible]= [illegible] SSL [illegible] (Baevski et al., 2022)[illegible]

- [illegible]LibriSpeech[illegible]960 [illegible]
- [illegible]Transformer[illegible]
- [illegible]

3.2 wav2vec 2.0[illegible] SSL [illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]

[illegible] [illegible]

[illegible] __ [illegible] → [illegible]

3.3 [illegible]

[illegible] [illegible]

[illegible] =[illegible] (Astrach & Pinter, 2025; Venkateswaran et al., 2025)[illegible]

3.3 [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]=[illegible]

4. VQ☒☒☒ ⟺ ☒☒☒☒☒☒

4.1 VQ [illegible]

[illegible] [illegible]

[illegible]Vector Quantization, VQ[illegible]

= [illegible] ⟶ [illegible]

[illegible][0.73, −0.45, 1.23] ⟶ [illegible]ID:15[illegible]

⟹ NLP [illegible] (Higy et al., 2021)[illegible]

[illegible]

- [illegible]/p/, /t/, /k/[illegible]
- NLP[illegible]
- VQ[illegible]

4.2 K-means [illegible] VQ [illegible]

[illegible]

1. wav2vec 2.0 [illegible]
2. K-means [illegible] 128 [illegible]
3. [illegible] ID [illegible]
4. [illegible]

4.2 K-means [illegible] VQ [illegible]

[illegible] [illegible]

[illegible]

- [illegible]MiniBatchKMeans
- [illegible]n_clusters=128, random_state=42, batch_size=2048, n_init=3
- [illegible]([illegible], 768) -[illegible]
- [illegible]128 [illegible]+[illegible]
- [illegible]joblib.dump [illegible] pickle [illegible]

[illegible]

1. [illegible]: all_frames.shape = (15,234, 768)
2. KMeans [illegible]: 128 [illegible]
3. [illegible]: cluster_centers_.shape = (128, 768)
4. [illegible]:[illegible]⟶ [illegible] ID (0-127)

4.2 K-means [illegible] VQ [illegible]

[illegible] [illegible]

[illegible]cat[illegible][ID:52, ID:23, ID:78][illegible][k æ t][illegible]

5. ☒☒☒☒☒☒☒☒☒☒

5.1 RQ1[illegible]

RQ1

[illegible]VQ [illegible] [illegible]

[illegible] [illegible]

[illegible]

5.1 RQ1[illegible]

[illegible]

- [illegible]wav2vec2-base-960h [illegible]
- [illegible] vs VQ [illegible](vs [illegible])
- [illegible]([illegible])

[illegible]

- **F1 [illegible]**[illegible]
- [illegible]
- [illegible]

5.2 RQ2[illegible]

RQ2

[illegible] [illegible] (Panchendrarajan & Zubiaga, 2024)

6. ☒☒☒☒☒☒☒☒

6.1 [illegible]

[illegible] [illegible]

[illegible]Proof of Concept[illegible]

[illegible]

- **Docker + Poetry**[illegible]
- [illegible]CPU [illegible]MacBook Pro[illegible]- GPU [illegible]
- [illegible] 100 [illegible]
- [illegible]3 [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
LibriSpeech	100	[illegible]	[illegible]

6.1 [illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Common Voice	100	[illegible]	[illegible]

[illegible] [illegible]

- LibriSpeech[illegible]
- Common Voice[illegible]Mozilla [illegible]

⟹ [illegible] 16kHz [illegible]

6.2 [illegible]

RQ1[illegible]

[illegible] [illegible]

[illegible]

- G2P-EN [illegible]text → phoneme list[illegible]
- [illegible]np.linspace [illegible]
- [illegible]-[illegible]

[illegible]

- [illegible]wav2vec2 [illegible]768 [illegible]
- [illegible]VQ [illegible] ID[illegible]0-127 [illegible]
- [illegible]

[illegible]

- [illegible]
- [illegible]train-test split (70%-30%)
- [illegible]63 [illegible]

6.2 [illegible]

RQ2[illegible]

[illegible]

[illegible]

- [illegible]wav2vec2 [illegible]768 [illegible]
- [illegible]StandardScaler [illegible]
- [illegible]8 [illegible]

[illegible]+[illegible]

- [illegible]768 [illegible]
- [illegible]F0 [illegible]
- [illegible]librosa.pyin [illegible]
- [illegible] 772 [illegible]
- [illegible] StandardScaler [illegible]

6.3 [illegible]

[illegible] 1[illegible]

[illegible] [illegible]

LibriSpeech test.clean [illegible]RQ1 [illegible]

- Hugging Face [illegible]
- [illegible] 100 [illegible]
- [illegible]
- [illegible]+[illegible]

Common Voice 13.0 [illegible]RQ2 [illegible]

- Mozilla [illegible]
- [illegible]
- [illegible]teens, twenties, thirties, forties, fifties, sixties, seventies, eighties
- [illegible]+[illegible]+[illegible]

6.3 [illegible]

[illegible] [illegible]

[illegible]

