



Beyond End-to-End ASR: Integrating Long-Context Acoustic and Linguistic Insights

Tae Jin Park, Huck Yang, Kyu J. Han, Shinji Watanabe

Session 15:30 to 18:30
Aug 17th 2025



Scan for
References

Speakers

INTERSPEECH 2025



Prof. Shinji Watanabe

Carnegie Mellon
University (CMU)



Dr. Taejin Park

NVIDIA
NeMo SpeechAI



Dr. Huck Yang

NVIDIA
Research



Dr. Kyu J. Han

Oracle Cloud
Infrastructure (OCI)

Introduction

Shinji Watanabe

Abstract:

This tutorial explores the advancements and challenges in long-context automatic speech recognition (ASR), emphasizing its critical role in improving fairness, inclusivity, and performance across diverse linguistic groups.

While modern ASR systems excel in data-rich languages such as English, they often underperform for low-resource languages, accented speech, and underrepresented communities due to limited context modeling.

(Speech Benchmarks) The tutorial also examines benchmarks such as SLUE, Speech QA, and Dynamic SUPERB, which assess ASR performance in noisy environments, spoken language understanding, and long-context comprehension.

(Evaluations for modern speech topics) This tutorial introduces robust evaluation pipelines for long-form ASR, leveraging datasets such as CHiME and LibriHeavy, and discusses metrics such as multi-talker diarization, semantic evaluation, and retrieval-augmented generation (RAG) techniques.

(Acoustic and Semantic Context modeling) We delve into acoustic and semantic context modeling, highlighting innovations in multi-speaker processing, speech-LLM integration, and RAG-based error correction.

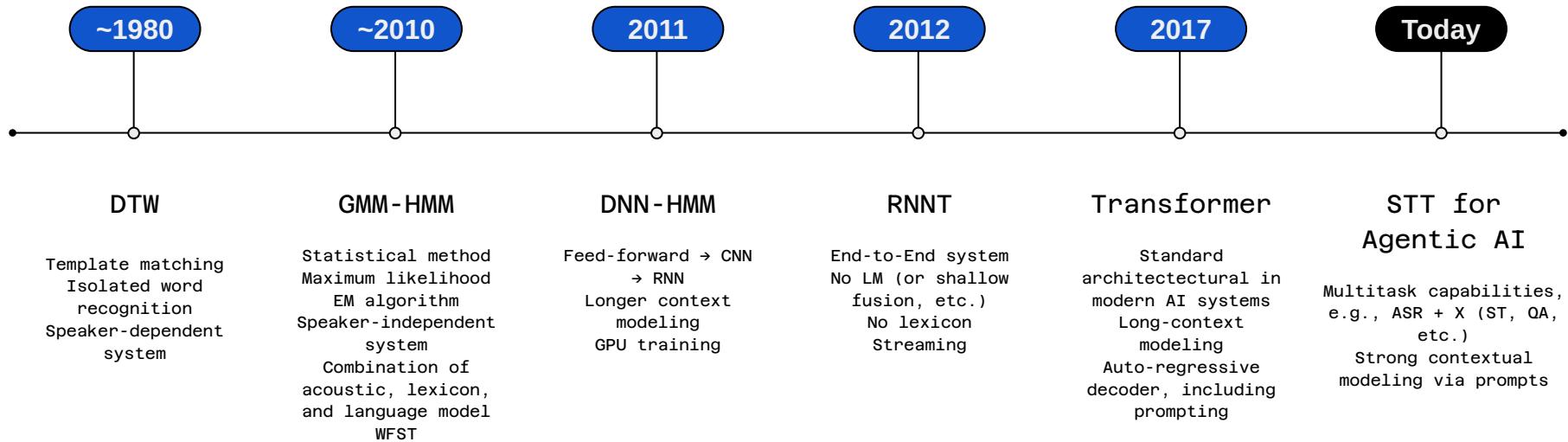
(Long Context in ASR) By integrating long-context processing and large language models (LLMs), ASR systems can better handle disfluencies, code-switching, and speaker variability, reducing biases and improving accessibility for marginalized communities.

(Summary of Summary) This tutorial underscores the importance of long-context ASR in advancing speech technology toward fairer, more inclusive systems that serve all users equitably.

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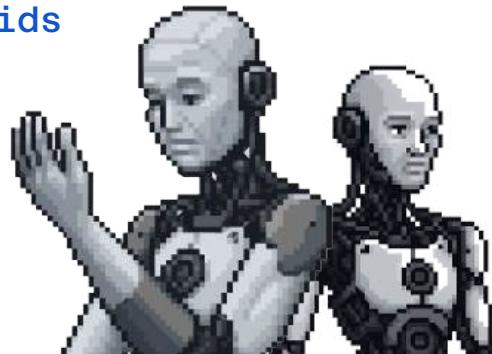
Introduction (10 mins) 15:30-15:40		
Shinji (30 min) 15:40-16:10	Speech-to-Text Benchmark	
Taejin (40 min) 16:10-16:50	Leveraging Long Acoustic Context	
Recess (10 min) 16:50-17:00		
Huck (40 min) 17:00-17:40	Semantic Context and Speech-Language Modeling	
Kyu (30 min) 17:40-18:10	Contextual Biasing and Methods Leveraging Longer Semantic Context for Speech Systems	
Closing Remark (10 min) 18:10-18:20		
Q&A Session (10 min) 18:20-18:30		

A short history of speech-to-text systems



Modern day Speech-to-Text Applications

- Human-computer interface
- Humanoids



- Voice Assistants
- Voice Agents



What is missing?



CONTEXT

Long-Context Acoustic and Linguistic Insights



Acoustic Insights

- How **intrinsic variability** (Physiological traits, speaker characteristics) and **extrinsic variability** (mic, codecs) construct acoustic context for ASR
- How streaming ASR application and speaker attributed ASR takes advantage of acoustic context
- **Alternative architectures** for speech recognition
- Speech encoders and **ASR endpointing** in voice agents applications.



Linguistic Insights

- **Semantic Information Modeling** in End-to-End ASR: Classical ASR-LM, Post-processing ASR corrections
- Preference-based Semantic Modeling in Post-training
- **Semantic Understanding** from ASR to Audio Contexts
- Limitation and New Evaluation of Semantic Modeling: Data Leakage via Text, Pre-training Agentic & Instruction Evaluation



Context Biasing

- **Contextual Biasing** for E2E ASR Decoder, Encoder, Hybrid Biasing
- Retrieval Toward Large-Scale Biasing
- **Retrieval Augmented Generation (RAG)** and how RAG is used for contextual Biasing

Tutorial flow

INTERSPEECH 2025



Section 1: Speech-to-Text Benchmark



Section 2: Leveraging Long Acoustic Context



Section 3: Semantic Context and Speech-Language Modeling



Section 4: Contextual Biasing and Methods Leveraging Longer Semantic Context for Speech Systems

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Speech-to-Text Benchmark

Shinji Watanabe



Speech-to-Text Benchmark

- 1. Long form Beyond Utterances**
 - a. Classical Speech-to-Text
 - b. Long-form Conversational Speech-to-Text
- 2. Evaluation Metrics**
 - a. Speaker Attributed Contents
 - b. Timestamp
 - c. Semantics
 - d. Dialog
- 3. Databases**
 - a. Revising existing databases
- 4. Selected Benchmarks**

Long form Beyond Utterances

Classical Speech-to-Text: Utterance based

- **Utterance**
 - Speech segment corresponds to a (part of) sentence or phrase
 - A few seconds to 20 seconds (We cannot bress it so long)
 - This unit provides a lot of benefits on the **computational cost or semantic/syntactic processing** for speech
- **How to prepare a utterance?**
 - Read speech
 - Segmented speech

Classical Speech-to-Text: Read speech

- **Read a prompt**
- We can make a pair data of a prompt and corresponding audio
 - Ex) TIMIT, Wall Street Journal (WSJ), Commonvoice:
<https://commonvoice.mozilla.org/en>,
- **Easy to collect**
 - We still need to check whether the person can correctly utter a prompt
- **Easy to anonymize**
- **Easy to cover phonetic variations**
- **But still not a real conversation** 😔



 Speak  Listen  Write

Click  then read the sentence aloud

START RECORDING 

Eisenhower adviser Charles Douglas Jackson
coordinated psychological warfare against
Communism.

2

3

4

5



Speak

Listen

Write

Click  did they accurately speak the sentence?

1

All but thirty of Nemed's people were wiped out.

2

3

4

5



YES



NO

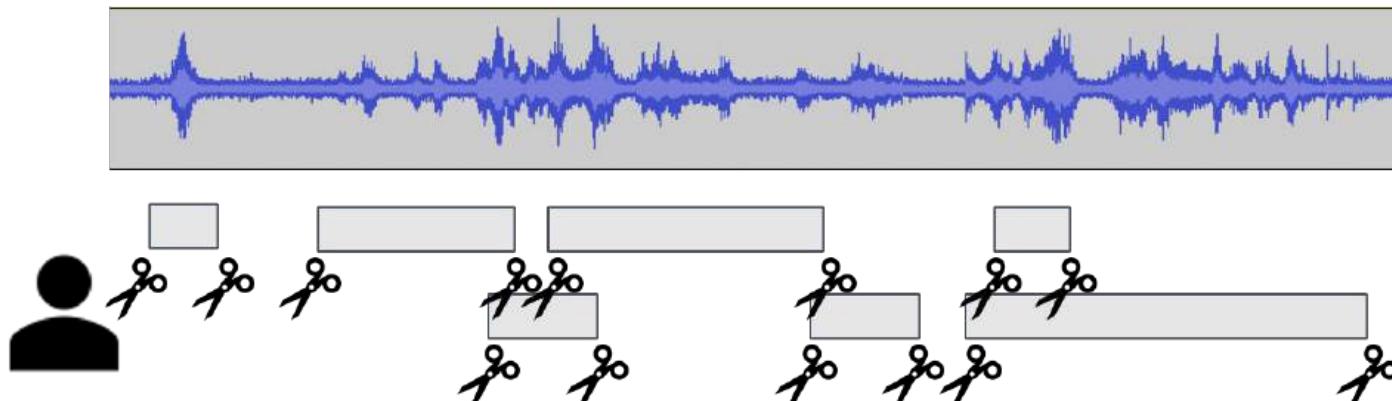
Trash

Classical Speech-to-Text: Read speech

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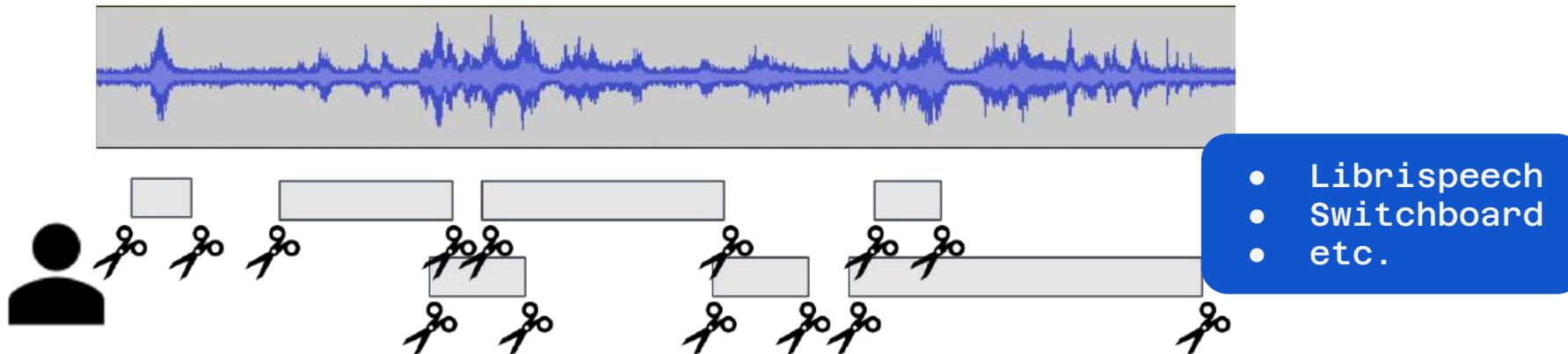
Classical Speech-to-Text: Segmented speech



Segment ID	Speaker ID	Onset	Offset	Transcription
A00011-001	A	0:01:26	0:05:04	
A00011-002	B	0:05:52	0:08:56	Oh really? Do you think you'll check out CMU?
A00011-003	A	0:09:22	0:13:04	

Given

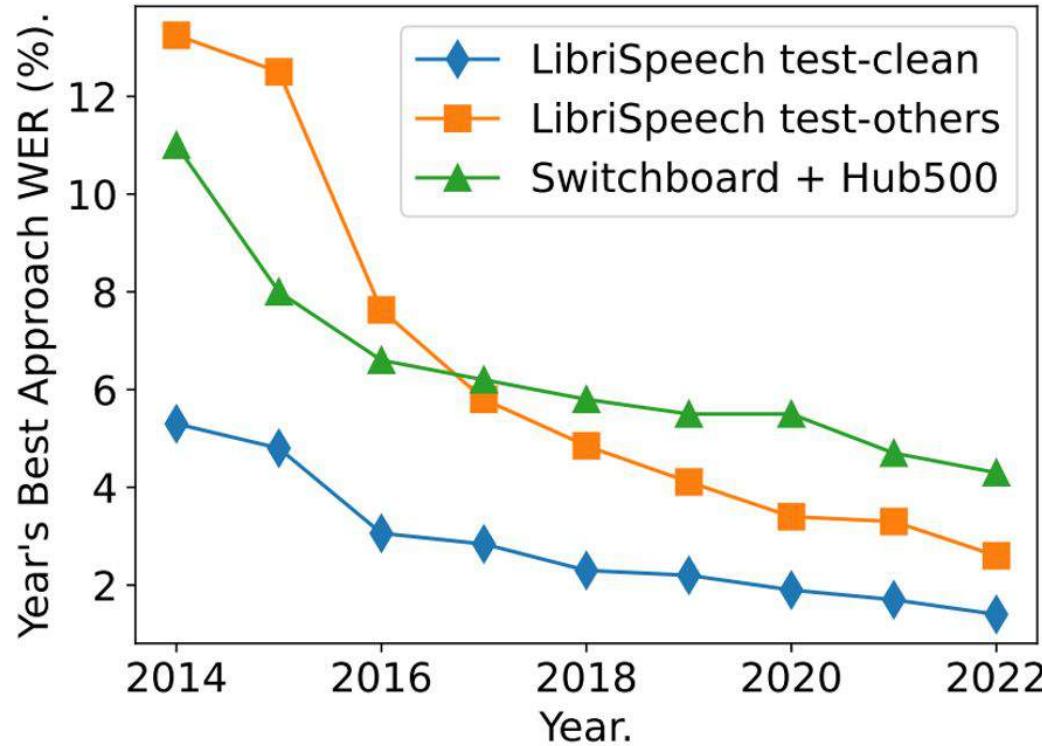
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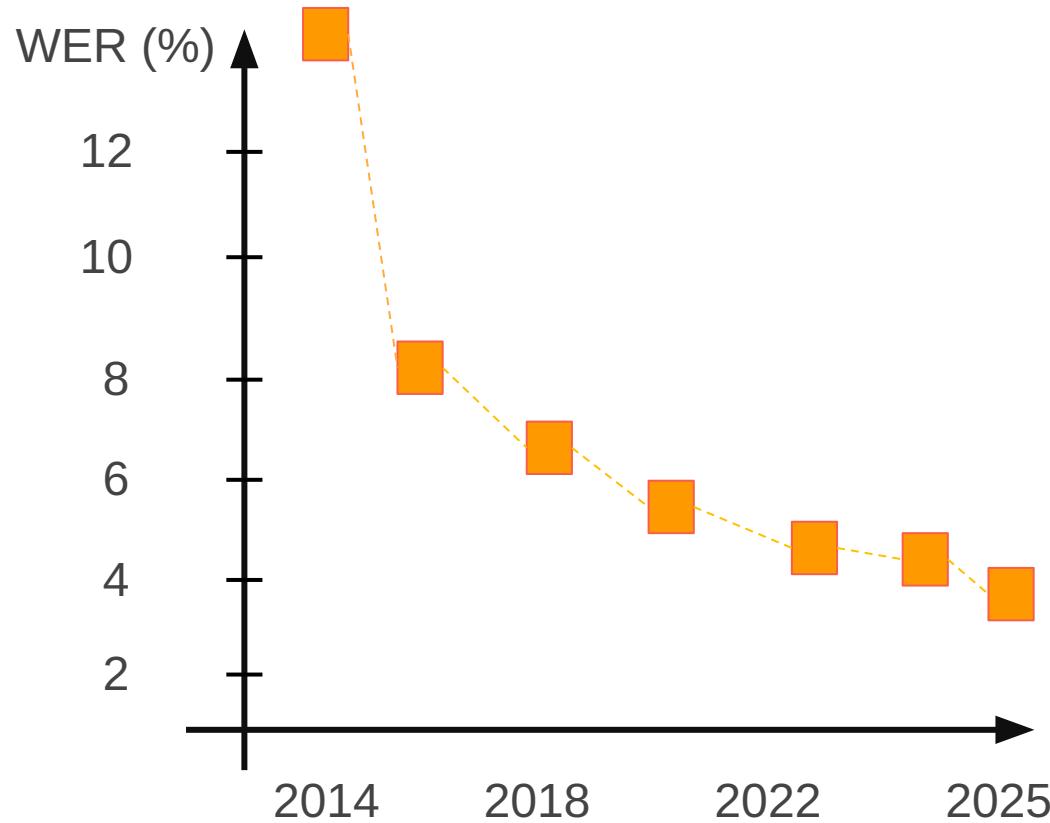
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Do short-form ASR

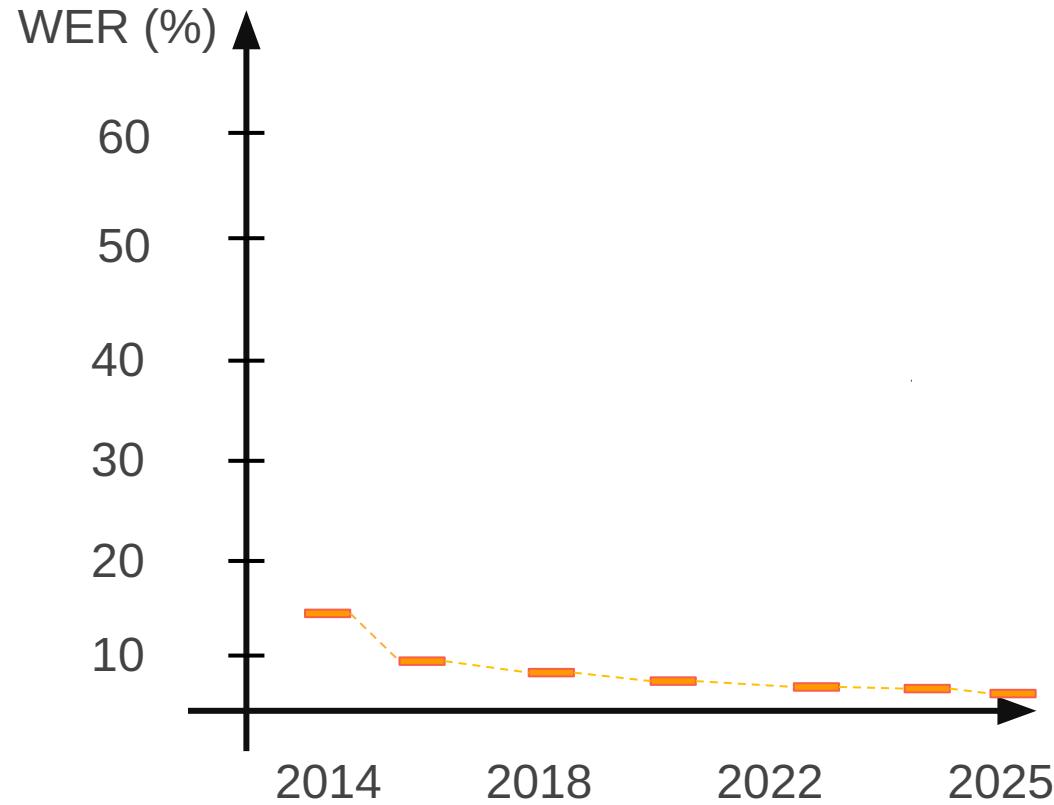
ASR is solved?



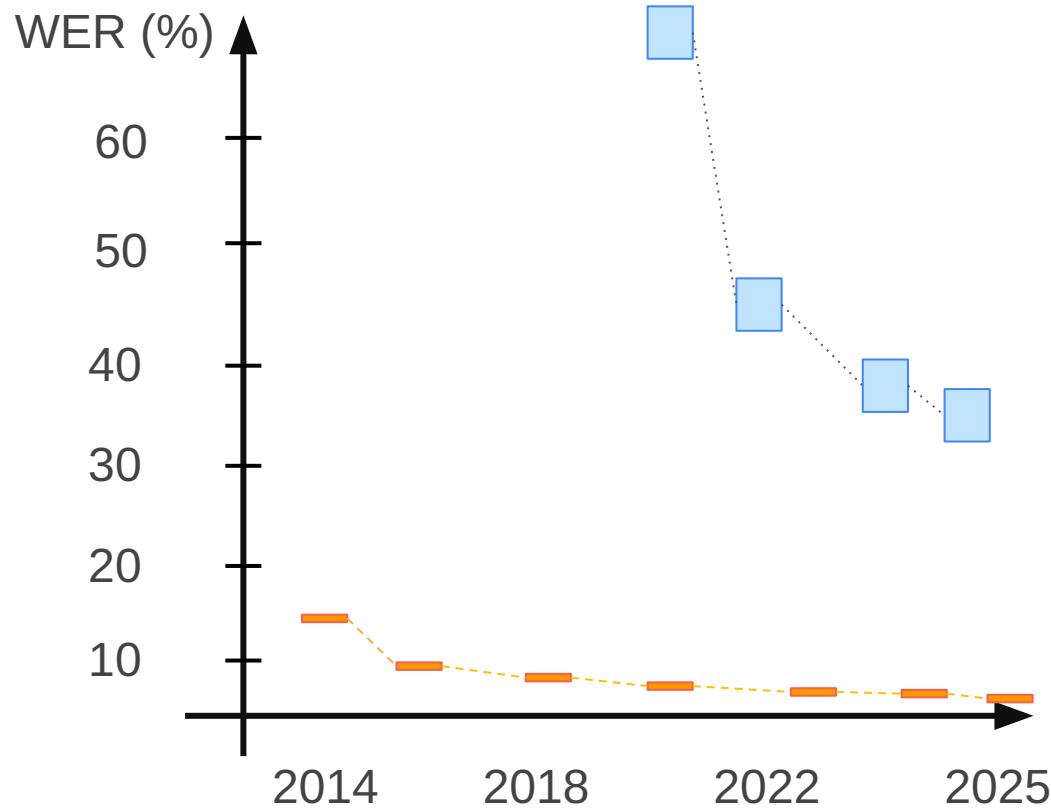
Is ASR solved (LibriSpeech etc.)



Is ASR solved (Librispeech etc.)

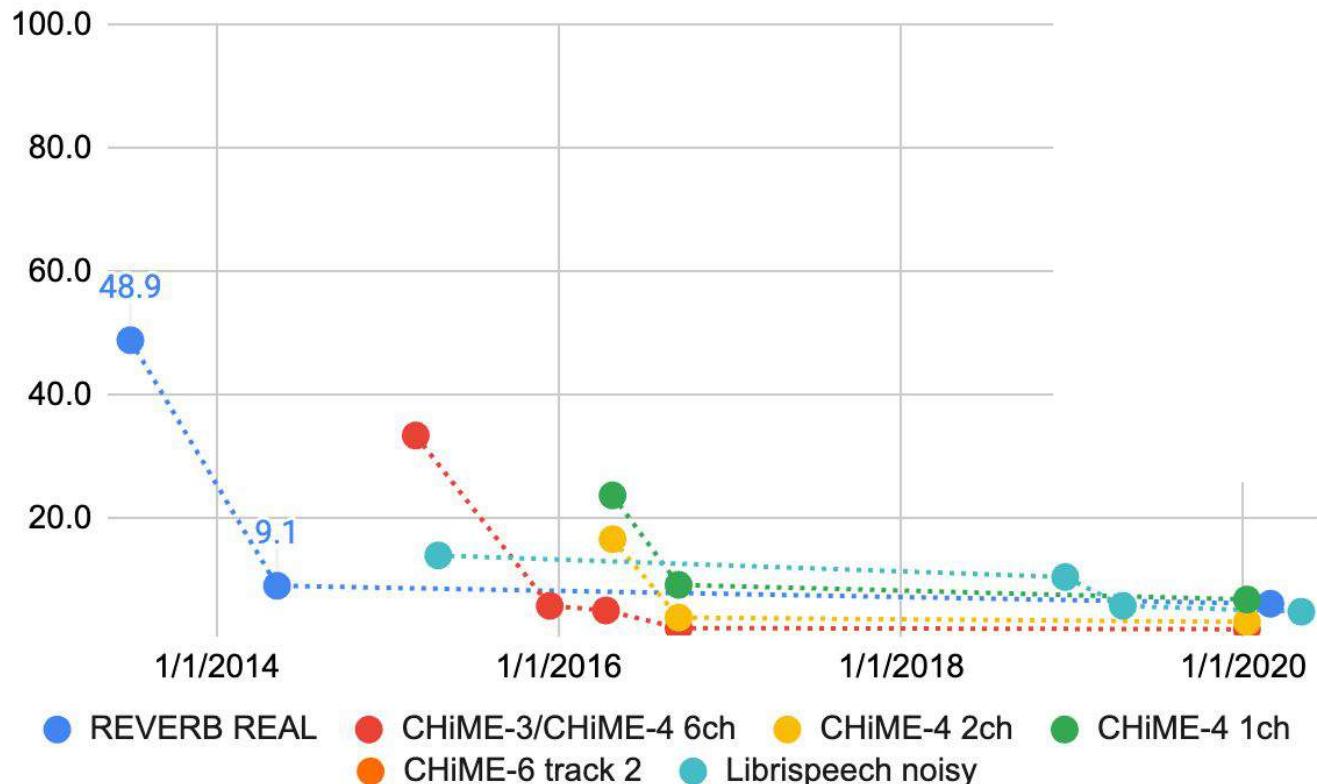


Not yet! (CHiME-6)

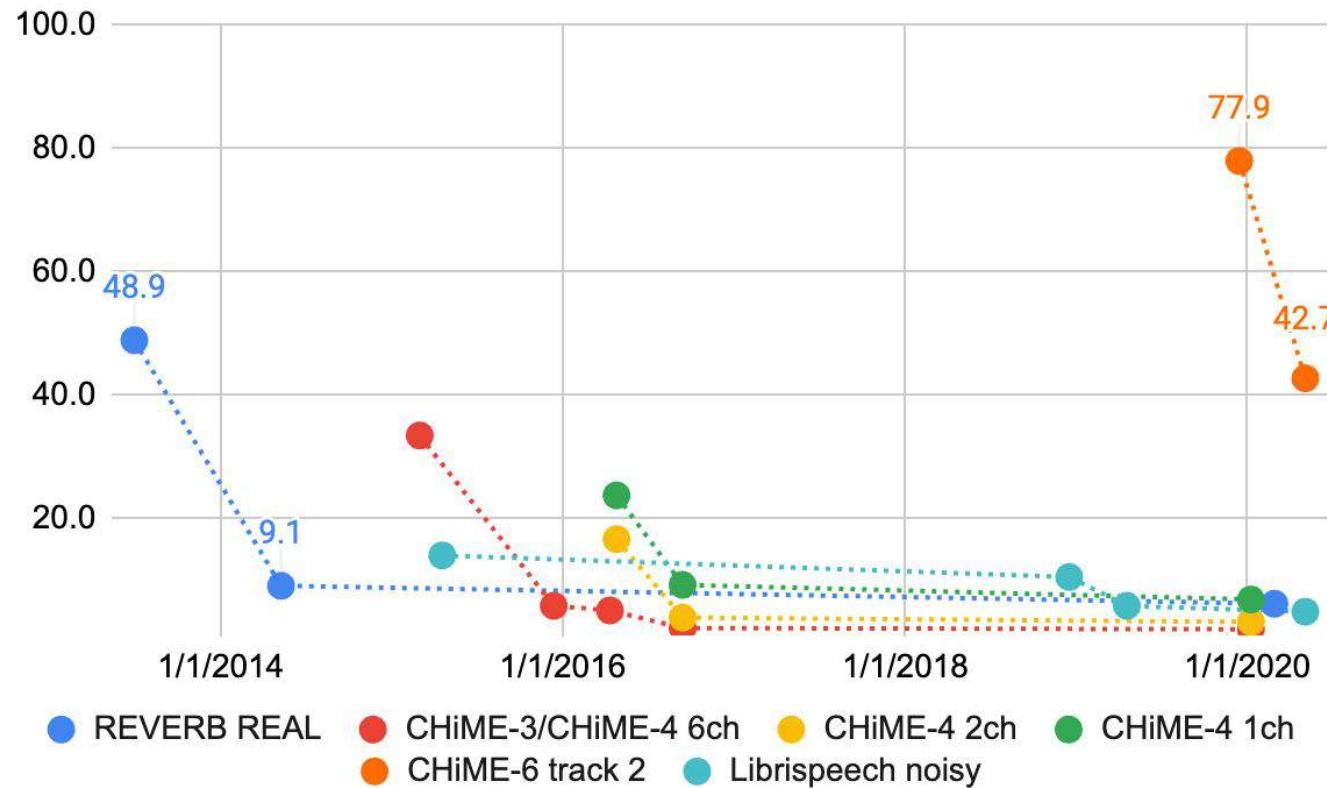


We have to
deal with
various
contexts

Is ASR solved?

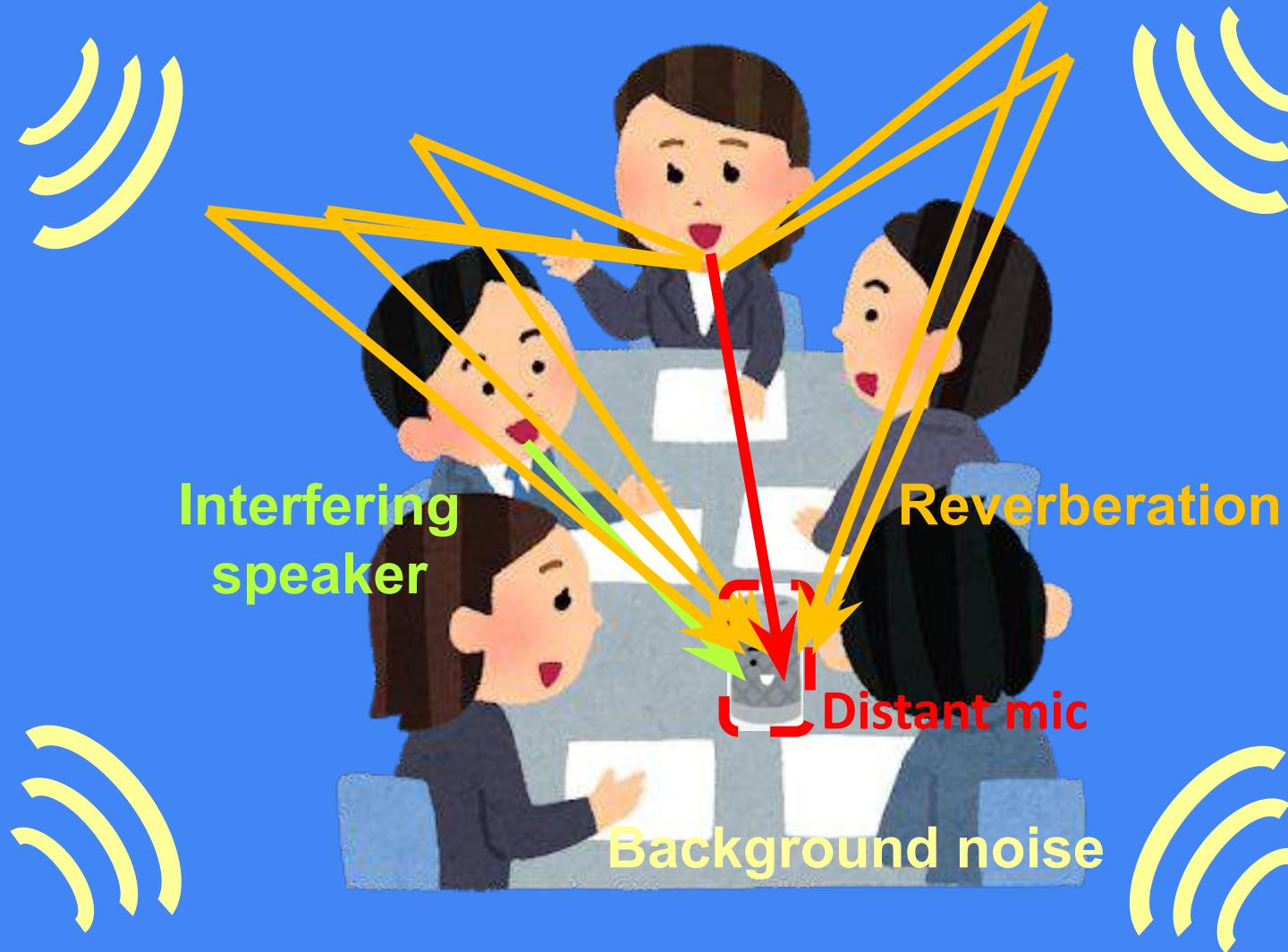


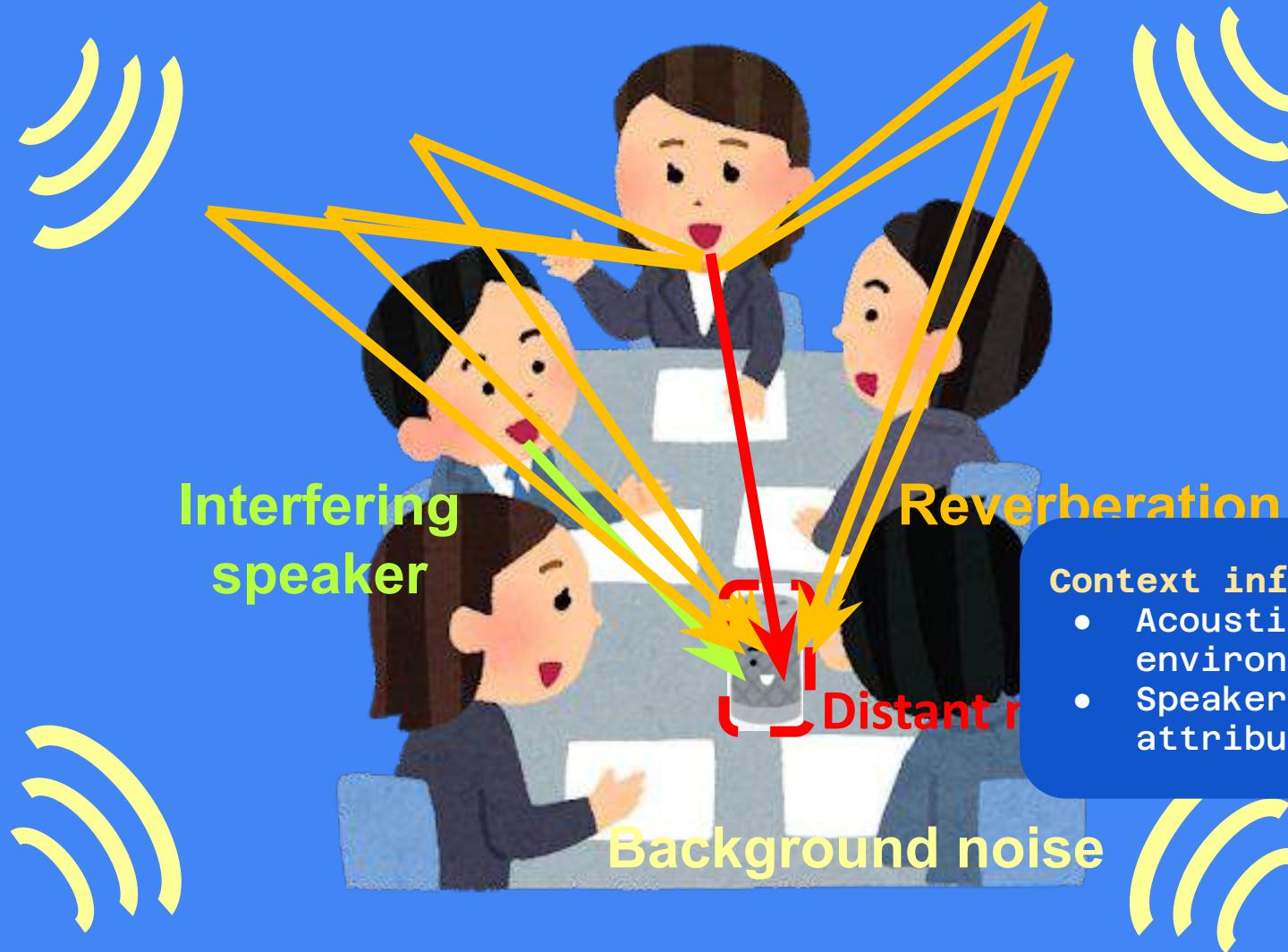
Not solved yet!



CHiME-6 <https://chimechallenge.github.io/chime6/>

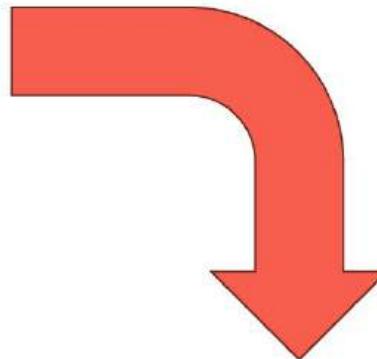






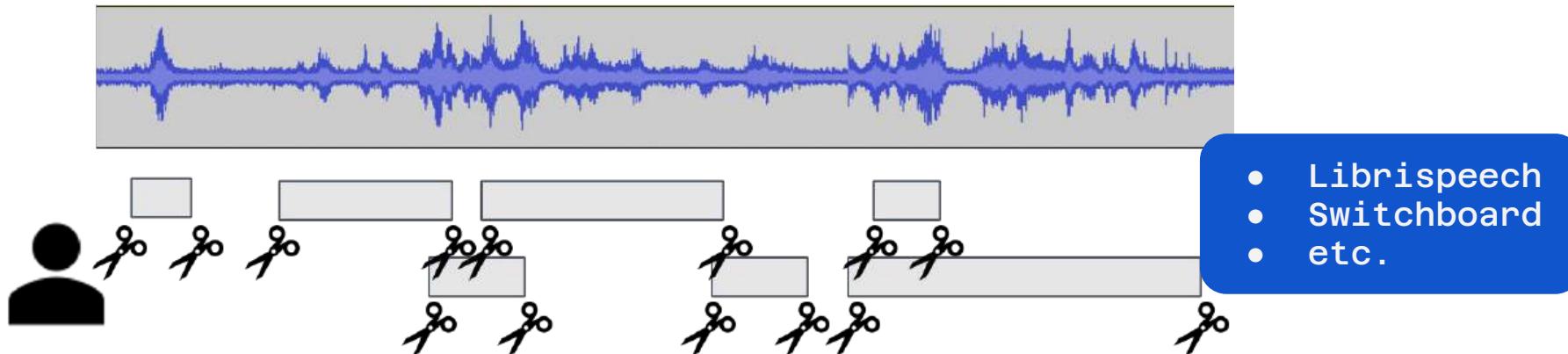
Rich transcriptions

```
{  
    "end_time": "11.370",  
    "start_time": "11.000",  
    "words": "so ummm",  
    "speaker": "P03",  
    "session_id": "S05"},  
  
{  
    "end_time": "14.110",  
    "start_time": "12.100",  
    "words": "where is he?",  
    "speaker": "P01",  
    "session_id": "S05"}  
}
```



Segment ID τ	Speaker Cluster k	Onset (sec) $b(\tau)$	Offset (sec) $e(\tau)$	Transcription W_τ
S05_P03_001	P03	11.000	11.370	So ummm
S05_P01_002	P01	12.100	14.110	where is he?

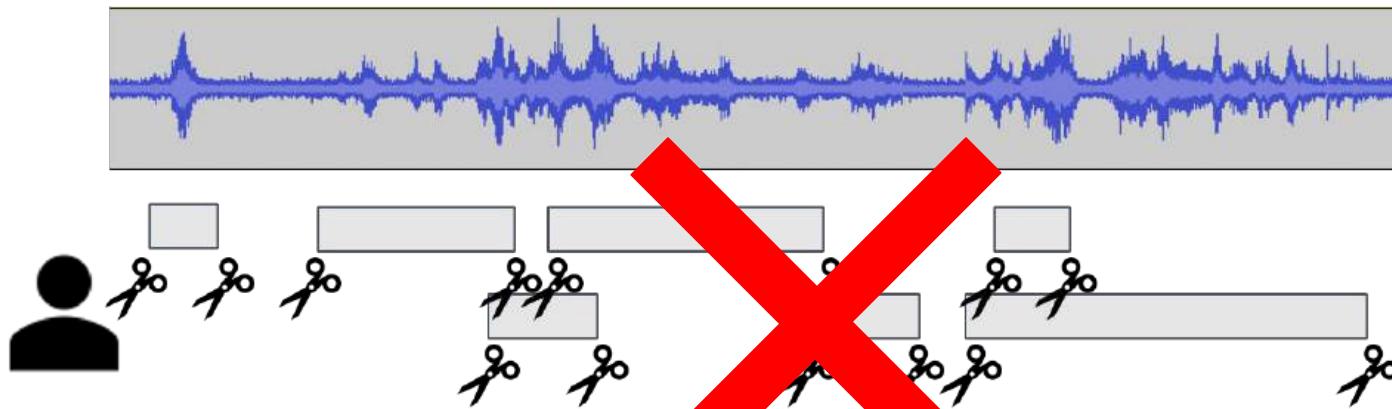
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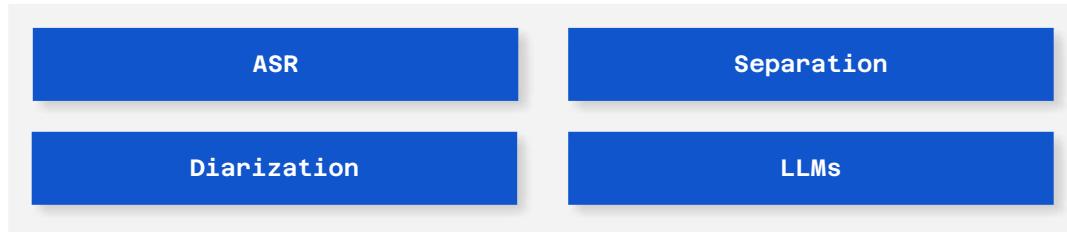
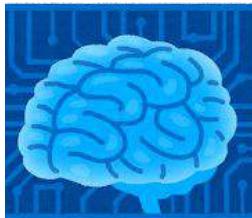
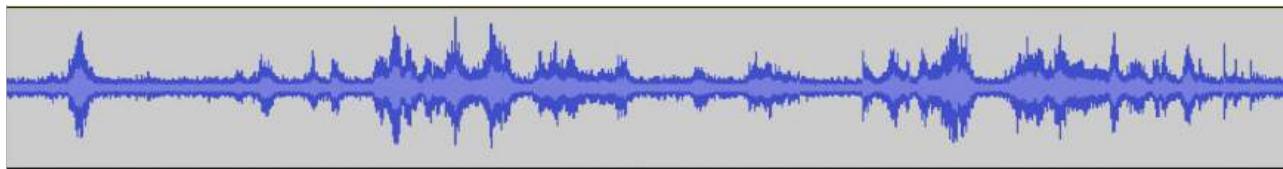
Do short-form ASR

Classical Speech-to-Text: Segmented speech



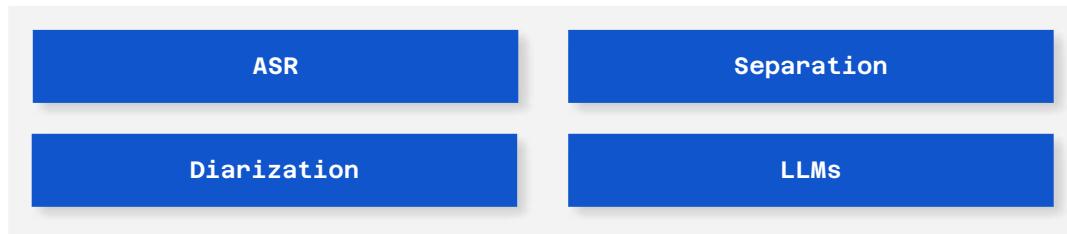
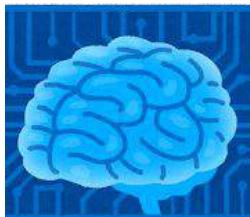
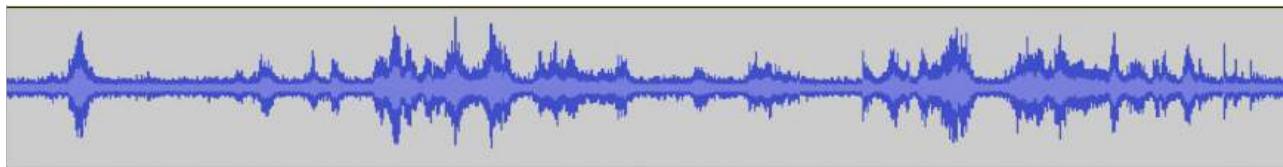
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Long-form conversation recognition



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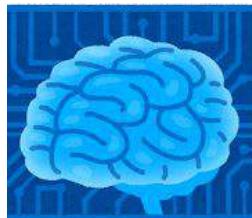
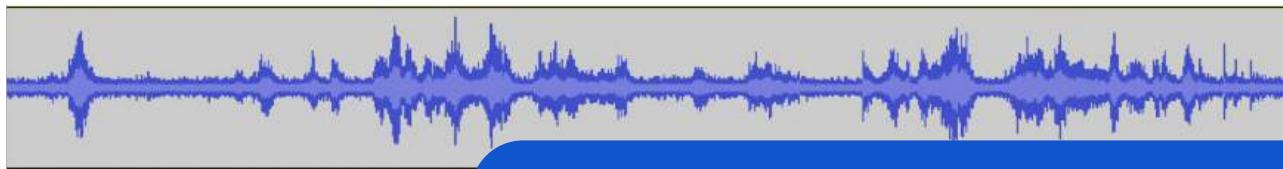
Long-form conversation recognition



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Predict everything by AI

Long-form conversation recognition



Context information

- Speaker attribution contents
- Timestamp
- Dialog

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A00011-001	A	0:01:26	0:05:04	Yeah, um, I'm kinda thinking about going to Pittsburgh
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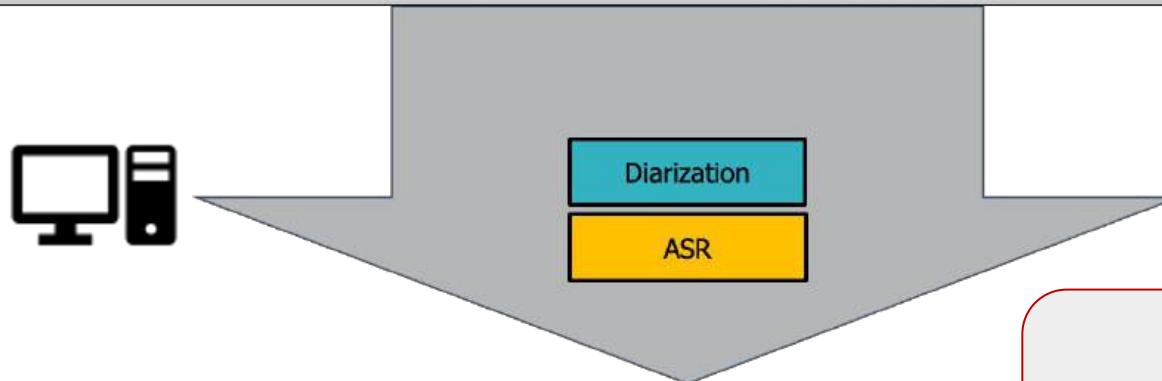
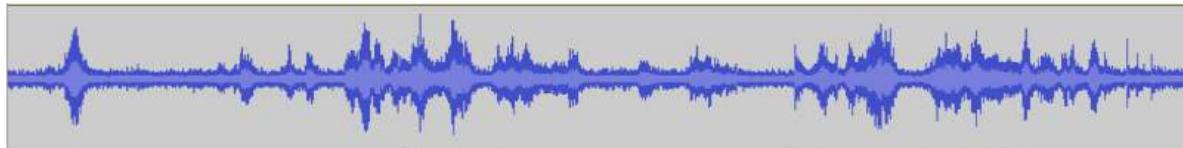
Semantic information

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Context information

- Semantic information
 - Irrelevant filler information
 - keywords (Pittsburgh, CMU)
 - Location context → CMU is Carnegie Mellon University, not Central Michigan University

Long-form conversation recognition



Without any given information

Segment ID τ	Speaker Cluster k	Onset (sec) $b(\tau)$	Offset (sec) $e(\tau)$	Transc.
A-0007400-0007588	A	74.0	75.88	yes
A-0008380-0009435	A	83.8	94.35	hey did you put...
B-0031242-0031700	B	312.42	317.0	hmm

- Contextも言う

Time Marked
(RTTM)

Conversational speech (I will change it to better examples)

Shinji: Heyyy, Kyu! Man, it's been a while. How've you been?

Kyu: Oh, you know... same ol', same ol'. Still trying to win the war against my inbox. *laughs* How about you?

Shinji: Hmm... let's just say my "to-do later" pile is now an actual tower. Anyway—hey, did you check out the Interspeech 2025 lineup yet?

Kyu: Uh, not really. I've been meaning to, but... yeah, life. Anything good?

Shinji: Oh, yeah. Taejin's doing this tutorial—

Semantic information

- What is this conversation talking about
- Keywords: Interspeech, Taejin's tutorial, etc.

How to evaluate it?