LibriSpeech[illegible]

```
{
  "file": "6930-75918-0000.flac",
  "audio": {"array": [-6.10e-05, 9.15e-05, ...], "sampling_rate": 16000},
  "text": "CONCORD RETURNED TO ITS PLACE AMIDST THE TENTS",
  "speaker_id": 6930
}
```

Common Voice[illegible]

```
{
  "audio": {"array": [0.001, -0.002, ...], "sampling_rate": 48000},
  "sentence": "The quick brown fox jumps over the lazy dog",
  "age": "twenties"
}
```

6.3 [illegible]

[illegible] 2[illegible]

[illegible] [illegible]

[illegible]

1. wav2vec2-base-960h [illegible]
2. [illegible]16kHz [illegible]
3. [illegible]Shape ([illegible], 768 [illegible])
4. [illegible]librispeech_micro_continuous.npy

VQ [illegible]

1. [illegible]Shape ([illegible], 768)
2. MiniBatchKMeans [illegible]128 [illegible]
3. [illegible]vq_kmeans_128_micro.pkl
4. [illegible]

6.3 [illegible]

[illegible] [illegible]

[illegible]

- 1 [illegible]: (149, 768) ⟶ 149 [illegible]×768 [illegible]
- 100 [illegible]: (15,234, 768) ⟶ [illegible] 15,234 [illegible]
- VQ [illegible]: (128, 768) ⟶ 128 [illegible]

VQ [illegible]

- [illegible]: [0.73, −0.45, 1.23, …] (768 [illegible])
- ⟶ [illegible] ID: 25 (0-127 [illegible])
- VQ [illegible]: [25, 25, 25, 52, 52, 78, 78, …]

[illegible] 3[illegible] notebook [illegible]

Notebook	[illegible]	[illegible]
rq1_probing_pipeline	[illegible]	[illegible] vs VQ [illegible]

6.3 [illegible]

Notebook	[illegible]	[illegible]
rq2_hybrid_model_poc	[illegible]	[illegible]+[illegible]

6.3 [illegible]

[illegible]

6.3 [illegible]

[illegible] [illegible]

[illegible]

```
[illegible]: /workspace/data/.cache
[[illegible]] LibriSpeech[illegible] 100 [illegible]
[[illegible]] [illegible]LibriSpeech[illegible]:
{'file': '6930-75918-0000.flac', 'text': 'CONCORD RETURNED...'}
LibriSpeech[illegible] 100 [illegible] /workspace/data/raw/librispeech_micro [illegible]
```

[illegible]

```
[[illegible]] K-Means[illegible]all_frames[illegible]shape: (15234, 768), Dtype: float32
VQ[illegible] (KMeans) [illegible] 128 [illegible]...
[[illegible]] [illegible]shape: (128, 768)
VQ[illegible] outputs/models/vq_kmeans_128_micro.pkl [illegible]
```

[illegible]

- Poetry [illegible] Python [illegible]
- Docker [illegible] OS [illegible]
- requirements [illegible] [illegible]
- Hugging Face datasets/transformers [illegible]

7. ☒☒☒☒☒☒☒

7.1 RQ1[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]63 [illegible]
- [illegible]LibriSpeech micro (100 [illegible] 33,464 [illegible])
- [illegible]G2P-EN +[illegible]
- [illegible]train-test split (70%-30%) [illegible]

[illegible]wav2vec 2.0[illegible]

- [illegible]768 [illegible]
- [illegible]
- [illegible]
- [illegible]1/63≈1.6%[illegible]

7.1 RQ1[illegible]

[illegible] [illegible]

[illegible]

- G2P-EN[illegible] “A MAN SAID...” ⟶ [illegible][‘AH0’, ‘ ‘, ‘M’, ‘AE1’, ‘N’, ...]
- [illegible]np.linspace [illegible]
- [illegible]150 [illegible]10 [illegible]⟶ [illegible] 15 [illegible]
- [illegible]

[illegible]

- [illegible]“CONCORD RETURNED TO ITS PLACE AMIDST THE TENTS”
- [illegible]42 [illegible][‘K’, ‘AA1’, ‘N’, ‘K’, ‘AO2’, ‘R’, ‘D’, ‘ ‘, ‘R’, ‘IH0’, ‘T’, ‘ER1’, ‘N’, ‘D’, ...]
- [illegible]175 [illegible]
- [illegible][0, 4, 8, 12, 16, 20, 25, 29, ...] ⟶ [illegible] 4 [illegible]
- [illegible]33,464 [illegible] 100 [illegible]× 768 [illegible]

7.1 RQ1[illegible]

VQ [illegible]

[illegible] [illegible]

[illegible]

- VQ [illegible]128 [illegible] 2 [illegible]
- [illegible]⟶ [illegible] ID[illegible]0-127 [illegible]

VQ [illegible]

- [illegible]
- [illegible]768 [illegible]⟶1 [illegible]
- [illegible]

7.1 RQ1[illegible]

[illegible] [illegible]

VQ [illegible]

[illegible]

- [illegible]
- 768 [illegible]⟶1 [illegible]
- [illegible] ID =[illegible]
- [illegible]

[illegible] VQ [illegible]