- Speaker Attributed Contents
- Timestamp
- Dialog
- Semantics

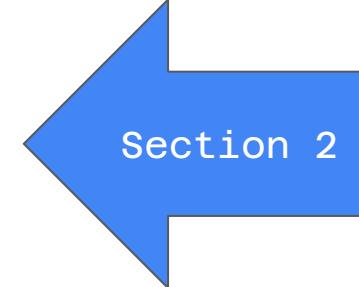
Evaluation Metrics

Evaluation Metrics

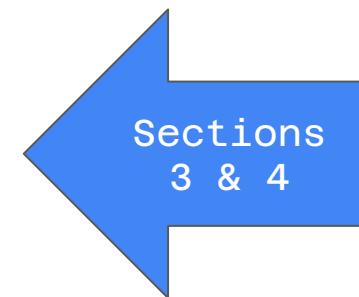
- **Speaker Attributed Contents**
 - concatenated minimum permutation WER (cpWER)
 - Speaker consistency across the segments
- **Timestamp**
 - Diarization error rate (DER)
 - Time-constrained cpWER (tcpWER)
- **Dialog**
 - Turn taking accuracy
- **Semantics**
 - Biased WER
 - n-gram matching approaches: BLEU, METEOR, ...
 - Embedding based: BERTScore
 - LLM-based: Perplexity, LLM-as-a-judge

Evaluation Metrics

- **Speaker Attributed Contents**
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Section 2



Sections
3 & 4

Concatenated minimum-Permutation Word Error Rate

Lowest WER →

(hi) (dd e ii jj kk) (aa bb c ff)
(dd e ii jj kk) (hi) (aa bb c ff)
(hi) (aa bb c ff) (dd e ii jj kk)
(aa bb c ff) (dd e ii jj kk) (hi)
(aa bb c ff) (hi) (dd e ii jj kk)
(dd e ii jj kk) (aa bb c ff) (hi)

aa bb cc ff dd ee gg jj kk hh ii

Hypothesis

spk1: aa bb c
spk2: dd e
spk1: ff
spk3: hi
spk2: ii jj kk

Reference

Spk A: aa bb cc
Spk B: dd ee
Spk A: ff
Spk B: gg
Spk C: hh ii
Spk B: jj kk

cpWER calculation:

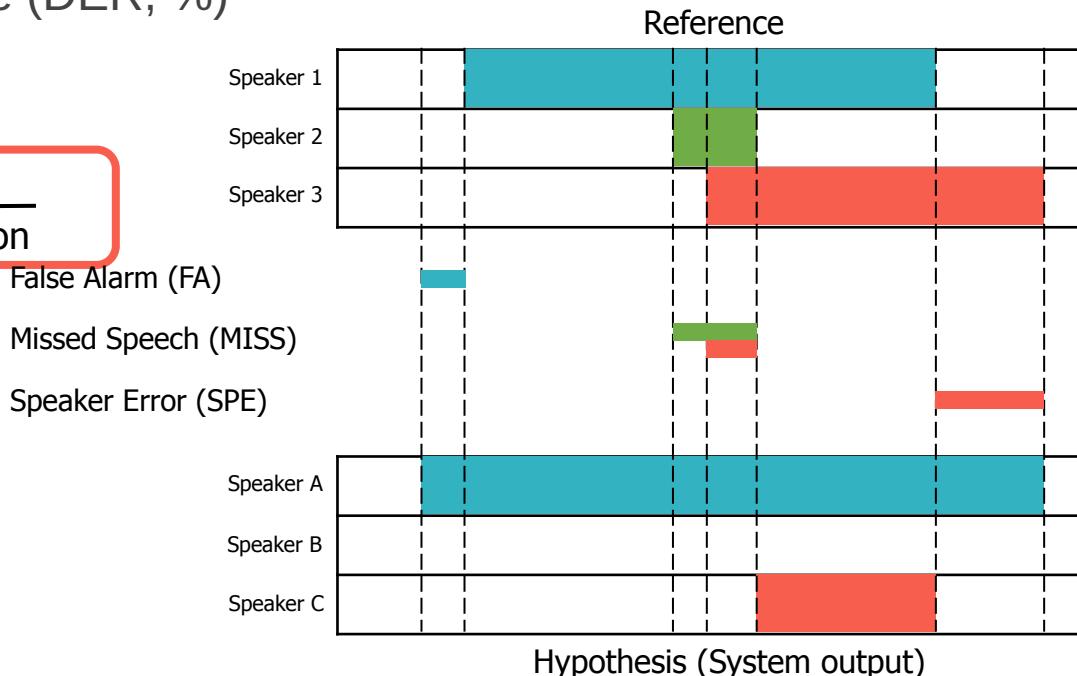
- Concatenate all utterances of each speaker for both reference and hypothesis files.
- Compute the WER between the reference and all possible speaker permutations of the hypothesis.
- Pick the lowest WER among them
- **tcp WER:** time-constrained cpWER

Speaker diarization metrics

- Diarization error rate (DER, %)

$$\text{DER} = \frac{\text{FA} + \text{MISS} + \text{SPE}}{\text{Total Speech Duration}}$$

A → 1
B → 2
C → 3



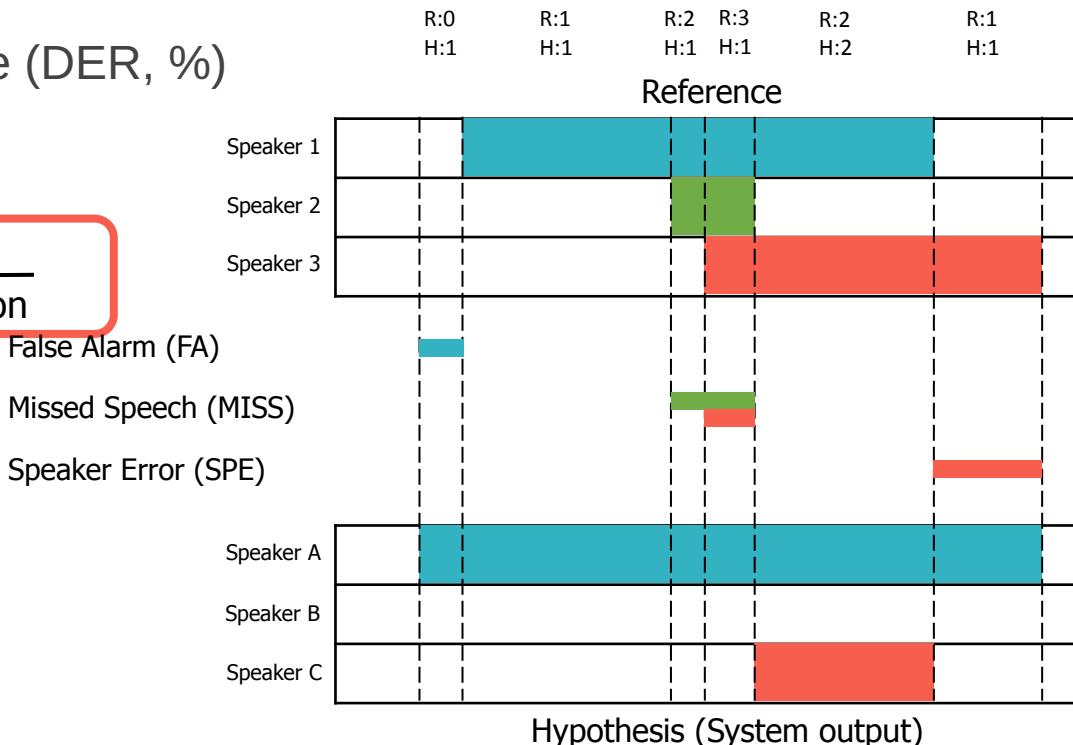
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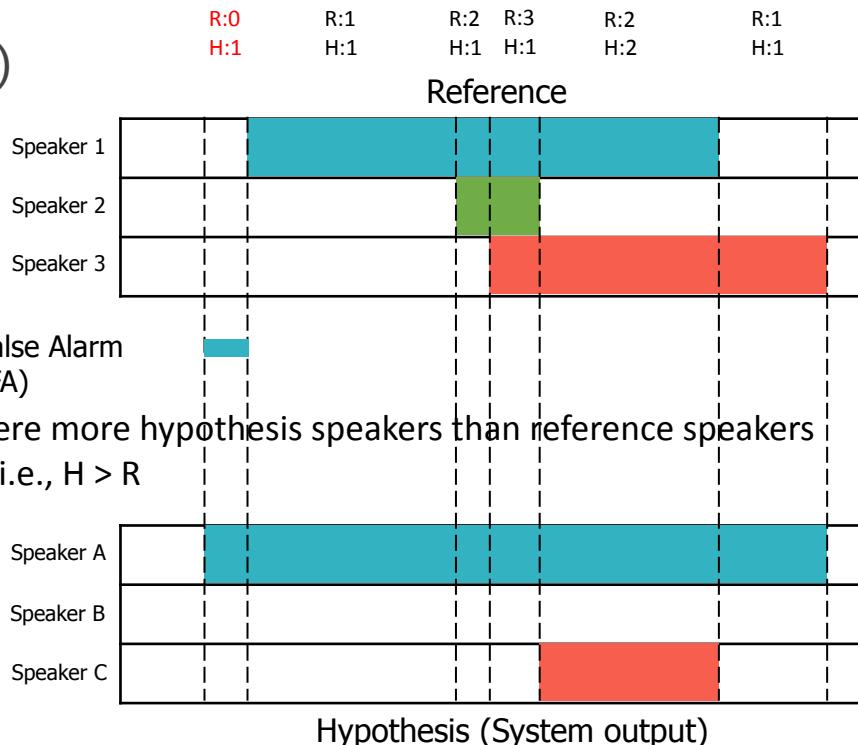
We first compute #speakers for reference **R** and hypothesis **H**, respectively for each segment



Speaker diarization metrics

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$$\text{DER} = \frac{\text{FA} + \text{MISS} + \text{SPE}}{\text{Total Speech Duration}}$$

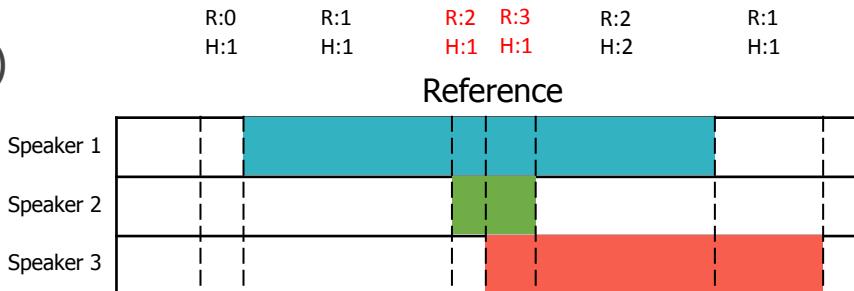


A → 1
B → 2
C → 3

Speaker diarization metrics

- Diarization error rate (DER, %)

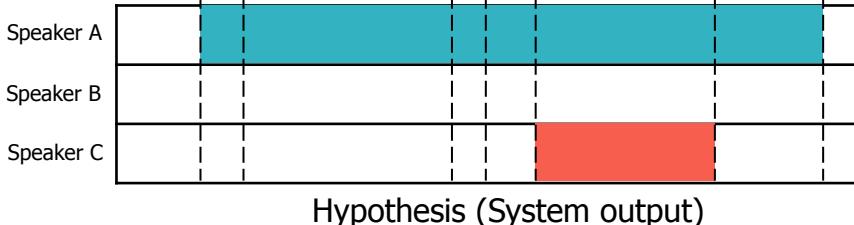
$$\text{DER} = \frac{\text{FA} + \text{MISS} + \text{SPE}}{\text{Total Speech Duration}}$$



Missed Speech (MISS)

Segments where more reference speakers than hypotheses speakers are speaking, i.e., $R > H$

A → 1
B → 2
C → 3

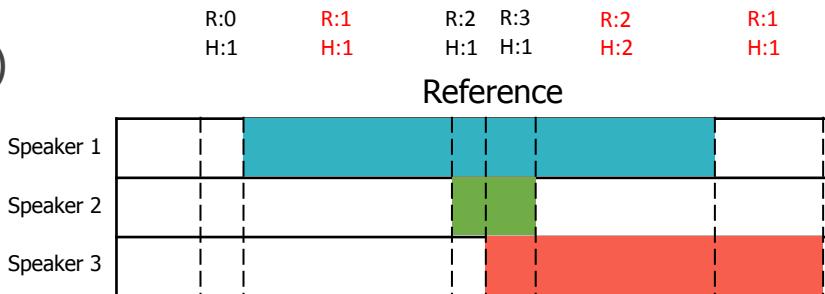


Hypothesis (System output)

Speaker diarization metrics

- Diarization error rate (DER, %)

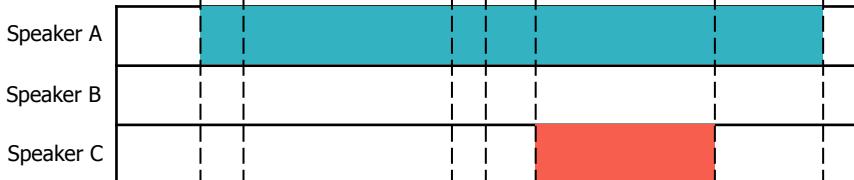
$$\text{DER} = \frac{(\% \text{ of time})}{\text{Total Speech Duration}} \quad \text{FA} + \text{MISS} + \text{SPE}$$



Check the speaker's confusion when the numbers of speakers are the same

Speaker Error (SPE)

A → 1
B → 2
C → 3

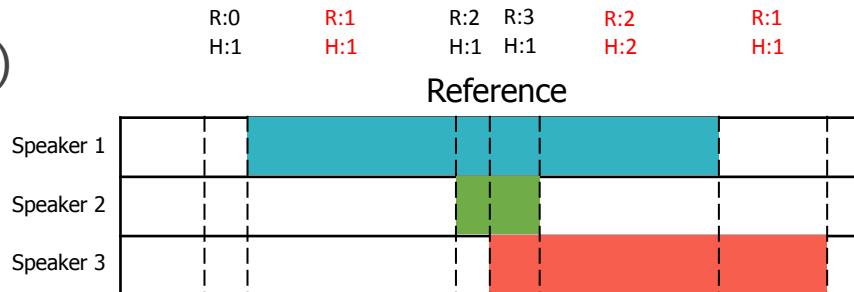


Hypothesis (System output)

Speaker diarization metrics

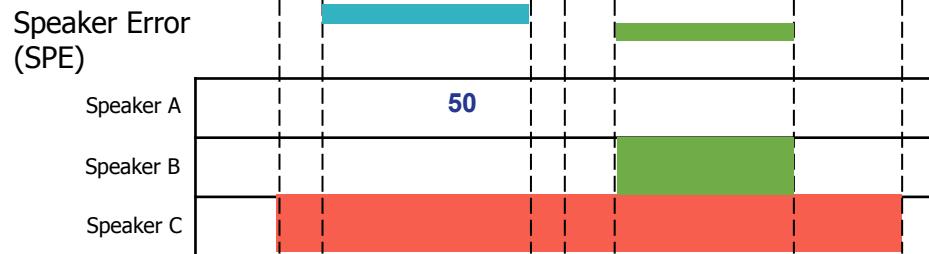
- Diarization error rate (DER, %)

$$\text{DER} = \frac{(\% \text{ of time})}{\text{Total Speech Duration}} \quad \text{FA} + \text{MISS} + \text{SPE}$$



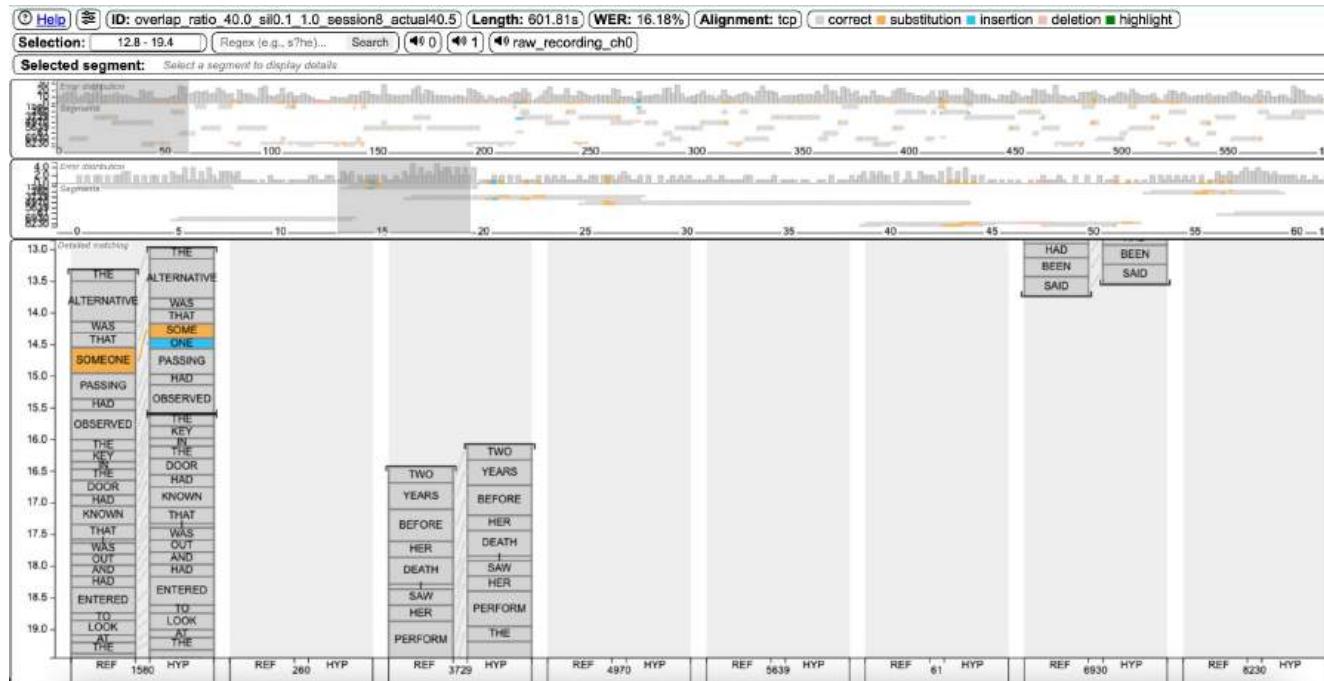
- Consider the **speaker permutation**

A → 2
B → 3
C → 1



We just pick up the minimum score of all possible permutations

Time-constrained cpWER (tcpWER) <https://github.com/fgnt/meeteval>

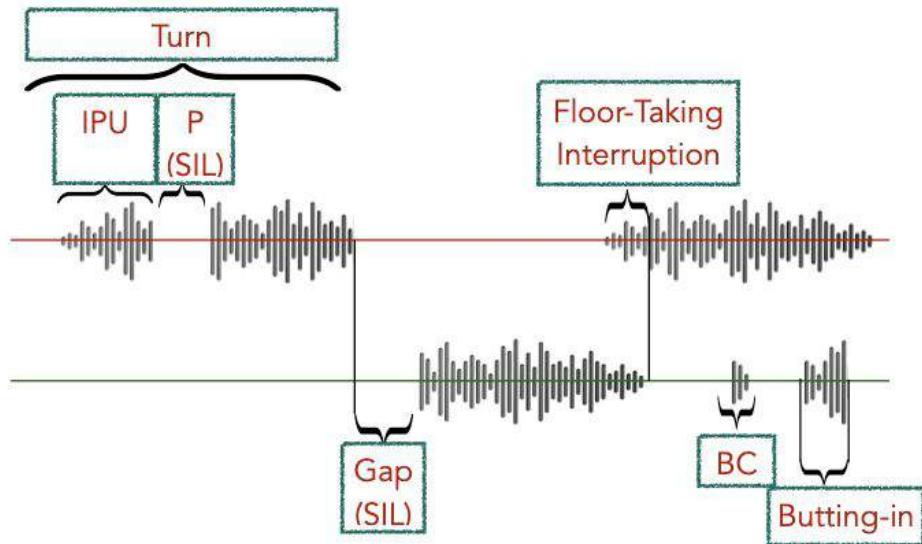


Examples from

https://groups.uni-paderborn.de/nt/meeteval/icassp2024-demo/libricss_diarization/overlap_ratio_40.0_sil0.1_1.0_session8_actual40.5_System_tcp.html?selection=12.2-18.8

Turn taking

- Turn taking attributes
 - IPU (Inter-Pausal Unit)
 - Pause
 - Gap
 - BC (Backchannel)
 - Butting-in
 - Etc.
- Evaluate turn taking prediction by human annotations or proxy estimator trained by SWBD



Arora, Siddhant, et al. "Talking Turns: Benchmarking Audio Foundation Models on Turn-Taking Dynamics." *ICLR* (2025)

Inoue, Koji, et al. "Yeah, Un, Oh: Continuous and Real-time Backchannel Prediction with Fine-tuning of Voice Activity Projection." *NAACL* (2025).

Work by Inoue-kun

Semantic metrics

Can we use word error rate?

Candidate 1: Shinji Watanabe is an Associate Professor at the University of Pittsburgh, next to Carnegie Mellon, PA.

Candidate 2: Cindy Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA.

Candidate 3: At Carnegie Mellon University in Pittsburgh, PA, Shinji Watanabe is an Associate Professor.

Ref1: Shinji Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA.

- Which one is the lowest WER?
- Which one is semantically most correct?

Can we use word error rate?

Candidate 1: Shinji Watanabe is an Associate Professor at the **University of Pittsburgh**, next to Carnegie Mellon, PA. **WER = 58%**

Candidate 2: **Cindy** Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA.
WER = 17%

Candidate 3: At Carnegie Mellon University in Pittsburgh, PA, Shinji Watanabe is an Associate Professor. **WER = 108%**

Ref1: Shinji Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA.

Can we use word error rate?

Candidate 1: Shinji Watanabe is an Associate Professor at the **University of Pittsburgh**, next to Carnegie Mellon, PA. **WER = 58%**

Candidate 2: **Cindy** Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA. **WER = 17%**

Candidate 3: At Carnegie Mellon University in Pittsburgh, PA, Shinji Watanabe is an Associate Professor. **WER = 108%**

Ref1: Shinji Watanabe is an Associate Professor at Carnegie Mellon University, Pittsburgh, PA.

- We should penalize the error of the important keywords → **Biased WER**
- We should avoid to use the order-dependent metrics → **BLEU** etc.

BLEU Score (Papineni+, 2002)

- Averaged N-gram precision (order agnostic)
- Extensions to deal with
 - Multiple references
 - Length penalty

N=4 (typically)

$$\text{BLEU} = \text{BP} \cdot \exp \left(\sum_{n=1}^N w_n \log p_n \right).$$

Brevity Penalty Modified Precision
n-gram weight (usually equal weight)

Brevity Penalty

$$\text{BP} = \begin{cases} 1 & \text{if } c > r \\ e^{(1-r/c)} & \text{if } c \leq r \end{cases}.$$

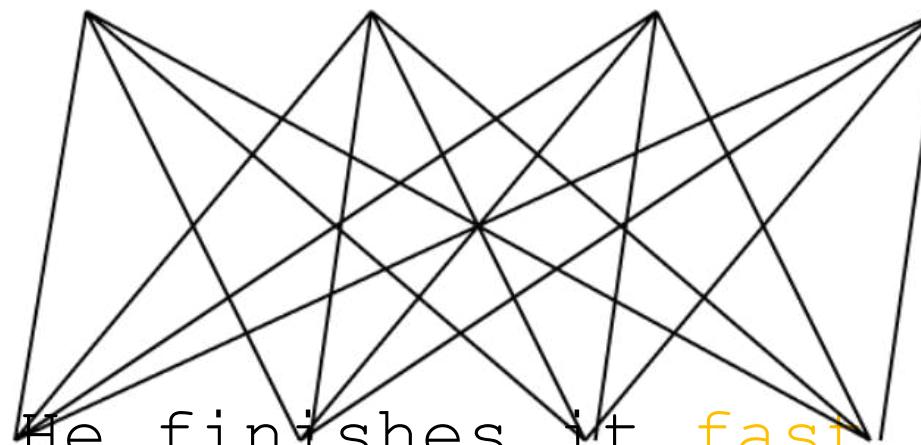
Modified Precision

$$p_n = \frac{\sum_{C \in \{\text{Candidates}\}} \sum_{n\text{-gram} \in C} \text{Count}_{clip}(n\text{-gram})}{\sum_{C' \in \{\text{Candidates}\}} \sum_{n\text{-gram}' \in C'} \text{Count}(n\text{-gram}')}$$

BERT Score

- Compute the pairwise similarity in the embedding space (again, order-agnostic)

Candidate: He finishes it **quickly**



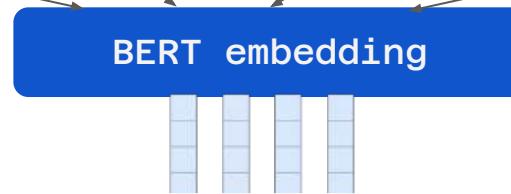
Similarity("fast," "quickly")=0

Reference1: He finishes it **fast**

BERT Score

- Compute the pairwise similarity in the embedding space

Candidate: He finishes it **quickly**



`BERTEmb("fast"),
BERTEmb("quickly")`

Reference1: He finishes it **fast**

Zhang, Tianyi, et al. "BERTScore: Evaluating Text Generation with BERT." *ICLR* (2019)

BERT Score

- Compute the pairwise similarity in the embedding space

Candidate: He finishes it **quickly**



Similarity(BERTEmbed("fast"),
BERTEmbed("quickly"))

Reference1: He finishes it **fast**



Zhang, Tianyi, et al. "BERTScore: Evaluating Text Generation with BERT." *ICLR* (2019)

LLM-based metrics

- **Perplexity:**

- Compute the average likelihood of generated sentences based on an LLM Θ
- Given J -length sentence $W^{\text{test}} = (w_i \in \mathcal{V} | i = 1, \dots, J)$ the perplexity is defined as

$$\text{PPL}(W^{\text{test}}) = (p(W^{\text{test}} | \Theta))^{-\frac{1}{J}}$$

- Lower is better

- **LLM as a judge:**

- Ask an LLM to judge which model output is better

W_1 and W_2 : generated sentences given prompt x

LLM judge model $J_{\Theta}(W_1, W_2, x)$:

- 1 If the LLM prefers W_1 over W_2
- 0 If the LLM prefers W_2 over W_1 , and
- 0.5 If they are even

LLM as a judge

System prompt (to LLM Judge):

You are an impartial evaluator. Given a question, a reference answer, and two candidate answers, decide which candidate is more accurate, complete, and relevant. Provide a score from 1 to 5 for each candidate and a brief justification.

Question:

Who wrote *Pride and Prejudice*?

Reference Answer:

Jane Austen.

Model A Answer:

Pride and Prejudice was written by Jane Austen in 1813.

Model B Answer:

It was written by Charlotte Brontë.

Judge LLM's Output:

- **Model A Score:** 5/5 — Correct author, includes additional accurate publication year.
- **Model B Score:** 1/5 — Incorrect author.
- **Decision:** Model A is clearly better.

Databases

Databases <https://arxiv.org/abs/2507.18161>

Corpus	Authors	Year	Real	Long	Multi Speaker	Far Field	Multi Domain
Santa Barbara	Du Bois et al.	2000	✓	✓	✓	✓	✓
Aurora2-6	Hirsch and Pearce	2000-2006	✗	✗	✗	✓	✓
RT evaluations	Garofolo et al..	2002-2009	✓	✓	✓	✓	✓
ICSI	Janin et al.	2003	✓	✓	✓	✓	✗
Fisher	Cleri et al.	2004	✓	✓	✓	✗	✗
AMI	Carlotta et al.	2005	✓	✓	✓	✓	✗
Pascal	Cooke et al.	2006	✗	✗	✓	✗	✗
CHIL	Mostefa et al.	2007	✓	✓	✓	✓	✗
CHiME Corpus	Christensen et al.	2010	✗	✗	✗	✓	✗
Mixer 6 Speech	Brandschain et al.	2010	✓	✓	✓	✓	✗
CHiME-1	Barker et al.	2011	✗	✗	✗	✓	✗
COSINE	Stupakov et al.	2012	✓	✓	✓	✓	✗
Sheffield Wargames	Fox et al.	2013	✓	✓	✓	✓	✗
REVERB8	Kinoshita et al.	2013	✗	✗	✗	✓	✗
CHiME-2	Vincent et al.	2013	✗	✗	✓	✓	✗
DIRHA	Cristoforetti et al.	2014	✗	✗	✗	✓	✗
CHiME-3	Barker et al.	2015	✗	✗	✓	✗	✗
CHiME-4	Vincent et al.	2015	✗	✗	✓	✗	✗
ASPIRE	Harper	2015	✓	✓	✗	✓	✗
CHiME-5	Barker et al.	2018	✓	✗	✓	✓	✗
VOICES	Richey et al.	2018	✗	✗	✗	✓	✗
DIPCo	Van Segbroeck et al.	2019	✓	✓	✓	✓	✗
CHiME-6	Watanabe et al.	2020	✓	✓	✓	✓	✗
Aishell-4	Fu et al.	2020	✓	✓	✓	✓	✗
AllMeeting	Yu et al.	2020	✓	✓	✓	✓	✗
LibriCSS	Chen et al.	2020	✗	✓	✓	✓	✗
EGO4D	Grauman et al.	2022	✓	✓	✓	✓	✓
MISP	Wang et al.	2022	✓	✓	✓	✓	✓
CHiME-7 DASR	Cornell et al.	2023	✓	✓	✓	✓	✓
CHiME-8 DASR	Cornell et al.	2024	✓	✓	✓	✓	✓
CHiME-8 NOTSOFAR-1	Vinnikov et al.	2024	✓	✓	✓	✓	✗
CHiME-8 MMCSG	Zmolikova et al.	2024	✓	✓	✓	✓	✗

Cornell, Samuele, et al.
"Recent Trends in Distant Conversational Speech Recognition: A Review of CHiME-7 and 8 DASR Challenges." arXiv preprint arXiv:2507.18161 (2025).

Databases

<https://arxiv.org/abs/2507.18161>

Corpus	Authors	Year	Real	Long	Multi Speaker	Far Field	Multi Domain
Sant							
Auro							
RT e							
ICSI	Authors	Year	Real	Long	Multi Speaker	Far Field	Multi Domain
Fisher	Cleri et al.	2004	✓	✓	✓	✗	✗
AMI	Carletta et al.	2005	✓	✓	✓	✓	✗
Pascal	Cooke et al.	2006	✗	✗	✓	✗	✗
CHIL	Mostefa et al.	2007	✓	✓	✓	✓	✗
CHiME Corpus	Christensen et al.	2010	✗	✗	✗	✓	✗
Mixer 6 Speech	Brandschain et al.	2010	✓	✓	✓	✓	✗
CHiME-1	Barker et al.	2011	✗	✗	✗	✓	✗
COSINE	Stupakov et al.	2012	✓	✓	✓	✓	✗
Sheffield Wargames	Fox et al.	2013	✓	✓	✓	✓	✗
REVERB8	Kinoshita et al.	2013	✗	✗	✗	✓	✗
CHiME-2	Vincent et al.	2013	✗	✗	✓	✓	✗
DIRHA	Cristoforetti et al.	2014	✗	✗	✗	✓	✗
CHiME-3	Barker et al.	2015	✗	✗	✓	✗	✗
CHiME-4	Vincent et al.	2015	✗	✗	✓	✗	✗
ASPIRE	Harper	2015	✓	✓	✗	✓	✗
CHiME-5	Barker et al.	2018	✓	✗	✓	✓	✗
VOICES	Richey et al.	2018	✗	✗	✗	✓	✗
DIPCo	Van Segbroeck et al.	2019	✓	✓	✓	✓	✗
CHiME-6	Watanabe et al.	2020	✓	✓	✓	✓	✗
Aishell-4	Fu et al.	2020	✓	✓	✓	✓	✗
AllMeeting	Yu et al.	2020	✓	✓	✓	✓	✗
LibriCSS	Chen et al.	2020	✗	✓	✓	✓	✗
EGO4D	Grauman et al.	2022	✓	✓	✓	✓	✓
MISP	Wang et al.	2022	✓	✓	✓	✓	✓
CHiME-7 DASR	Cornell et al.	2023	✓	✓	✓	✓	✓
CHiME-8 DASR	Cornell et al.	2024	✓	✓	✓	✓	✓
CHiME-8 NOTSOFAR-1	Vinnikov et al.	2024	✓	✓	✓	✓	✗
CHiME-8 MMCSG	Zmolikova et al.	2024	✓	✓	✓	✓	✗

Cornell, Samuele, et al.

"Recent Trends in Distant Conversational Speech Recognition: A Review of CHiME-7 and 8 DASR Challenges." arXiv preprint arXiv:2507.18161 (2025).

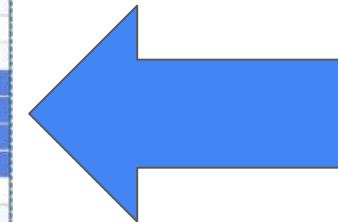
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<https://arxiv.org/abs/2507.18161>

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RT evaluations	Garofolo et al..	2002-2009	✓	✓	✓	✓	✓
ICSI	Janin et al.	2003	✓	✓	✓	✓	✗
Fisher	Cleri et al.	2004	✓	✓	✓	✗	✗
AMI	Carlotta et al.	2005	✓	✓	✓	✓	✗
Pascal	Cooke et al.	2006	✗	✗	✓	✗	✗
CHIL	Mostefa et al.	2007	✓	✓	✓	✓	✗
CHiME Corpus	Christensen et al.	2010	✗	✗	✗	✓	✗
Mixer 6 Speech	Brandschain et al.	2010	✓	✓	✓	✓	✗
CHiME-1	Barker et al.	2011	✗	✗	✗	✓	✗
COSINE	Stupakov et al.	2012	✓	✓	✓	✓	✗
Sheffield Wargames	Fox et al.	2013	✓	✓	✓	✓	✗
REVERB8	Kinoshita et al.	2013	✗	✗	✗	✓	✗
CHiME-2	Vincent et al.	2013	✗	✗	✓	✓	✗
DIRHA	Cristoforetti et al.	2014	✗	✗	✗	✓	✗
CHiME-3	Barker et al.	2015	✗	✗	✓	✗	✗
CHiME-4	Vincent et al.	2015	✗	✗	✓	✗	✗
ASPIRE	Harper	2015	✓	✓	✗	✓	✗
CHiME-5	Barker et al.	2018	✓	✗	✓	✓	✗
VOICES	Richey et al.	2018	✗	✗	✗	✓	✗
DIPCo	Van Segbroeck et al.	2019	✓	✓	✓	✓	✗
CHiME-6	Watanabe et al.	2020	✓	✓	✓	✓	✗
Aishell-4	Fu et al.	2020	✓	✓	✓	✓	✗
AllMeeting	Yu et al.	2020	✓	✓	✓	✓	✗
LibriCSS	Chen et al.	2020	✗	✓	✓	✓	✗
EGO4D	Grauman et al.	2022	✓	✓	✓	✓	✓
MISP	Wang et al.	2022	✓	✓	✓	✓	✓
CHiME-7 DASR	Cornell et al.	2023	✓	✓	✓	✓	✓
CHiME-8 DASR	Cornell et al.	2024	✓	✓	✓	✓	✓
CHiME-8 NOTSOFAR-1	Vinnikov et al.	2024	✓	✓	✓	✓	✗
CHiME-8 MMCSG	Zmolikova et al.	2024	✓	✓	✓	✓	✗

Cornell, Samuele, et al.

"Recent Trends in Distant Conversational Speech Recognition: A Review of CHiME-7 and 8 DASR Challenges." arXiv preprint arXiv:2507.18161 (2025).



Long-form Databases

<https://domklement.github.io/sbcvae/>



	SBCSAE	AliMeeting	AMI	CHiME-6	DIHARD3	DiPCo
# Recordings	60	237	169	20	513	10
# Speakers	439	537	189	48	581	32
Average Duration (min.)	23:18 ± 04:25	31:59 ± 03:09	35:11 ± 13:32	150:31 ± 11:26	07:51 ± 02:52	32:00 ± 12:12
Overlap by Time (%)	10.3 ± 8.3	27.2 ± 18.4	12.9 ± 6.1	33.2 ± 10.5	9.4 ± 10.8	26.9 ± 7.5

- Much longer than the utterance-based processing (5–20 sec)
- Various overlap ratios

Maciejewski, Matthew, et al. "Evaluating the Santa Barbara Corpus: Challenges of the Breadth of Conversational Spoken Language." *Interspeech* (2024).

CHiME-5 → CHiME-6

- **Revisiting** the CHiME-5 corpus
- Removing the segmentation boundary information
- Multi-speaker scenario
- Longer duration (2.5 hours)
- Similar corpus: AMI, DiPCo, AliMeeting, NOTSOFAR
- This setup is often discussed in Section 2

	Segmentation	Metrics	Length
CHiME-5	Given	WER	5 – 20 sec.
CHiME-6	Not given	DER + cpWER	2.5 hours

Watanabe, Shinji, et al. "CHiME-6 Challenge: Tackling Multispeaker Speech Recognition for Unsegmented Recordings." Proc. CHiME Workshop (2020).

Librispeech → Libriheavy

- **Revisiting** the Librispeech corpus
- 50,000h English read speech from LibriVox
- Rich transcripts: punctuation, casing, **previous text context** ➔ Enables **context-aware ASR research**
- Open-source audio-text alignment pipeline
- Longer duration version (from 20 - 100 seconds)

	Amount	Transcripts	Length
Librispeech	~1000h	Normalized text	5 – 20 sec.
Libriheavy	~50,000h	Punctuation, casing, previous text context	20 – 100 sec. (long version)

Kang, Wei, et al. "Libriheavy: A 50,000 hours ASR corpus with punctuation casing and context." ICASSP (2024)

Selected Benchmarks

- **CHiME-5 → CHiME-6**
 - One of the first benchmarks for long-form setup
- **CHiME-7 DASR**
 - Multiple devices in diverse scenarios
 - CHiME-6 + DiPCo + Mixer 6
 - cpWER → tcpWER
- **CHiME-8 DASR**
 - + NOTSOFAR-1
 - Allow the use of **a strong LLM** (related to Section 3)

Librispeech for contextual biasing

- Specifies a biasing list with $N = \{100, 500, 1000, 2000\}$ distractors
- U-WER: **Unbiased WER** measured on words **NOT IN** the biasing List
- B-WER: **biased WER** measured on words **IN** the biasing list

Model	N = 100		N = 500		N = 1000		N = 2000	
	test-clean	test-other	test-clean	test-other	test-clean	test-other	test-clean	test-other
B1: RNNT Baseline	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)
S1: B1 + DB-RNNT	3.11 (2.3/9.8)	8.79 (7.1/23.4)	3.24 (2.3/10.7)	9.03 (7.2/25.1)	3.30 (2.4/11.0)	9.12 (7.2/26.1)	3.34 (2.3/11.4)	9.28 (7.3/27.0)
S2: B1 + WFST	3.06 (2.3/9.4)	8.60 (7.1/22.2)	3.10 (2.3/9.6)	8.72 (7.1/22.5)	3.11 (2.3/9.7)	8.78 (7.2/22.8)	3.09 (2.3/9.6)	8.83 (7.2/22.9)
S3: S2 + DB-RNNT	2.81 (2.2/7.4)	8.10 (7.0/17.7)	2.91 (2.3/8.1)	8.30 (7.1/19.1)	3.00 (2.3/8.5)	8.45 (7.1/20.5)	3.04 (2.3/8.9)	8.75 (7.3/21.8)
B2: B1 + NNLM	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)
S4: S3 + NNLM	2.28 (1.6/7.9)	6.50 (5.1/18.7)	2.35 (1.6/8.2)	6.64 (5.2/19.6)	2.40 (1.7/8.4)	6.72 (5.2/20.2)	2.41 (1.7/8.6)	6.81 (5.2/20.9)
S5: S3 + DB-NNLM	1.98 (1.5/5.7)	5.86 (4.9/14.1)	2.09 (1.6/6.2)	6.09 (5.1/15.1)	2.14 (1.6/6.7)	6.35 (5.1/17.2)	2.27 (1.6/7.3)	6.58 (5.2/18.9)

Table 1: LibriSpeech results with different biasing list size N . Reported metrics are in the following format: WER (U-WER/B-WER).

Librispeech for contextual biasing

- Specifies a biasing list with $N = \{100, 500, 1000, 2000\}$ distractors
- U-WER: **Unbiased WER** measured on words **NOT IN** the biasing List
- B-WER: **biased WER** measured on words **IN** the biasing list
- This will be further discussed in Section 4

Model	N = 100		N = 500		N = 1000		N = 2000	
	test-clean	test-other	test-clean	test-other	test-clean	test-other	test-clean	test-other
B1: RNNT Baseline	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)	3.65 (2.4/14.1)	9.61 (7.2/30.6)
S1: B1 + DB-RNNT	3.11 (2.3/9.8)	8.79 (7.1/23.4)	3.24 (2.3/10.7)	9.03 (7.2/25.1)	3.30 (2.4/11.0)	9.12 (7.2/26.1)	3.34 (2.3/11.4)	9.28 (7.3/27.0)
S2: B1 + WFST	3.06 (2.3/9.4)	8.60 (7.1/22.2)	3.10 (2.3/9.6)	8.72 (7.1/22.5)	3.11 (2.3/9.7)	8.78 (7.2/22.8)	3.09 (2.3/9.5)	8.82 (7.3/27.2)
S3: S2 + DB-RNNT	2.81 (2.2/7.4)	8.10 (7.0/17.7)	2.91 (2.3/8.1)	8.30 (7.1/19.1)	3.00 (2.3/8.5)	8.45 (7.1/20.5)	3.01 (2.3/8.6)	8.75 (7.3/21.8)
B2: B1 + NNLM	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)	2.79 (1.7/11.6)	7.35 (5.2/26.3)
S4: S3 + NNLM	2.28 (1.6/7.9)	6.50 (5.1/18.7)	2.35 (1.6/8.2)	6.64 (5.2/19.6)	2.40 (1.7/8.4)	6.72 (5.2/20.2)	2.41 (1.7/8.6)	6.81 (5.2/20.9)
S5: S3 + DB-NNLM	1.98 (1.5/5.7)	5.86 (4.9/14.1)	2.09 (1.6/6.2)	6.09 (5.1/15.1)	2.14 (1.6/6.7)	6.35 (5.1/17.2)	2.27 (1.6/7.3)	6.58 (5.2/18.9)

Table 1: LibriSpeech results with different biasing list size N . Reported metrics are in the following format: WER (U-WER/B-WER).

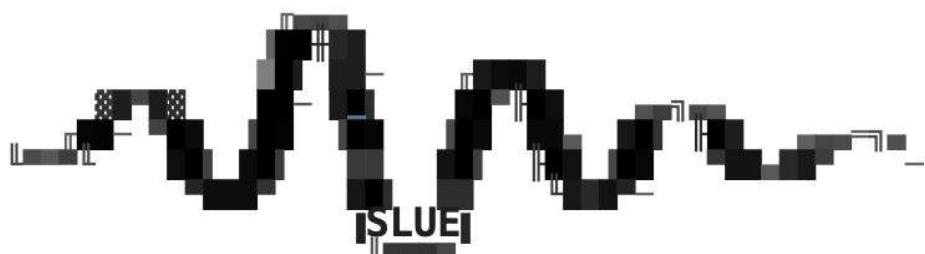
Normal WER
(U-WER/B-WER)

SLUE (Spoken Language Understanding Evaluation)

- A benchmark suite for spoken language understanding on **natural** speech (not read or synthesized)
 - ASR, Named Entity Recognition (NER), and Sentiment Analysis (SA)
- SLUE-Voxpopuli/SLUE-Voxcereb:
 - Built using freely available VoxCeleb and VoxPopuli datasets, with new transcriptions and annotations

Later extended to deal with

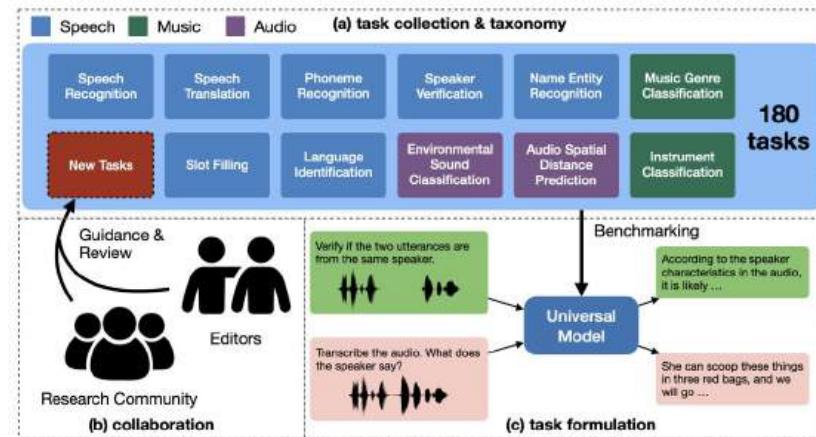
- Dialog act classification (DAC)
- Question answering (QA)
- Summarization (SUMM), and
- Named entity localization (NEL)



Shon, Suwon, et al. "SLUE: New benchmark tasks for spoken language understanding evaluation on natural speech." /CASSP (2022)
Shon, Suwon, et al. "SLUE Phase-2: A Benchmark Suite of Diverse Spoken Language Understanding Tasks." ACL (2023).

Dynamic SUPERB (Speech processing Universal PERformance Benchmark)

- Focuses on **dynamic** updates with community collaboration to keep benchmarks relevant.
- Covers a **wide range of speech/audio tasks** including ASR, speaker recognition, and more.
- Provides an open framework for researchers to add new tasks and datasets
- **Over 70 contributors and 180 tasks**



Huang, Chien-yu, et al. "Dynamic-superb: Towards a dynamic, collaborative, and comprehensive instruction-tuning benchmark for speech." */CASSP (2024)*

Huang, Chien-yu, et al. "Dynamic-superb phase-2: A collaboratively expanding benchmark for measuring the capabilities of spoken language models with 180 tasks." */ICLR (2024)*.



Computer Science > Computation and Language

[Submitted on 8 Nov 2024 (v1), last revised 9 Jun 2025 (this version, v2)]

Dynamic-SUPERB Phase-2: A Collaboratively Expanding Benchmark for Measuring the Capabilities of Spoken Language Models with 180 Tasks

Chien-yu Huang, Wei-Chih Chen, Shu-wen Yang, Andy T. Liu, Chen-An Li, Yu-Xiang Lin, Wei-Cheng Tseng, Anuj Diwan, Yi-Jen Shih, Jiatong Shi, William Chen, Chih-Kai Yang, Wenze Ren, Xuanjun Chen, Chi-Yuan Hsiao, Puyuan Peng, Shih-Heng Wang, Chun-Yi Kuan, Ke-Han Lu, Kai-Wei Chang, Fabian Ritte Gutierrez, Kuan-Po Huang, Siddhant Arora, You-Kuan Lin, Ming To Chuang, Eunjung Yeo, Kalvin Chang, Chung-Ming Chien, Kwanghee Choi, Jun-You Wang, Cheng-Hsiu Hsieh, Yi-Cheng Lin, Chee-En Yu, I-Hsiang Chiu, Heitor R. Guimarães, Jionghao Han, Tzu-Quan Lin, Tzu-Yuan Lin, Homu Chang, Ting-Wu Chen, Chun Wei Chen, Shou-Jen Chen, Yu-Hua Chen, Hsi-Chun Cheng, Kunal Dhawan, Jia-Lin Fang, Shi-Xin Fang, Kuan-Yu Fang Chiang, Chi An Fu, Hsien-Fu Hsu, Ching Yu Hsu, Shao-Syuan Huang, Lee Chen Wei, Hsi-Che Lin, Hsuan-Hao Lin, Hsuan-Ting Lin, Jian-Ren Lin, Ting-Chun Liu, Li-Chun Lu, Tsung-Min Pai, Ankita Pasad, Shih-Yun Shan Kuan, Suwon Shon, Yuxun Tang, Yun-Shao Tsai, Jui-Chiang Wei, Tzu-Chieh Wei, Chengxi Wu, Dien-Ruei Wu, Chao-Han Huang, Chieh-Chi Yang, Jia Qi Yip, Shao-Xiang Yuan, Vahid Noroozi, Zhehuai Chen, Haibin Wu, Karen Livescu, David Harwath, Shinji Watanabe, Hung-yi Lee

Multimodal foundation models, such as Gemini and ChatGPT, have revolutionized human-machine interactions by seamlessly integrating various forms of data. Developing a universal spoken language model that comprehends a wide range of natural language instructions is critical for bridging communication gaps and facilitating more intuitive interactions. However, the absence of a comprehensive evaluation benchmark poses a significant challenge. We present Dynamic-SUPERB Phase-2, an open and evolving benchmark for the comprehensive evaluation of instruction-based universal speech models. Building upon the first generation, this second version incorporates 125 new tasks contributed collaboratively by the global research community, expanding the benchmark to a total of 180 tasks, making it the largest benchmark for speech and audio evaluation. While the first generation of Dynamic-SUPERB was limited to classification tasks, Dynamic-SUPERB Phase-2 broadens its evaluation capabilities by introducing a wide array of novel and diverse tasks, including regression and sequence generation, across speech, music, and environmental audio. Evaluation results show that no model performed well universally. SALMONN-13B excelled in English ASR and Qwen2-Audio-7B-Instruct showed high accuracy in emotion recognition, but current models still require further innovations to handle a broader range of tasks. We open-source all task data and the evaluation pipeline at [this https URL](https://https://).

Dynamic SUPERB (Speech processing Universal PERformance Benchmark)



Figure 4: Task taxonomy of speech.