- [illegible]: [0.73, −0.45, 1.23, ...] (768 [illegible])
- VQ [illegible]:[illegible] ID=52 ([illegible])
- [illegible]cat[illegible]: [ID:52, ID:23, ID:78] ⟶ [illegible]
- [illegible]ID=52⟶/k/[illegible]ID=23⟶/æ/[illegible]ID=78⟶/t/ [illegible]

7.2 RQ2[illegible]

[illegible] [illegible]

[illegible]

[illegible]

- [illegible]Common Voice micro (100 [illegible])
- [illegible]8 [illegible](teens, twenties, thirties, forties, fifties, sixties, seventies, eighties)
- [illegible] vs [illegible]
- [illegible]train-test split +[illegible]+ classification_report

7.2 RQ2[illegible]

[illegible] [illegible]

[illegible]

- [illegible]Wav2Vec2 [illegible]768 [illegible]
- [illegible]StandardScaler [illegible]
- [illegible]8 [illegible]
- [illegible] $1/8 = 12.5\%$

7.2 RQ2[illegible]

[illegible] [illegible]

[illegible]+[illegible]

- [illegible](768 [illegible]) +[illegible](4 [illegible]) = 772 [illegible]
- [illegible]wav2vec2 [illegible]768 [illegible]
- [illegible]F0 [illegible]
- F0 [illegible]librosa.pyin(fmin=C2, fmax=C7) [illegible]
- [illegible]np.hstack [illegible]→ 772 [illegible]
- [illegible] StandardScaler [illegible]

7.2 RQ2[illegible]

[illegible] [illegible]

[illegible]

- X_neural: (100, 768) -[illegible]
- X_acoustic: (100, 4) - [mean_f0, std_f0, jitter, shimmer]
- X_hybrid: (100, 772) -[illegible]
- [illegible]≈0.0, [illegible]≈1.0 [illegible]

7.2 RQ2[illegible]

[illegible]

[illegible] [illegible]

[illegible]

- [illegible]1/8 = 12.5% (8 [illegible])
- [illegible]
- [illegible]
- [illegible]

[illegible]

- [illegible]'twenties'
- [illegible](768,) [illegible]
- [illegible][mean_f0: 192.33, std_f0: 15.7, jitter: 0.02, shimmer: 0.1]
- [illegible](772,) =[illegible](768) +[illegible](4)

7.2 RQ2[illegible]

[illegible]

[illegible]

RQ1 [illegible]

- [illegible]wav2vec 2.0 [illegible]
- VQ [illegible]
- [illegible]→[illegible]

RQ2 [illegible]

- [illegible]
- [illegible]
- [illegible]F0 [illegible]

7.2 RQ2[illegible]

[illegible] [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

7.2 RQ2[illegible]

[illegible]

[illegible] [illegible]

[illegible]

1. [illegible]numpy [illegible] 1 [illegible]
2. [illegible]torchaudio.transforms.Resample [illegible]
3. [illegible]Wav2Vec2Processor [illegible]
4. [illegible]torch.no_grad() [illegible] GPU [illegible]
5. [illegible]CPU [illegible]numpy [illegible]

7.3 [illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	G2P-EN [illegible]	Montreal Forced Aligner [illegible]
[illegible]	100 [illegible]×2 [illegible]	[illegible]
[illegible]	CPU [illegible]	[illegible] GPU [illegible]
[illegible]	wav2vec2-base	WavLM-Large [illegible]

[illegible] [illegible]

Montreal Forced Aligner (MFA) =[illegible] G2P-EN [illegible]

8. ☒☒☒☒☒☒☒☒

8.1 [illegible]

[illegible]

- MFA [illegible]
- [illegible]
- WavLM-Large [illegible]
- [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

8.2 [illegible]

[illegible]

- SSL [illegible]
- [illegible] (Panchendrarajan & Zubiaga, 2024; Tsvilodub et al., 2025)
- [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible] (Jarosz, 2019)

9. ☒☒☒

9.1 [illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

9.2 [illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]

[illegible] [illegible]

9.2 [illegible]

[illegible]

[illegible] [illegible]

[illegible]

- data/processed/librispeech_micro_continuous.npy[illegible]
- outputs/models/vq_kmeans_128_micro.pkl[illegible] VQ [illegible]
- outputs/figures/cm_Continuous.png[illegible]
- outputs/figures/cm_Discrete (VQ).png[illegible]VQ [illegible]
- outputs/figures/cm_[illegible].png, cm_[illegible] (VQ).png[illegible]

[illegible]

- [illegible]63 [illegible]‘ ‘, ‘AA0’, ‘AA1’, ‘AE1’, ‘AH0’, …[illegible]
- [illegible]33,464 [illegible]×768 [illegible]33,464×1 [illegible]
- [illegible]/[illegible]23,424/10,040 [illegible]
- VQ [illegible]128 [illegible](128, 768)[illegible]

[illegible]

- [illegible] notebooks/prepare.ipynb [illegible]
- Docker [illegible]
- random_state [illegible]

☒☒☒☒

Note: Reference file path needs to be adjusted for compilation

☒☒☒☒

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