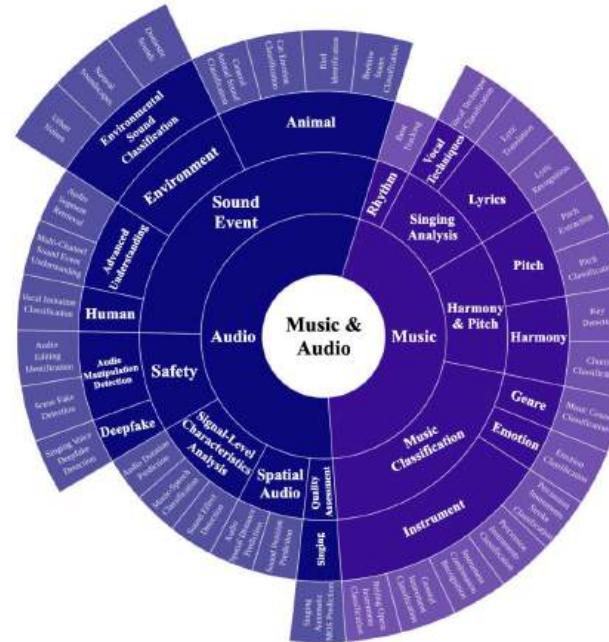


Figure 5: Task taxonomy of audio and music.

Huang, Chien-yu, et al. "Dynamic-superb: Towards a dynamic, collaborative, and comprehensive instruction-tuning benchmark for speech." ICASSP (2024)

Huang, Chien-yu, et al. "Dynamic-superb phase-2: A collaboratively expanding benchmark for measuring the capabilities of spoken language models with 180 tasks." ICLR (2024).

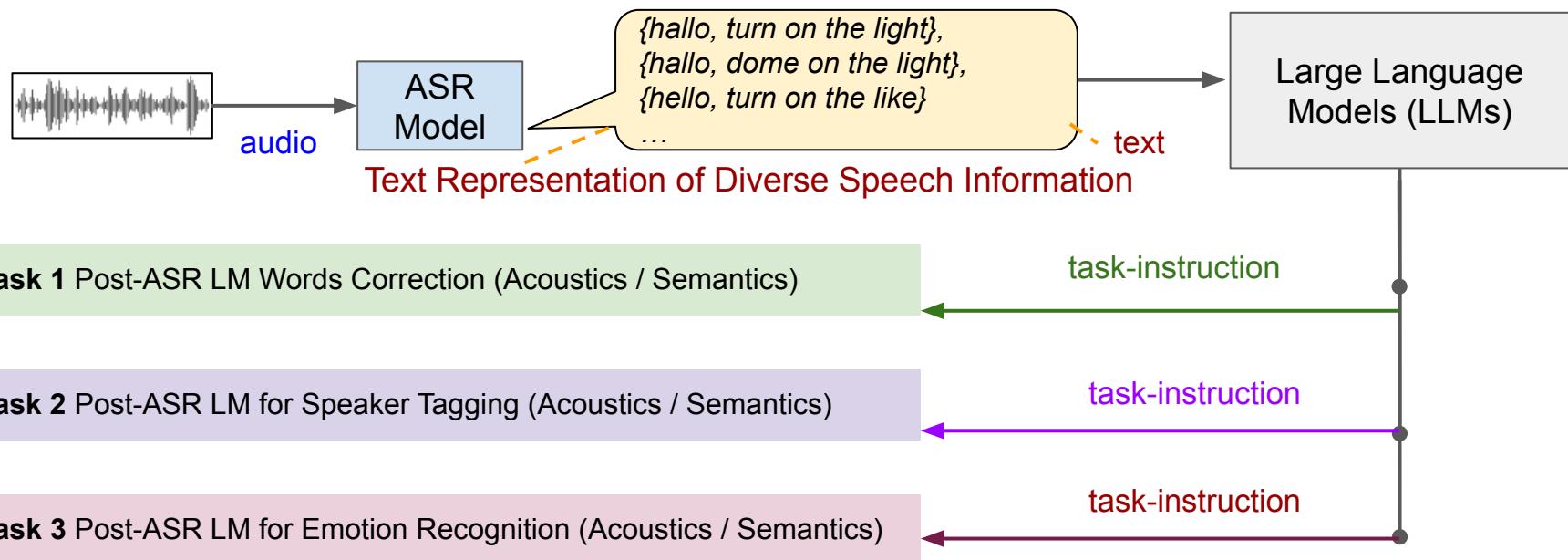
Speech QA Benchmarks

- Spoken SQuAD
 - **Synthesized** speech version of the SQuAD reading comprehension dataset.
- SLUE phase 2
 - Crowdsourcing platform for collecting spoken questions **read** by human speakers
 - 5 QA text database, including SQuAD
 - Frame F-1 score



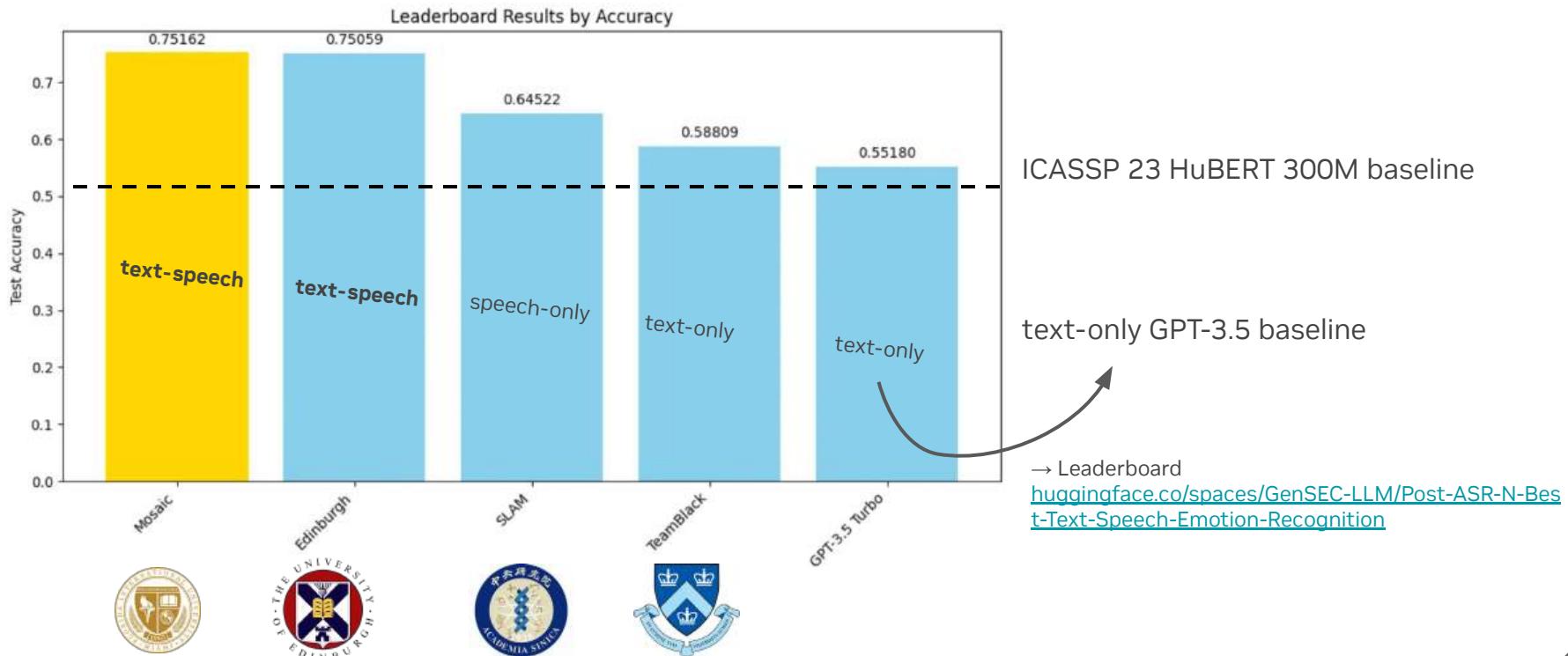
SLT 24 Post-ASR Multi-Task LM Benchmark (1/2)

- **Motivation:** Could ASR-Decoding **Text secretly contains Acoustic information?**
 - We design three new post-ASR LM tasks given decoding text as inputs



SLT 24 Post-ASR Task 3 Emotion Understanding (2/2)

- **Key finding:** text-only LM can identify emotion from ASR systems' hypotheses
 - Text model with speech information injection archived the best results



Takeaways

- Evolution in speech-to-text systems
 - From short-form ASR to contextual conversation understanding
- Evaluation metrics
 - Extended from WER
 - Semantic metrics
- Benchmarks
 - Handles long-form speech
 - Some are redesigned for long-form speech

To accelerate this research direction

- We need more realistic, conversational, and preferably large-scale public datasets!

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Taejin (40 min) 16:10-16:50	Leveraging Long Acoustic Context
	Recess (10 min) 16:50-17:00
Huck (40 min) 17:00-17:40	Semantic Context and Speech-Language Modeling
Kyu (30 min) 17:40-18:10	Contextual Biasing and Methods Leveraging Longer Semantic Context for Speech Systems
	Closing Remark (10 min) 18:10-18:20
	Q&A Session (10 min) 18:20-18:30

Leveraging Long Acoustic Context

Taejin Park



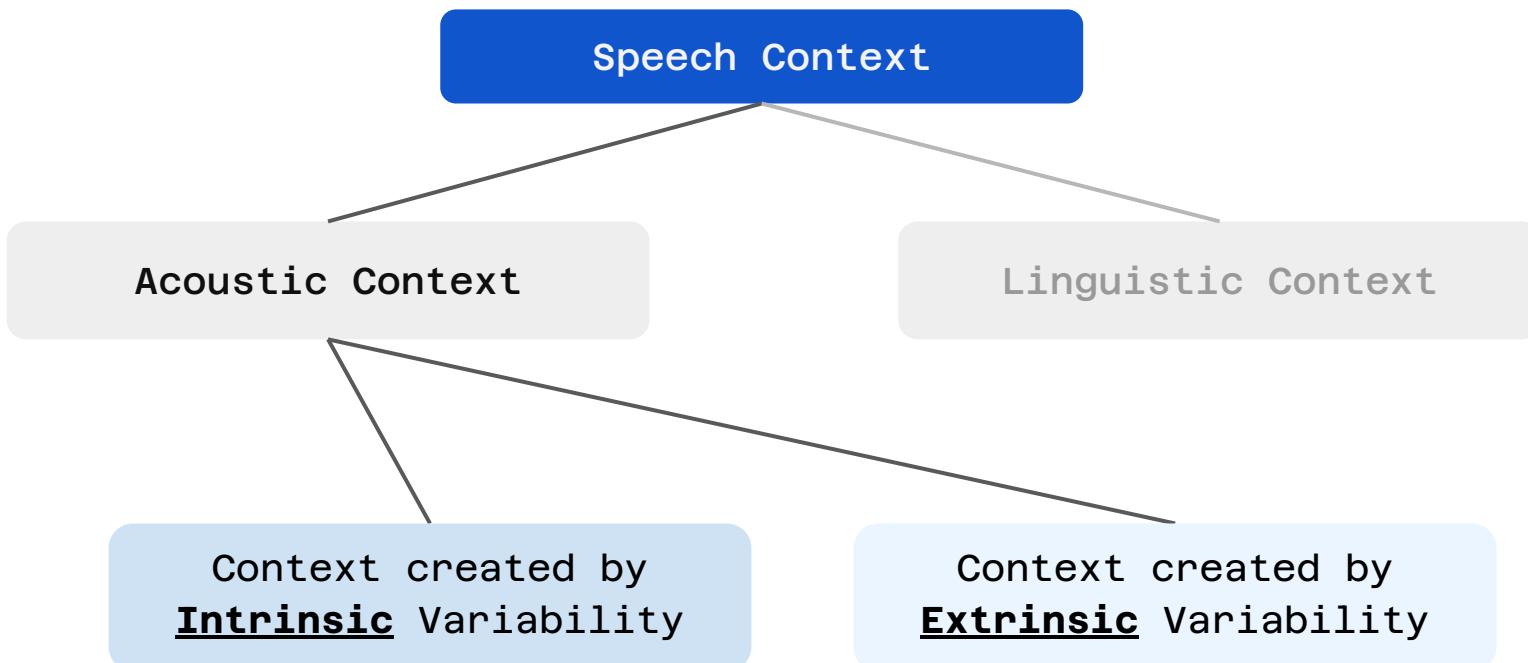
Leveraging Long Acoustic Context

- 1. The Dynamics of Acoustic Context in End-to-End ASR**
 - a. Speech Variability as a Source of Acoustic Context
 - b. Acoustic Context Experiments on ASR Systems
- 2. Speaker-attributed ASR and Acoustic Context**
 - a. Acoustic Context Problem in Multispeaker ASR
 - b. Multi-talker ASR
 - c. Target speaker ASR
- 3. Streaming with Long Acoustic Context**
 - a. Streaming Speaker Attributed ASR
 - b. Offline models to streaming
 - i. Wait-K and others
 - ii. ASR + MT: AST and Streaming ST
- 4. Alternate Architectures for Long Context ASR**
 - a. Variants of Transformer and Transducer
 - b. State space model for speech recognition
- 5. Voice-agent, Speech-LLM and Long context**
 - a. Modular (EOU-ASR + LLM + TTS) Systems and Long Context
 - b. Jointly trained duplex Speech LMs

The Dynamics of Acoustic Context in End-to-End ASR

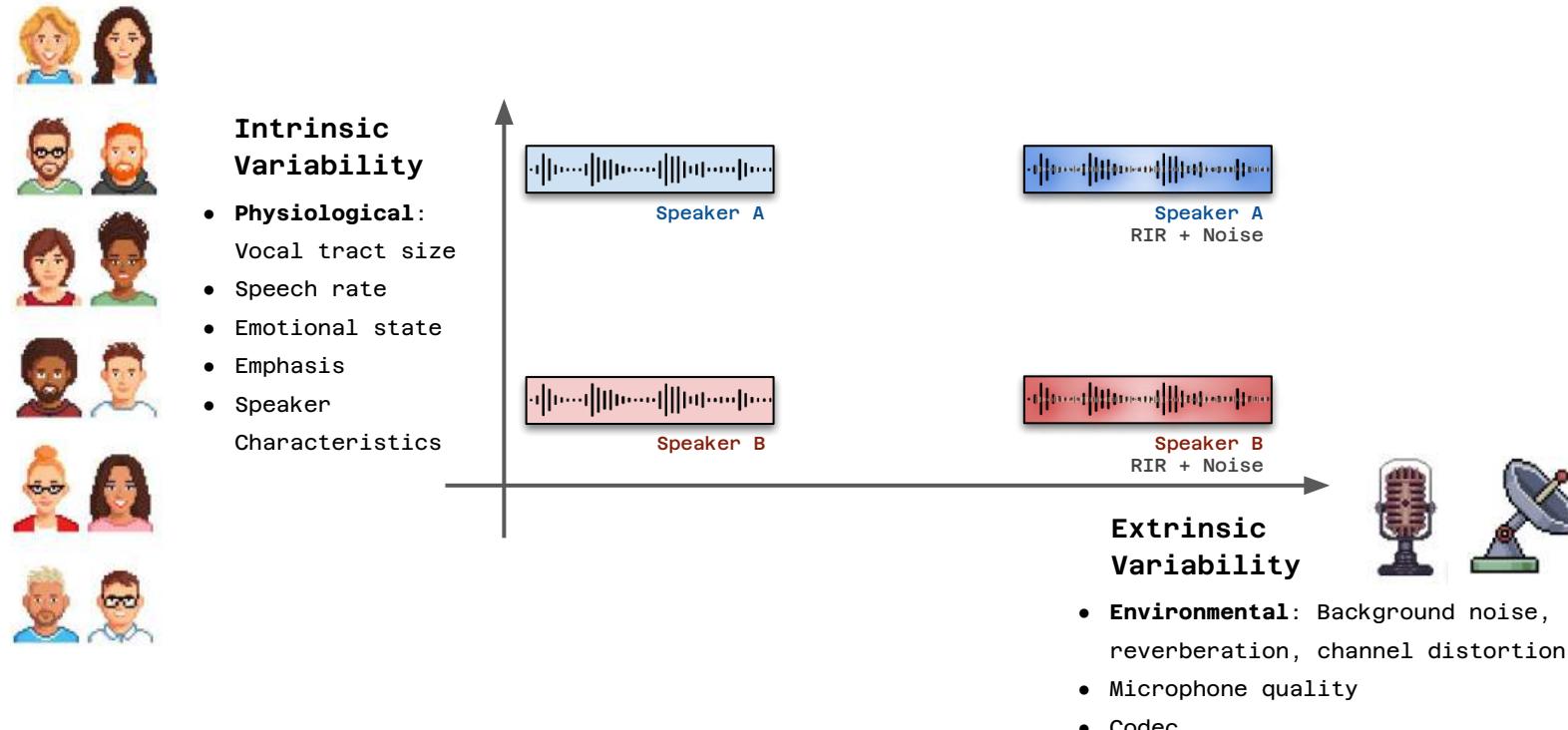
The Dynamics of Acoustic Context in End-to-End ASR

- Speech Variability as a Source of Acoustic Context



The Dynamics of Acoustic Context in End-to-End ASR

- Speech Variability as a Source of Acoustic Context



The Dynamics of Acoustic Context in End-to-End ASR

- **Acoustic Context Experiments on ASR Systems: Experiment Design**



Hugging Face Dataset Download: huggingface.co/datasets/taejinp/acoustic_context_switching

1. Use TTS to generate speech samples

- a. TTS enables Variable controlled experiments
- b. Created 384 utterances per each config
- c. Simulates intrinsic variability with multiple gender-balanced Speakers

2. Generate high-perplexity sentences to test

Acoustic Modality

- a. To minimize the effect of the internal language model in an End-to-end ASR model
- b. Tongue twisters and sophisticated words

3. Room impulse response (RIR) and additive noise

- a. To simulate extrinsic variabilities
- b. Harsh enough perturbations that drop WER

Text Example 1

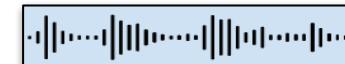
“
I scream, you scream, we all
scream for ice cream,
especially when it's free.
”

Text Example 2

“
Six slippery snails slid slowly
seaward.
”



Speaker A



Speaker A



Speaker A
RIR_1 + Noise_1



Speaker B



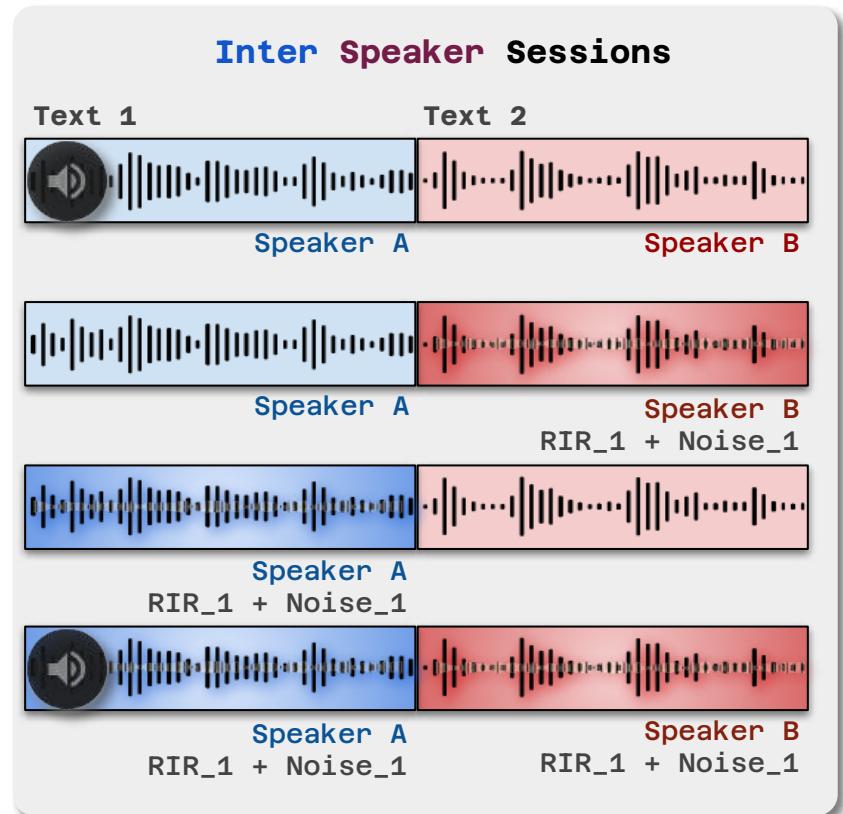
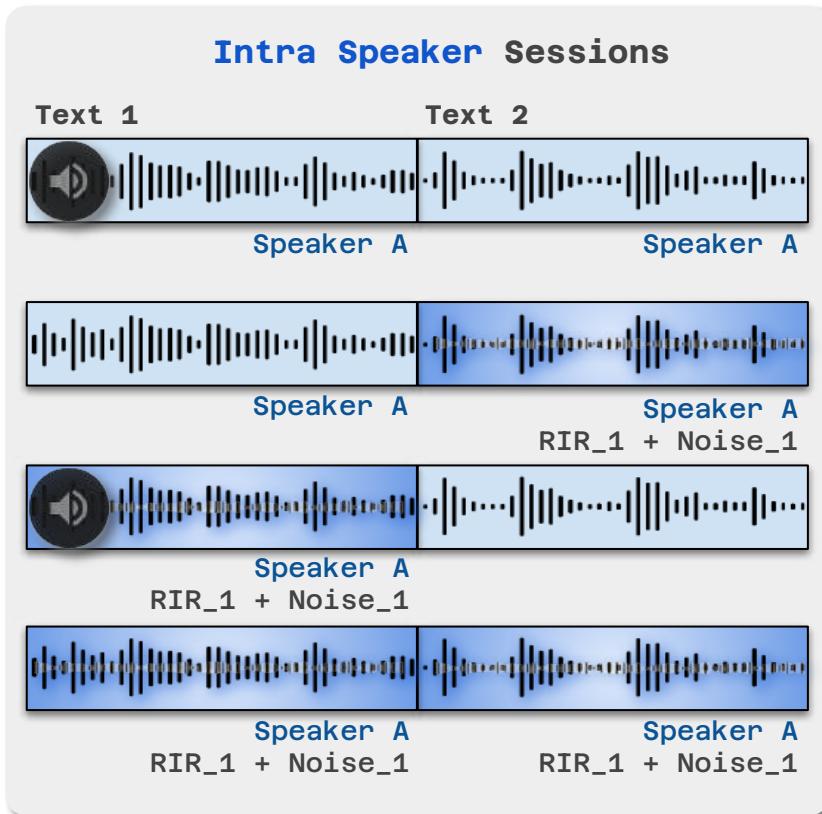
Speaker A
RIR_1 + Noise_1



Speaker B
RIR_1 + Noise_1

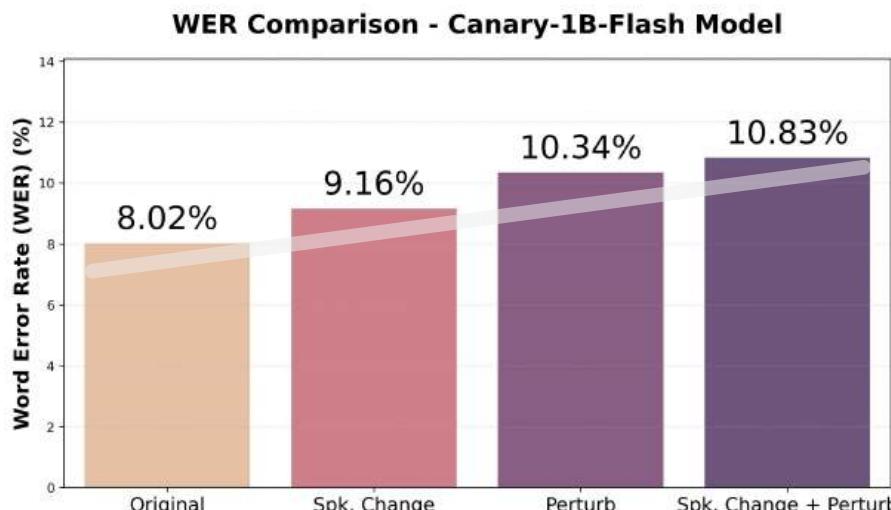
The Dynamics of Acoustic Context in End-to-End ASR

- Acoustic Context Experiments on ASR Systems: Example data points



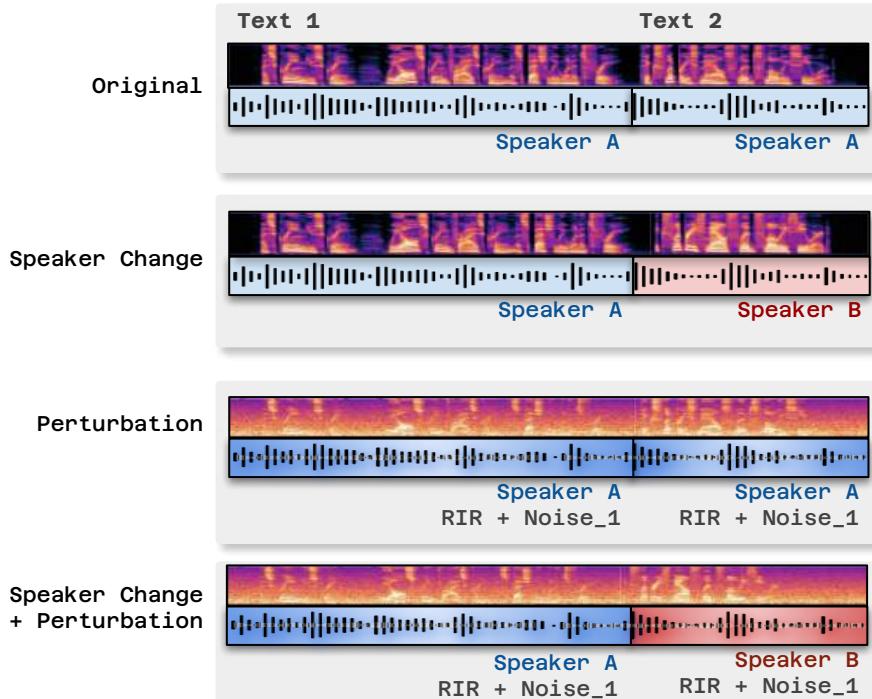
The Dynamics of Acoustic Context in End-to-End ASR

- The Mechanism of Acoustic Contextual Information in ASR



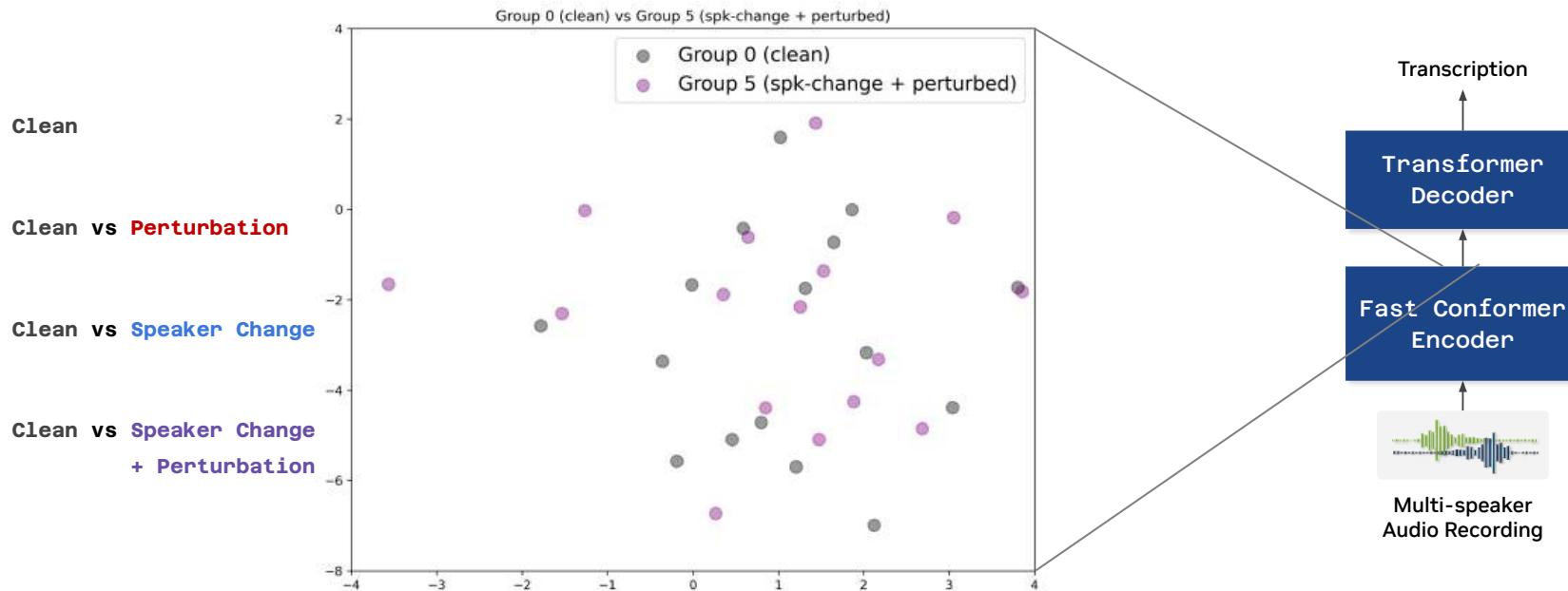
Hugging Face Dataset Download:

huggingface.co/datasets/taejinp/acoustic_context_switching



The Dynamics of Acoustic Context in End-to-End ASR

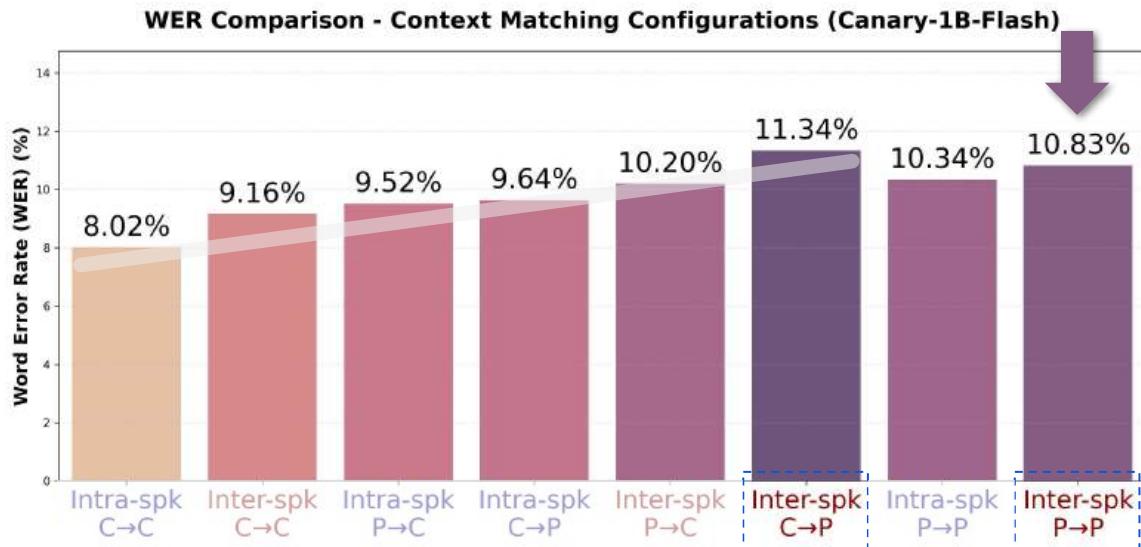
- Acoustic Context Experiments on ASR Systems



- ASR encoder state shifts and thus lead to WER drop.
- The shifted encoder state will affect the future inputs during decoding.

The Dynamics of Acoustic Context in End-to-End ASR

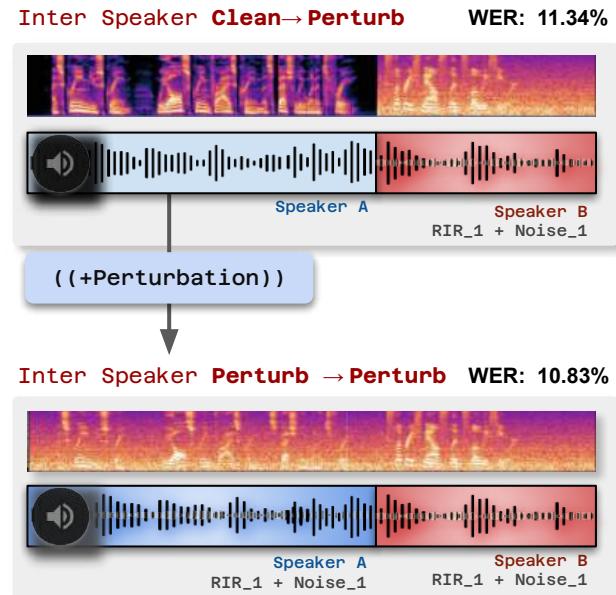
- Acoustic Context Experiments on ASR Systems



Inter Speaker Clean \rightarrow Perturb WER 11.34%

Inter Speaker Perturb \rightarrow Perturb WER 10.83%

Add more perturbation then get a lower WER ?



The Dynamics of Acoustic Context in End-to-End ASR

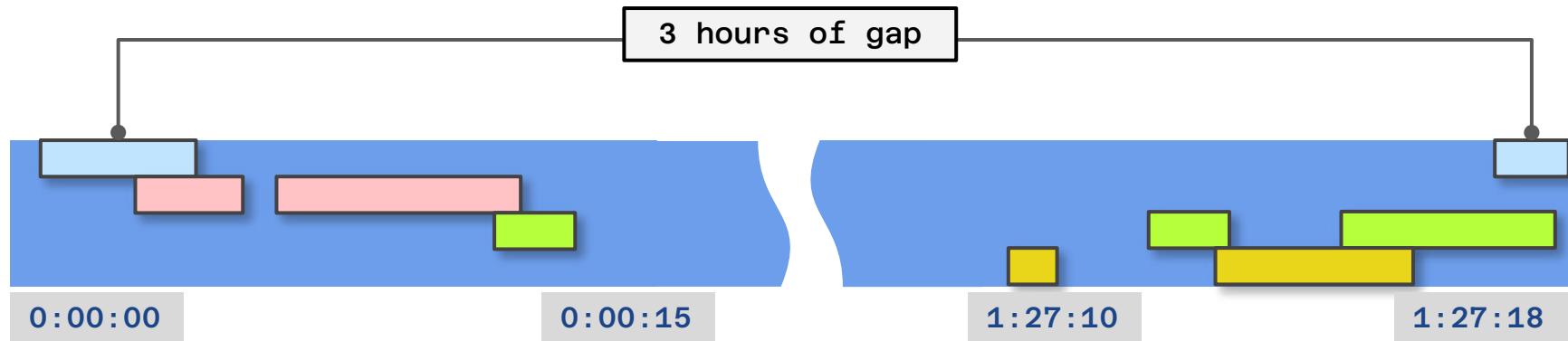
Takeaways

1. The sudden shift of acoustic context change leads to word error rate degradation.
2. Preconditioning with proper contextual information can be beneficial for ASR performance.
3. How can we leverage such behavior of end-to-end ASR model ?
 - a. For speaker-attributed ASR models (Multi-talker, target-speaker ASR models)
 - b. For streaming ASR models

Speaker-attributed ASR and Acoustic Context

Speaker-attributed ASR and Long-Context

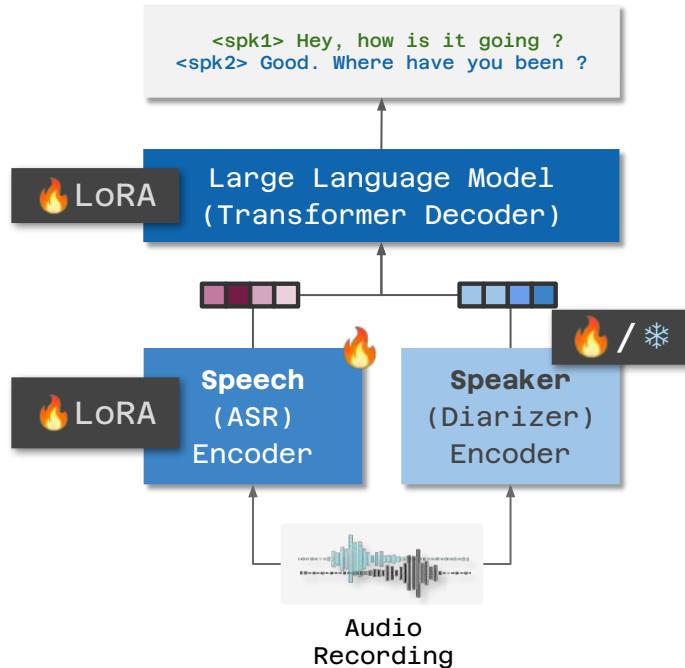
- Acoustic Context Problem in Multispeaker ASR



- Multispeaker ASR or Speaker Diarization need an exceptionally long acoustic context
- Imbalanced speaking time poses lack of context for certain speakers.

Speaker-attributed ASR and Long-Context

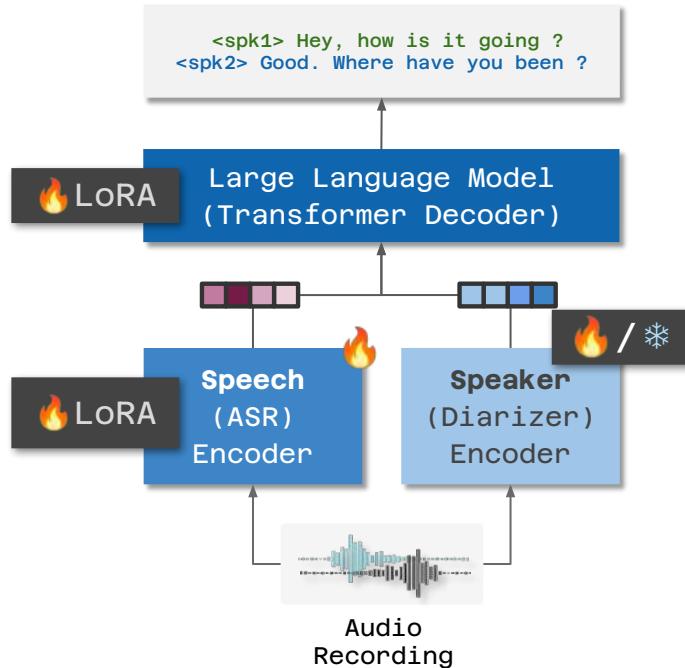
- Acoustic Context Problem in Multispeaker ASR



- The most recent multispeaker ASR systems share similarities:
 - Speech (ASR) Encoder part
 - Speaker (Diarization) encoder part
 - Adapter (LoRA) on Transformer Decoder
- Why separately...?

Speaker-attributed ASR and Long-Context

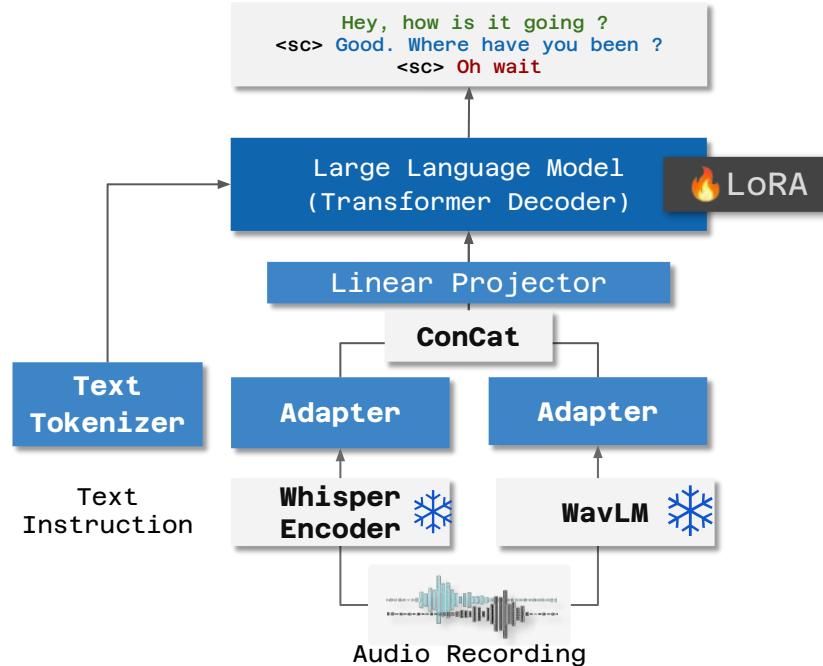
- Acoustic Context Problem in Multispeaker ASR



- Speech (ASR) encoder state minimizes:
Variabilities other than **phonetic information**.
- Speaker encoder state minimizes:
Variabilities other than **speaker information**.
- Speaker encoder and Speech encoder can be initialized from the same base speech encoder
- BUT, **universal embeddings fail to achieve SoTA**.
- In addition, for exceptionally long acoustic context, we need to save **speaker-cache separately**.

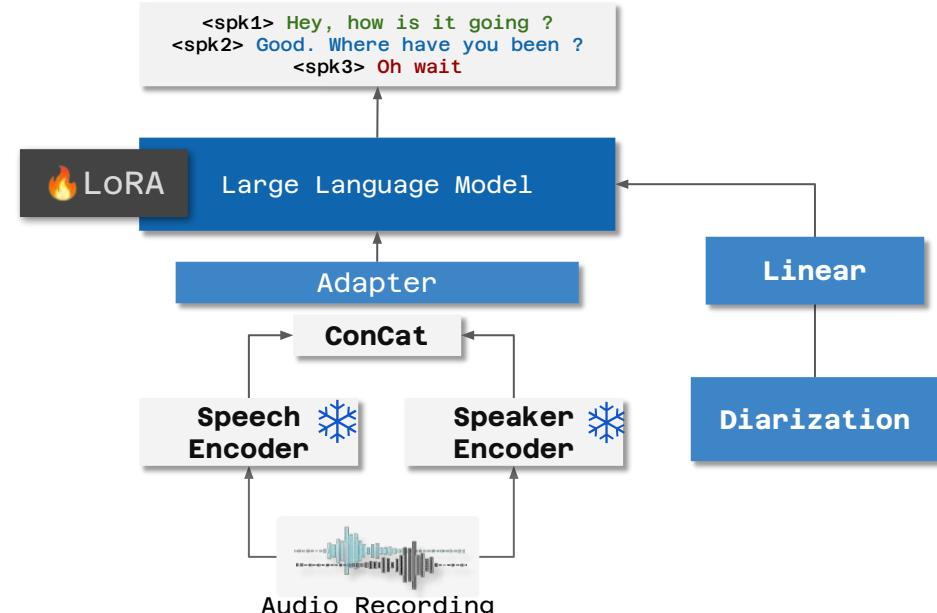
Speaker-attributed ASR and Long-Context

- Multi-speaker ASR with Speaker Context



MT-LLM: Multi-Talker LLLM

Meng, Lingwei, et al. "Large language model can transcribe speech in multi-talker scenarios with versatile instructions." ICASSP 2025

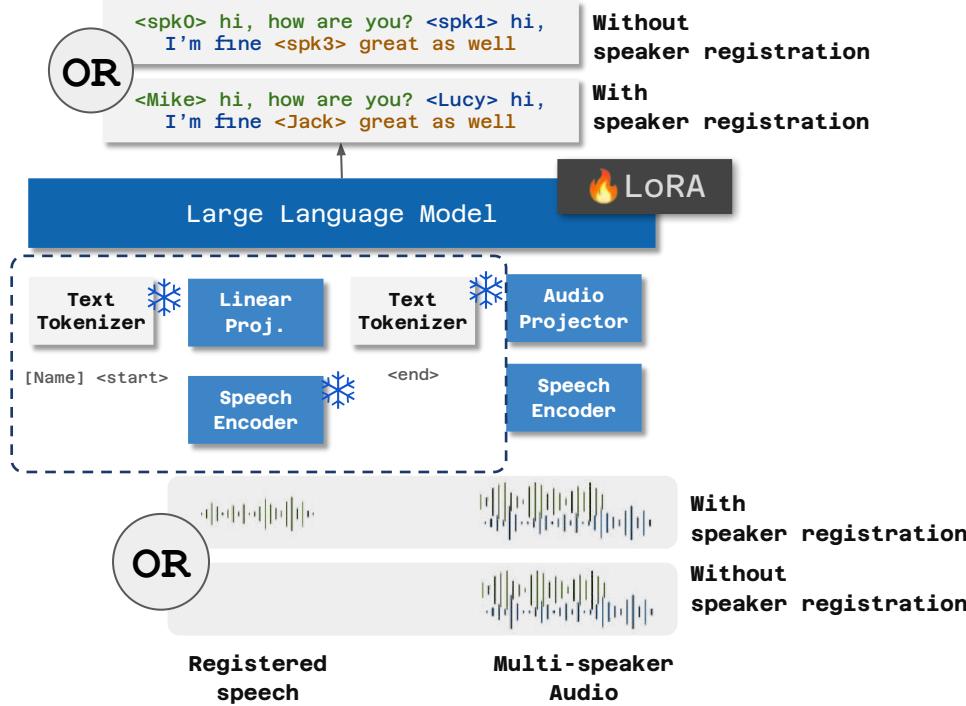


Diar-aware MS-ASR via LLM

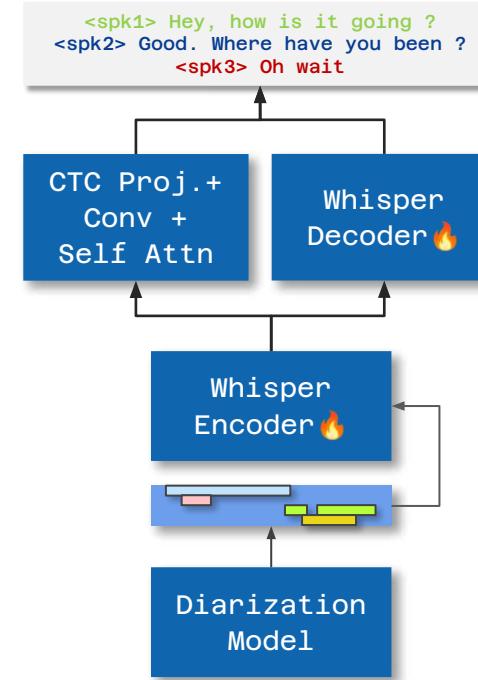
Lin, Yuke, et al. "Diarization-Aware Multi-Speaker Automatic Speech Recognition via Large Language Models." arXiv:2506.05796 (2025).

Speaker-attributed ASR and Long-Context

- Multi-speaker ASR with Speaker Context



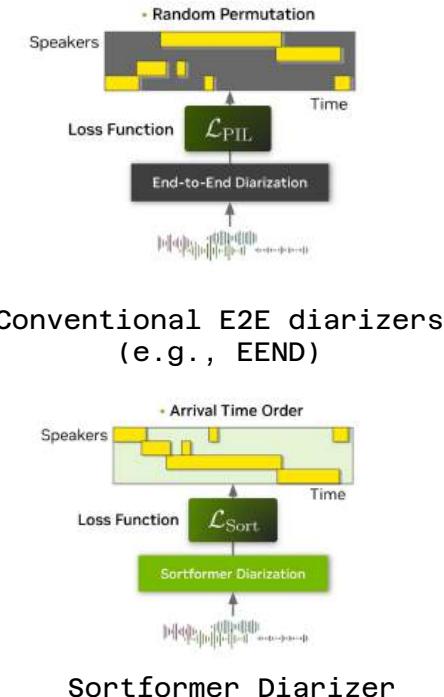
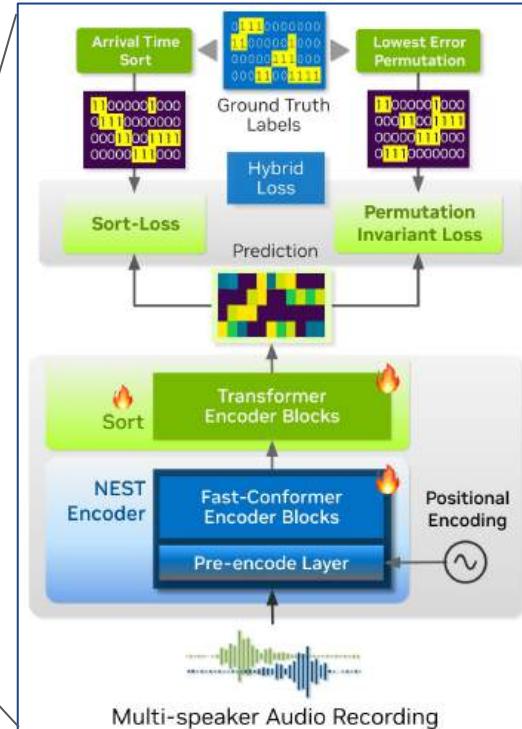
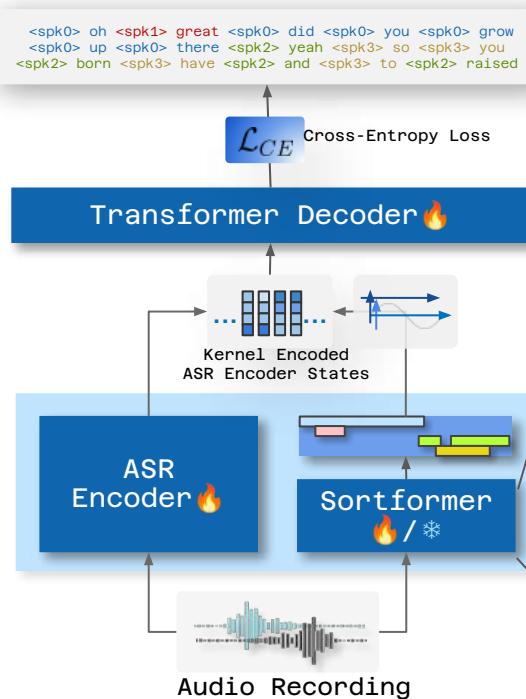
Yin, Han, et al. SpeakerLM: "End-to-End Versatile Speaker Diarization and Recognition with Multimodal Large Language Models." 2025. arXiv:2508.0637 (2025).



Polok, Alexander, et al. "DiCow: Diarization-conditioned whisper for target speaker automatic speech recognition." *Computer Speech & Language* 95 (2026): 101841.

Speaker-attributed ASR and Long-Context

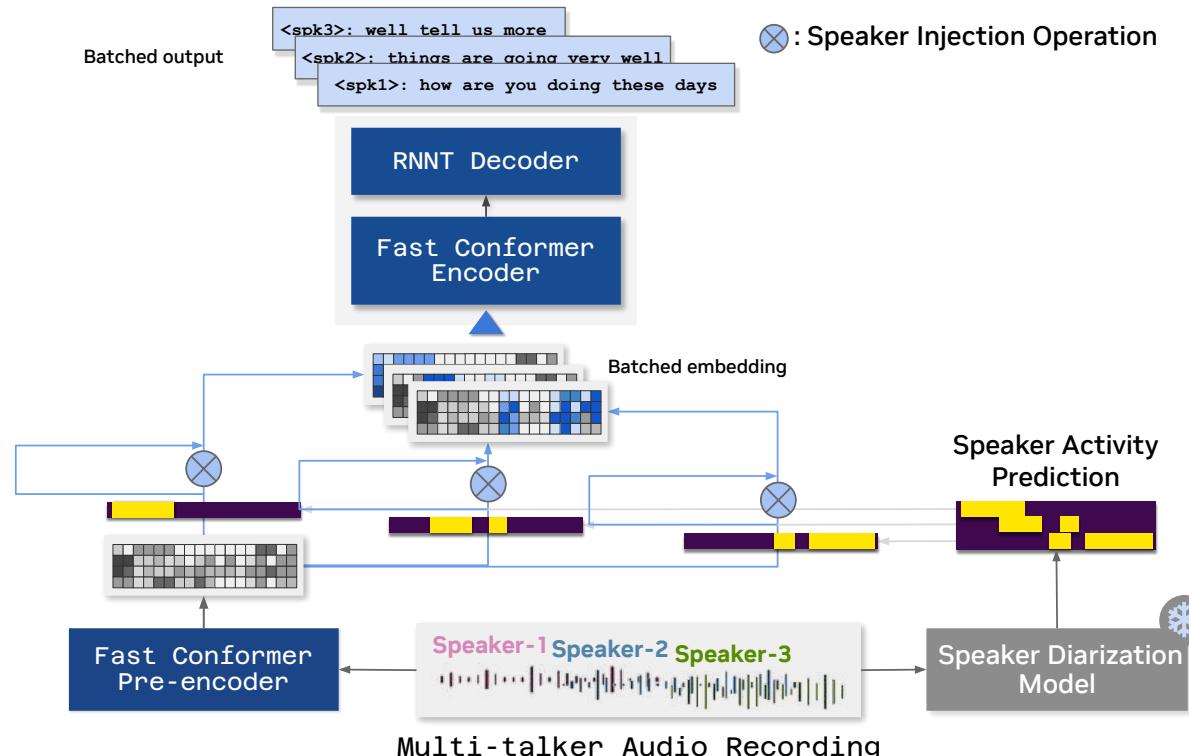
- Multi-speaker ASR with Speaker Context



Park, Taejin, Ivan Medennikov, Kunal Dhawan, Weiqing Wang, He Huang, et. al., "Sortformer: A Novel Approach for Permutation-Resolved Speaker Supervision in Speech-to-Text Systems." *Forty-second International Conference on Machine Learning (ICML 2025)*.

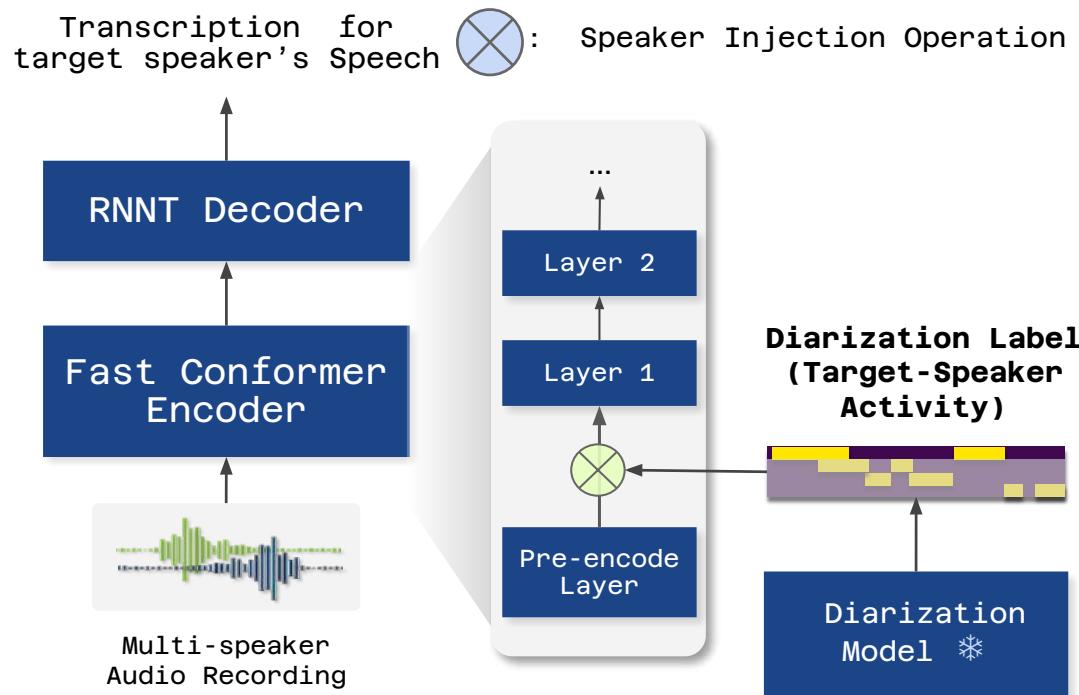
Speaker-attributed ASR and Long-Context

- Multi-speaker ASR with Speaker Context: Use Speaker (Acoustic) Context!



Speaker-attributed ASR and Long-Context

- Multi-speaker ASR with Speaker Context: Batch the multiple speakers!



Speaker-attributed ASR and Long-Context

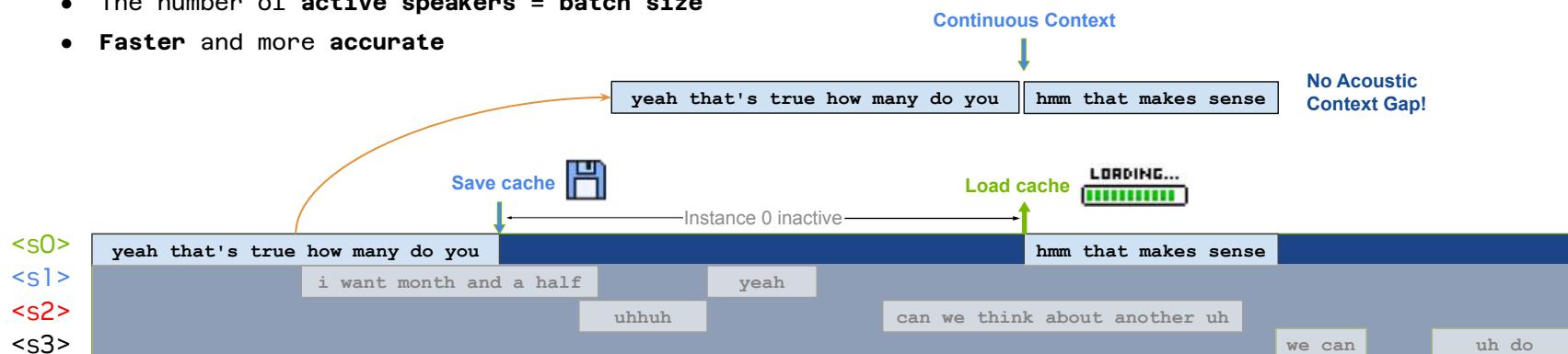
- Multi-speaker ASR with Speaker Context

Diarization Context Gating

- Inefficient when keeping 4 instance simultaneously
- Computations are 4x more than single speaker ASR

Solution ?

- Save speaker cache and load at the next speaker-active region
- The number of active speakers = batch size
- Faster and more accurate



Speaker-attributed ASR and Long-Context

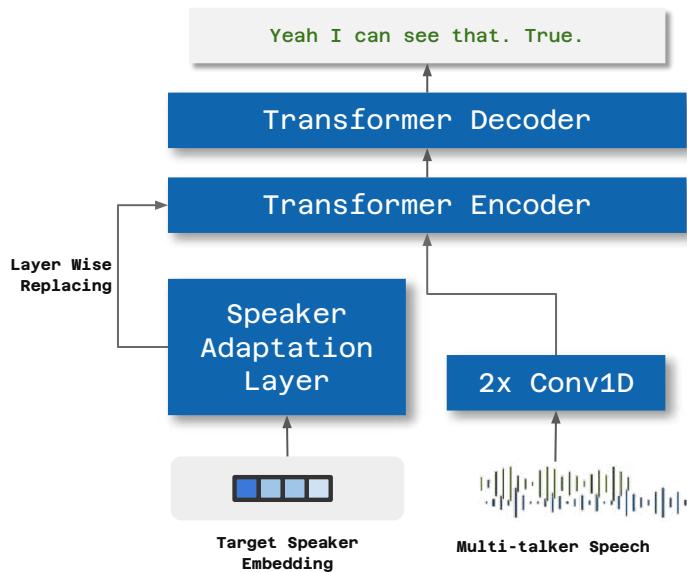
The screenshot shows a user interface for speech recognition. On the left, there's a configuration panel with a 'Number of Speakers' slider set to 2, and checkboxes for 'Enable Cache Gating' (checked), 'Enable Binary Diarization' (checked), and 'Enable Real-time Mode' (unchecked). Below this is a 'Load Models' button. To the right is a main area titled 'Microphone' with tabs for 'Microphone' (selected) and 'File Upload'. It features a waveform visualization and a 'Record from Microphone' button with a red 'Stop' button next to it. A status message at the bottom indicates: 'Models reloaded with new settings: - Speakers: 2 - Cache Gating: On - Binary Diarization: On - Real-time Mode: Off'. A 'Default - Yeti Na...' dropdown is also visible.



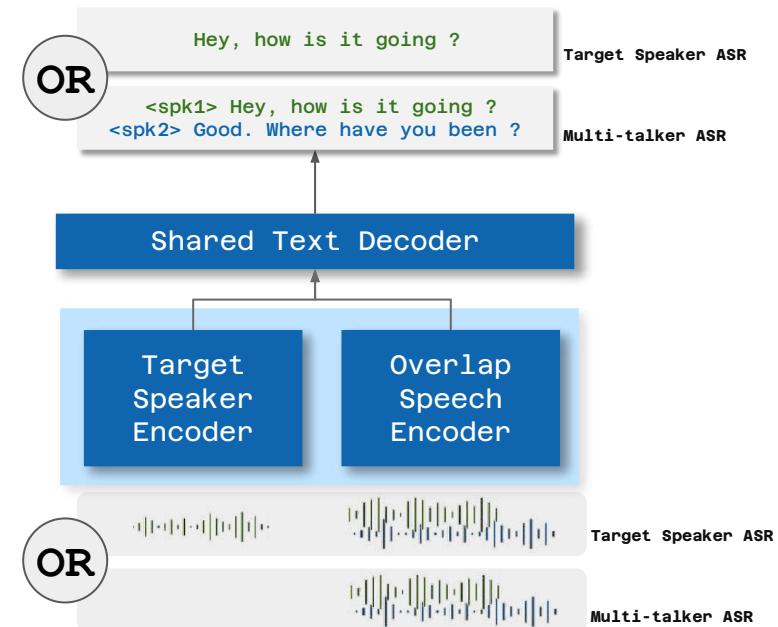
Speaker-attributed ASR and Long-Context

- Target speaker ASR with Speaker Context

Whisper with prompt:Target-speaker ASR [1]



Unified Multi-Talker/Target-speaker ASR [2]

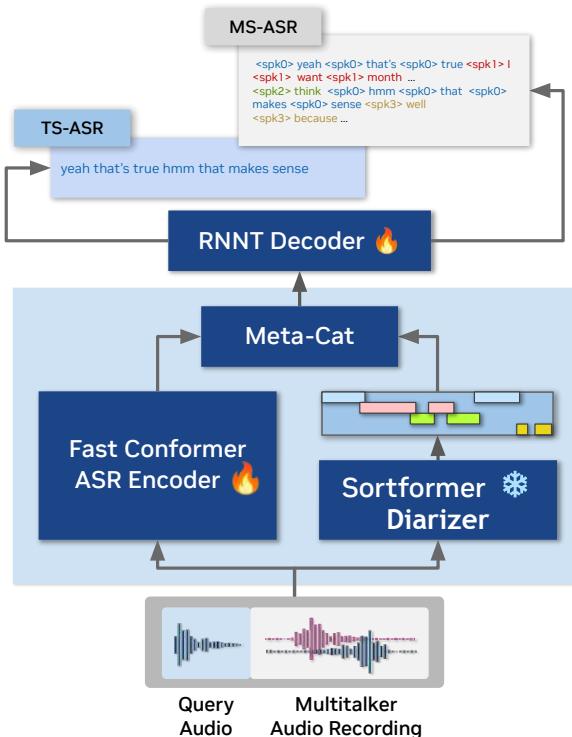


[1] Ma, Hao, et al. "Extending Whisper with prompt tuning to target-speaker ASR." ICASSP 2024

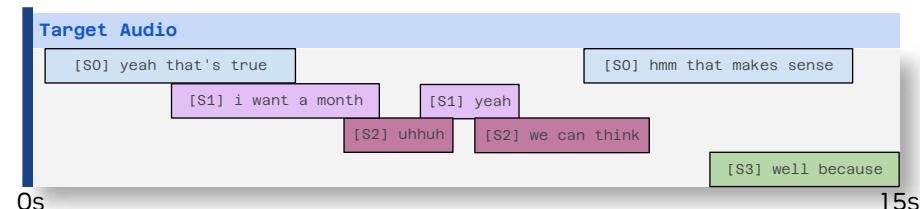
[2] Masumura, Ryo, et al. "Unified multi-talker ASR with and without target-speaker enrollment." Interspeech. Vol. 2024. 2024.

Speaker-attributed ASR and Long-Context

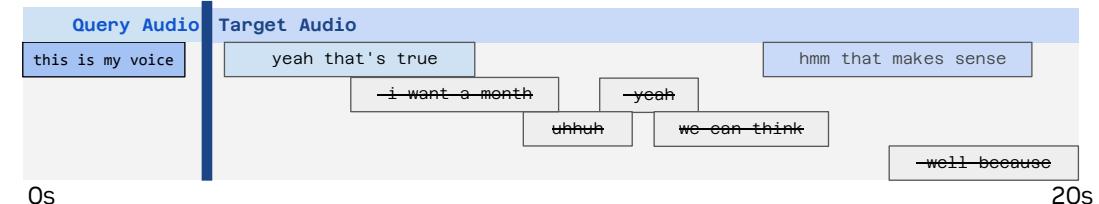
- Target speaker ASR with Speaker Context



(a) Multispeaker ASR Scenario



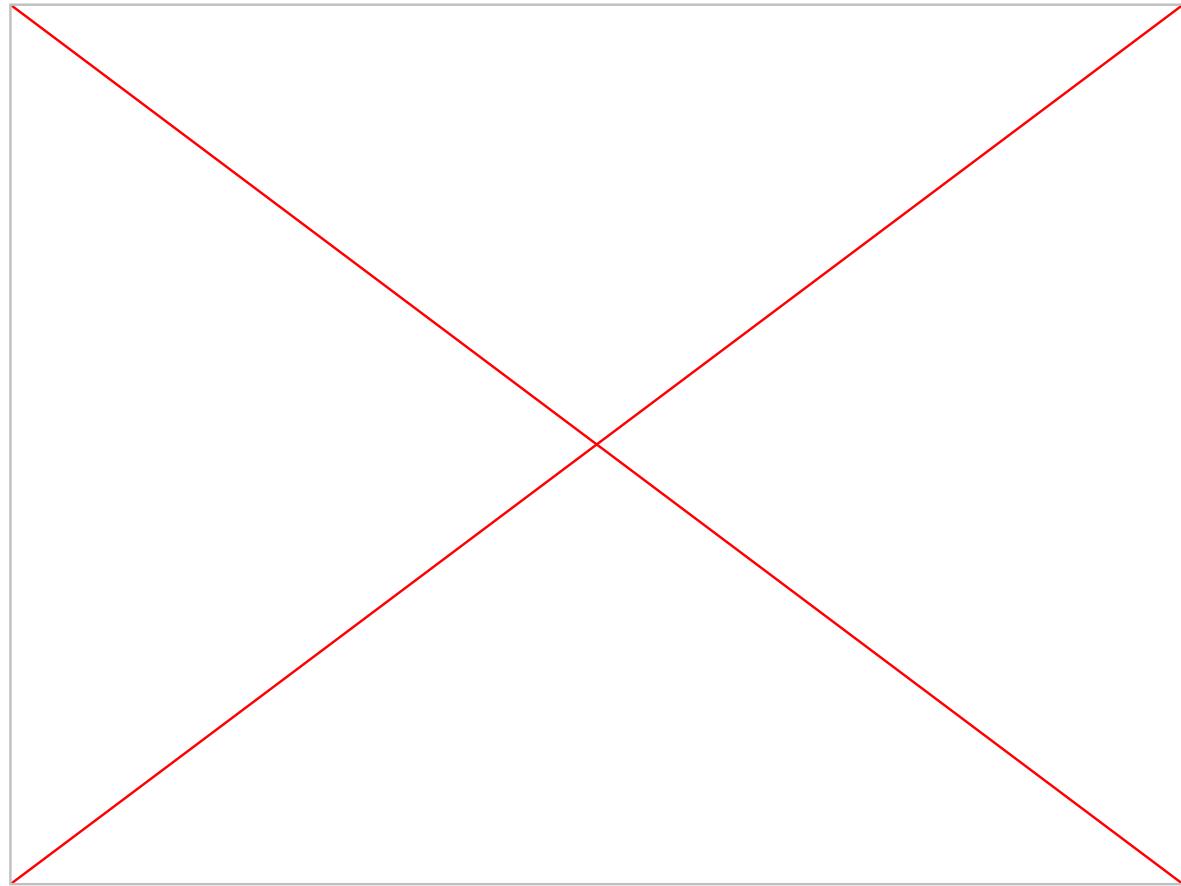
(b) Targetspeaker ASR Scenario



- Use Sortformer Diarizer: First speaker = query speaker.
- No architecture changes for performing target speaker ASR and multi-speaker ASR.

Speaker-attributed ASR and Long-Context

- Target speaker ASR
Demo Video



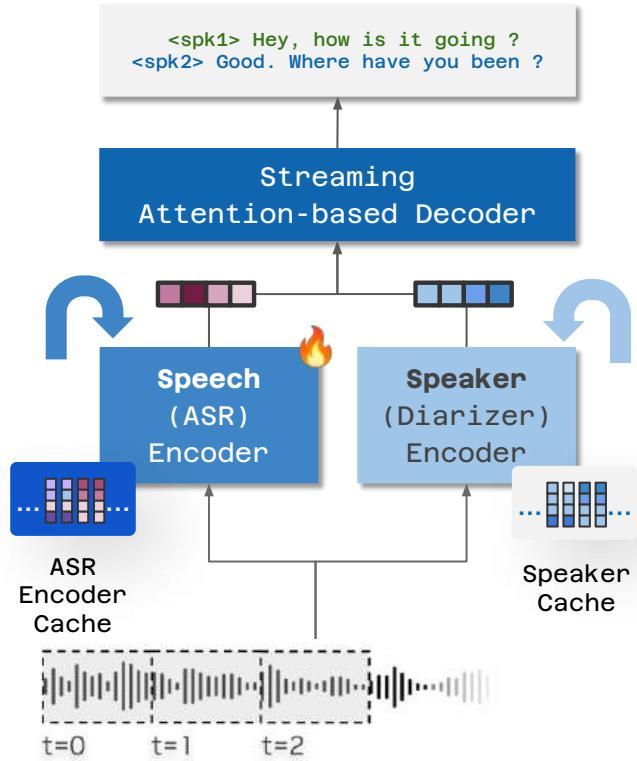
Speaker-attributed ASR and Long-Context

- Takeaways
 - 1. We can leverage the behavior of acoustic context biasing for multispeaker ASR and target speaker ASR.
 - 2. Speaker cache should be handled separately from ASR cache for streaming and long form audio handling.

Streaming with Long Acoustic Context

Speaker-attributed ASR and Long-Context

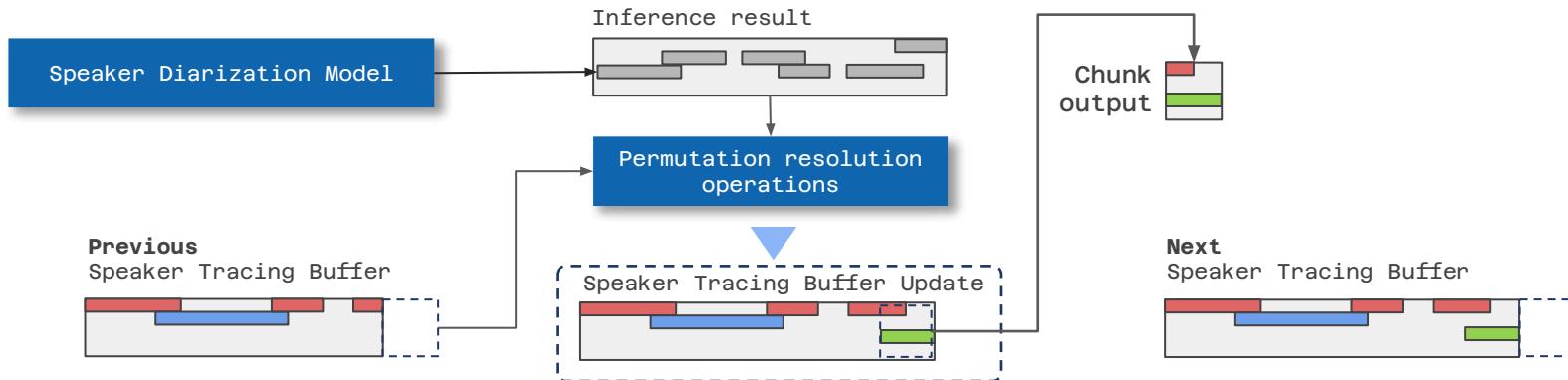
- Streaming multispeaker ASR with Speaker Cache



- Since we have separate encoders for both ASR and speaker diarization, we need to maintain **ASR cache and speaker cache separately**.
- The arrival time ordering of Sortformer makes speaker cache operating.

Streaming with Long Acoustic Context

- Streaming Speaker Diarization for SA-ASR: Speaker Tracing Buffer
- How can we maintain speaker cache for diarization ?



- "Permutation resolution operations" requires **cubic** time complexity
 $n=(\# \text{ of speakers})$
- Needs to maintain the whole history

Xue, Yawen, et al. "Online end-to-end neural diarization with speaker-tracing buffer." 2021 IEEE SLT Workshop.

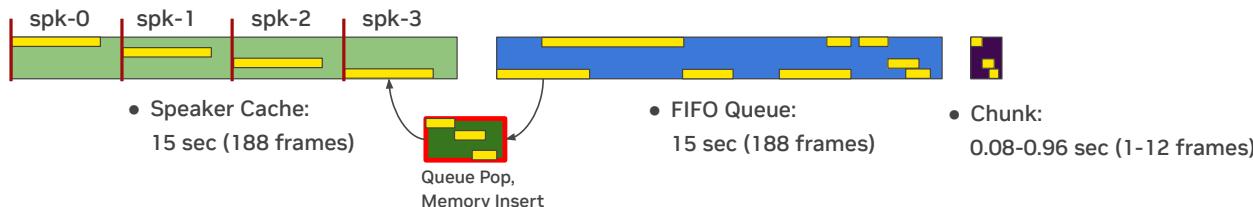
Horiguchi, Shota, et al. "Online neural diarization of unlimited numbers of speakers using global and local attractors." IEEE/ACM TASLP (2022): 706-720.

Streaming with Long Acoustic Context

- Streaming Speaker Diarization for SA-ASR

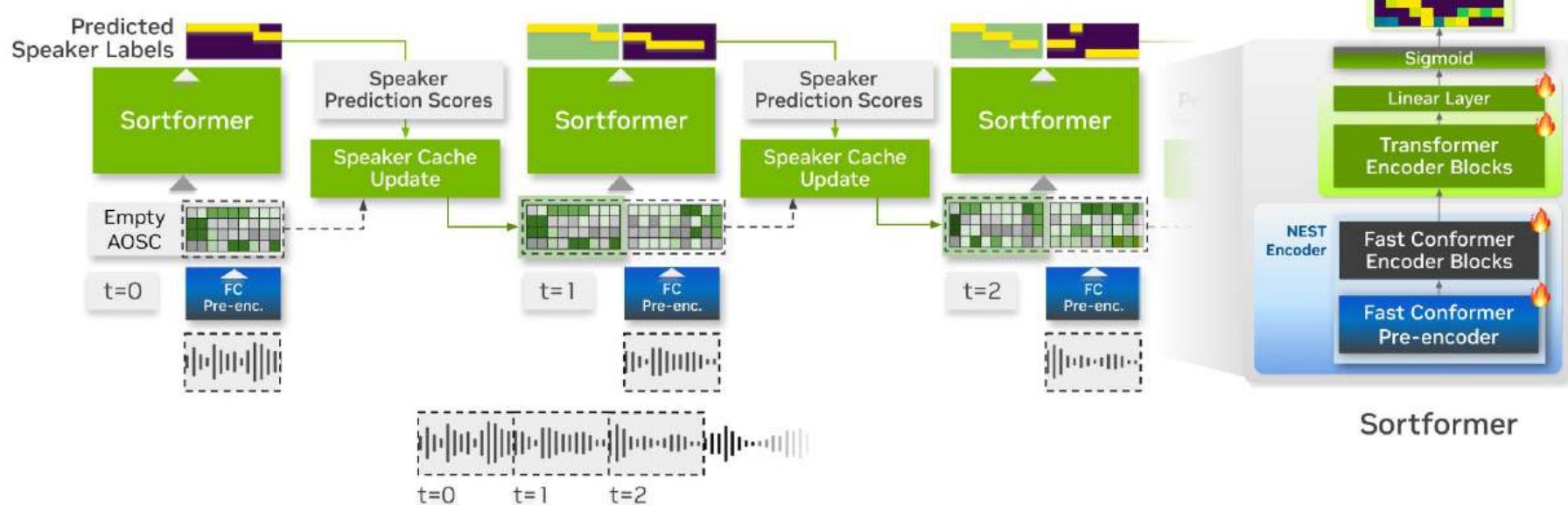
How it works: **Streaming Sortformer**

- Chunk-wise processing
- Arrival-Ordered Speaker Cache (AOSC) resolves between-chunk permutations
- FIFO queue adds recent context



Streaming with Long Acoustic Context

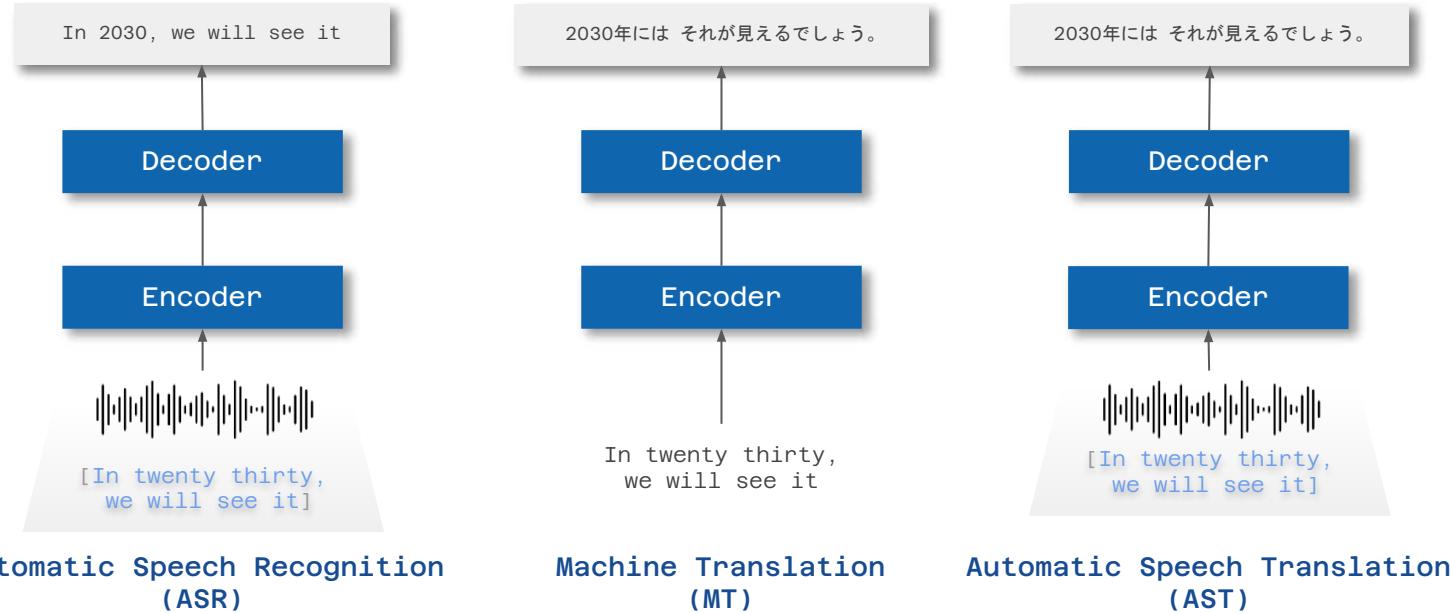
- Streaming Speaker Diarization for SA-ASR



Streaming with Long Acoustic Context

- Offline models to streaming: ASR with Translation

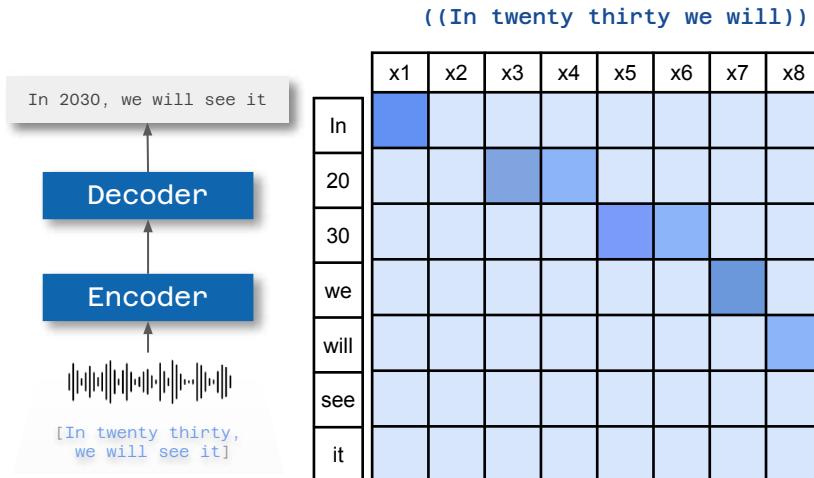
Beyond ASR: ASR vs MT vs AST



Streaming with Long Acoustic Context

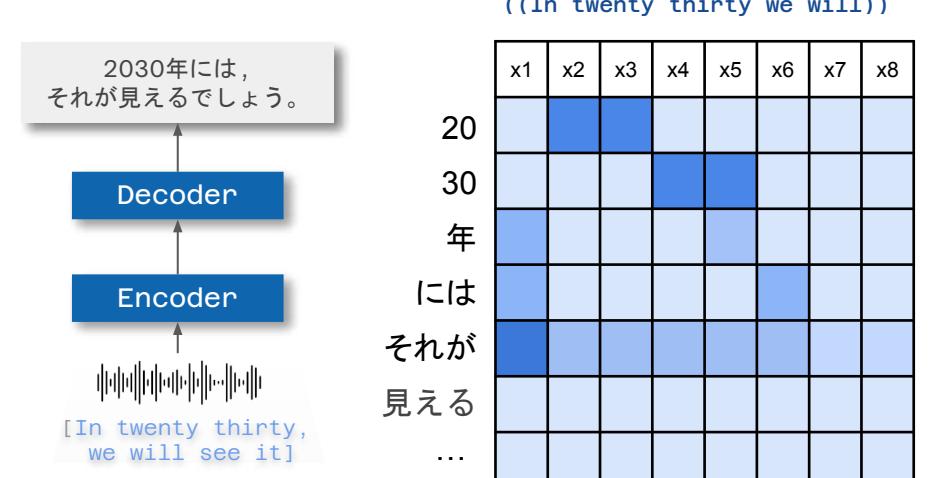
- Offline models to streaming: Streaming ASR with Translation

Streaming ASR with Translation = Simultaneous Speech Translation



Automatic Speech Recognition
(ASR)

Monotonic Alignment

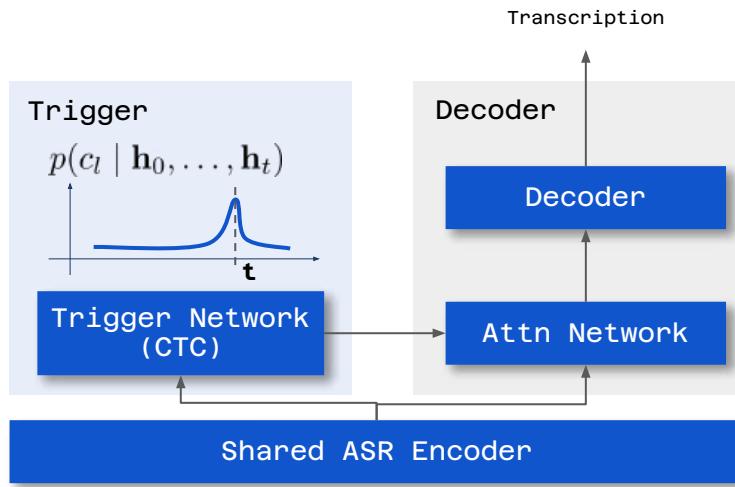


Automatic Speech Translation
(AST)

Non-monotonic Alignment

Streaming with Long Acoustic Context

- Long-context Transformers: Attention Mechanisms for Streaming

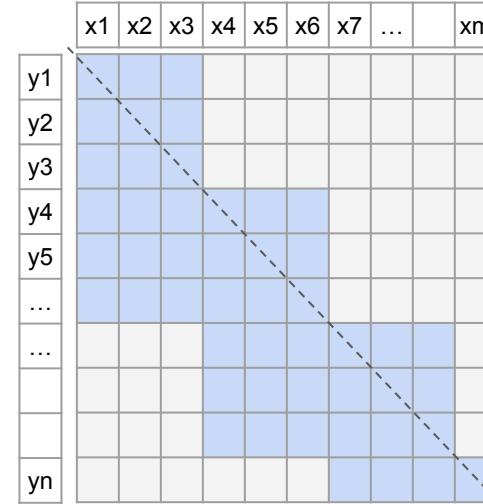


- CTC-trained trigger network estimates when to activate the attention

Moritz, Niko, Takaaki Hori, and Jonathan Le Roux. "Triggered attention for end-to-end speech recognition." ICASSP 2019

Hori, Takaaki, et al. "Transformer-Based Long-Context End-to-End Speech Recognition." *Interspeech 2020*

Hori, Takaaki, et al. "Advanced Long-Context End-to-End Speech Recognition Using Context-Expanded Transformers." *Interspeech 2021*



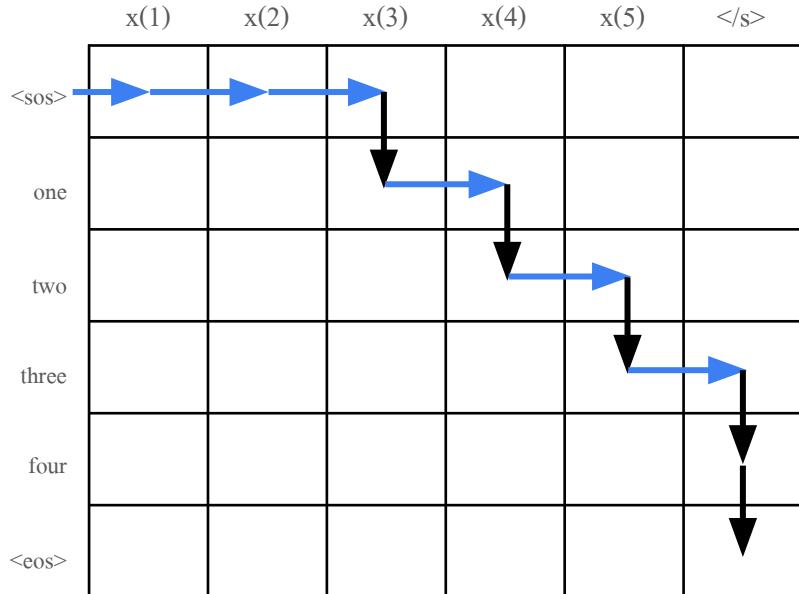
- Masked Attention for Streaming:
Train with mask and limit the left context cache

Chen, Xie, et al. "Developing real-time streaming transformer transducer for speech recognition on large-scale dataset." ICASSP 2021

Noroozi, Vahid, et al. "Stateful conformer with cache-based inference for streaming automatic speech recognition." ICASSP 2024

Streaming with Long Acoustic Context

- Offline models to streaming Without Training : Wait-K and other methods



Wait-3 Example:

Input:

$x(1)$ $x(2)$ $x(3)$ $x(4)$ $x(5)$ $</s>$

Output:

one two three four $<\text{eos}>$

👍 Pros:

- Stable latency
- Simple to implement

👎 Cons:

- Fixed delay could be suboptimal
- Poor with long reordering

Elbayad, Maha, Laurent Besacier, and Jakob Verbeek. "Efficient Wait-k Models for Simultaneous Machine Translation." *Proc. Interspeech 2020*. 2020.

Elbayad, M. Ma, L. Huang, H. Xiong et al., "STACL: Simultaneous trans-ation with implicit anticipation and controllable latency using prefix-to-prefix framework," in Proc. ACL 2019, Florence, Italy, Jul. 2019.

Streaming with Long Acoustic Context

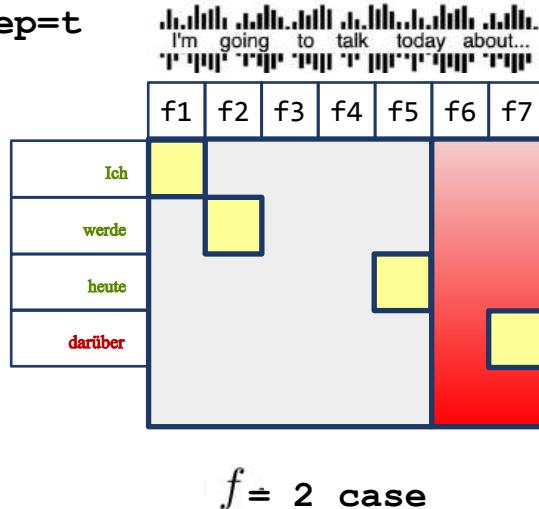
- Offline models to streaming: Wait-K and other methods

AlignATT: Simple decision policy that aligns attention

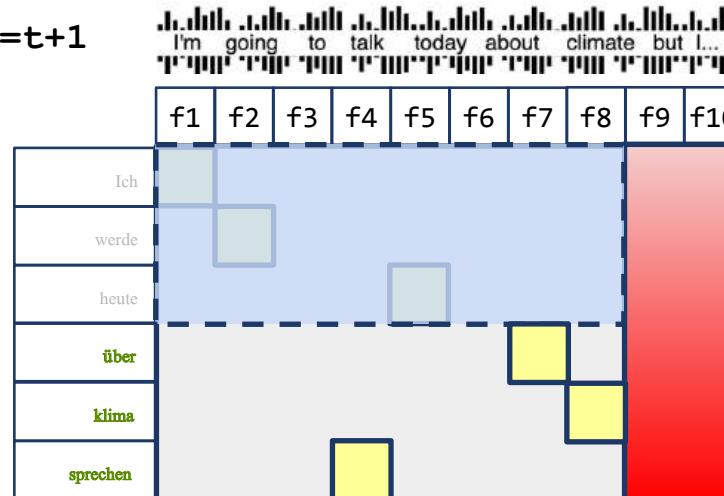
Decision Policy:

Iterate over the prediction and continue the emission until: $Align_i \notin \{n - f + 1, \dots, n\}$

Step=t



Step=t+1



Papi, Sara, Marco Turchi, and Matteo Negri. "ALIGNATT: Using Attention-based Audio-Translation Alignments as a Guide for Simultaneous Speech Translation.", Interspeech 2023.

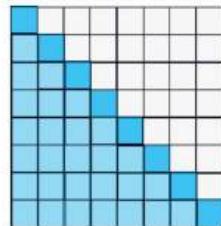
Speaker-attributed ASR and Long-Context

- Takeaways
 - 1. Speaker information needs to be separately cached or attended to have a competitive multispeaker ASR performance
 - 2. Even without retraining, Attention Encoder-Decoder models for streaming ASR or simultaneous speech translation models can perform to a certain extent.

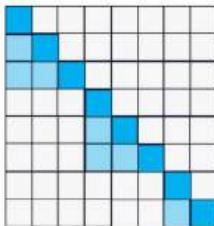
Alternative Architectures

Alternative Architectures for Long Context ASR

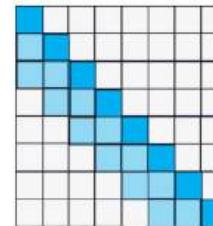
- Long-context Transformers: Attention Mechanisms for Streaming



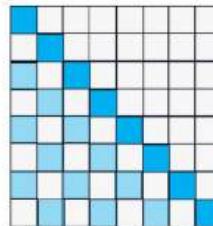
(a) Dense Attention
(L=8)



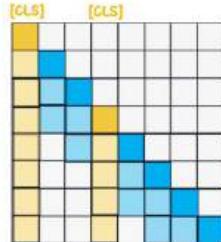
(b) Block-wise Attention
(B=3)



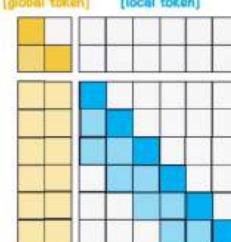
(c) Sliding-Window Attention
(w=3)



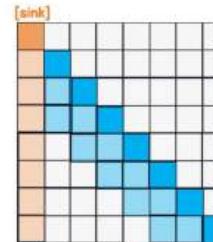
(d) Dilated-Window Attention
(w=3, d=2)



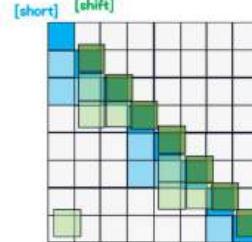
(e) Global-Local Hybrid Attention
(Special Token)



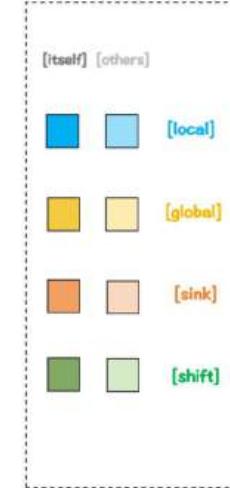
(f) Global-Local Hybrid Attention
(Global Token)



(g) Attention Sink
(StreamLLM)

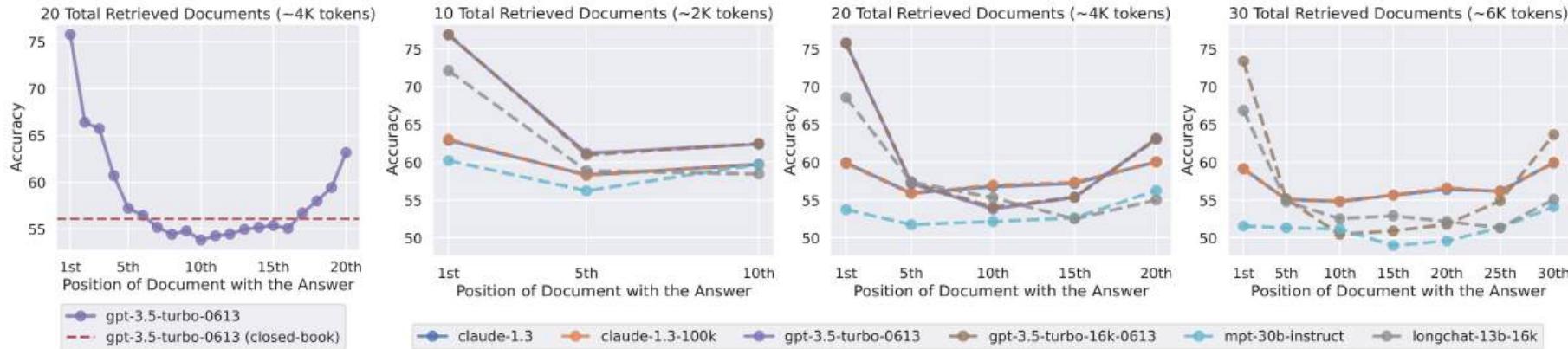


(h) Shift-Short Attention
(LongLoRA)



Alternative Architectures for Long Context ASR

- Long-context Transformers: Text vs Speech



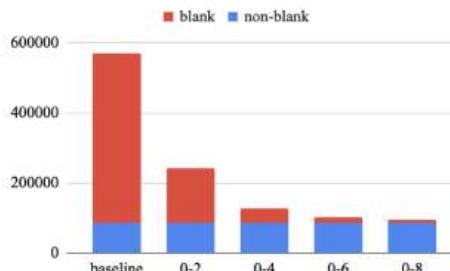
- Only the beginning and end of the long context survives.



Alternative Architectures for Long Context ASR

- Token Duration Transducer (TDT)

Predict Token AND Duration!



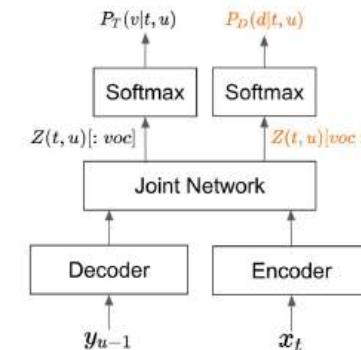
- Same as RNN-T with additional duration predictions
- Outputs token and its duration at each time frame
- TDT loss (2D lattice loss)
- Faster inference and More accurate than RNN-T

- TDT decoding: Skip frames based on duration predictions.

Frame:	0	1	2	3	4	5	6	6	7	8	9	10	11	12	13	14	15
Token:	This	->	_is	blank	->	->	_output	_from	blank	->	...						
Duration:	2		1	3			0	1	2								

TDT config	WER(%)	time(s)	rel. speed-up
RNNT	2.14	256	-
0-2	2.35	175	1.46X
0-4	2.17	129	1.98X
0-6	2.14	119	2.15X
0-8	2.11	117	2.19X

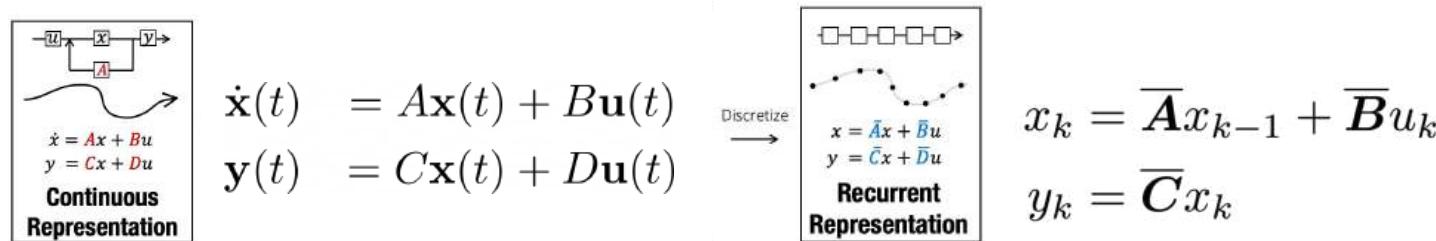
TDT config	WER(%)	time(s)	rel. speed-up
RNNT	5.11	244	-
0-2	5.50	171	1.43X
0-4	5.06	128	1.91X
0-6	5.05	118	2.07X
0-8	5.16	115	2.12X



Xu, Hainan, et al. "Efficient Sequence Transduction by Jointly Predicting Tokens and Durations." Proceedings of the 40th International Conference on Machine Learning (ICML), 2023.

Alternative Architectures for Long Context ASR

- State-Space Models: SSM in a nutshell



- SSMs are broadly used in many scientific disciplines.
- SSMs are related to **latent state models** such as Hidden Markov Models (HMM).
- A **State Space Model (SSM)** describes a system using hidden “state” variables that evolve over time and produce “observable outputs” in the form of differential equations.

[1] https://en.wikipedia.org/wiki/State-space_representation

[2] Gu, Albert, Karan Goel, and Christopher Ré. "Efficiently modeling long sequences with structured state spaces." arXiv preprint arXiv:2111.00396 (2021)

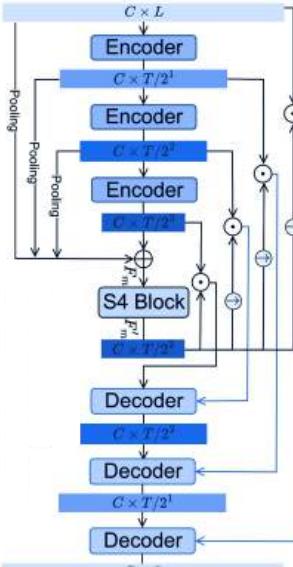
Alternative Architectures for Long Context ASR

- State-Space Models: Applications of SSMs

	MFCC	RAW	$0.5 \times$
Transformer	90.75	X	X
Performer	80.85	30.77	30.68
ODE-RNN	65.9	X	X
NRDE	89.8	16.49	15.12
ExpRNN	82.13	11.6	10.8
LipschitzRNN	88.38	X	X
CKConv	95.3	71.66	<u>65.96</u>
WaveGAN-D	X	<u>96.25</u>	X
LSSL	93.58	X	X
S4	93.96	98.32	96.30

- S4[1]** model's Raw timeseries speech classification
- S4** model outperforms RNN and attention-variants

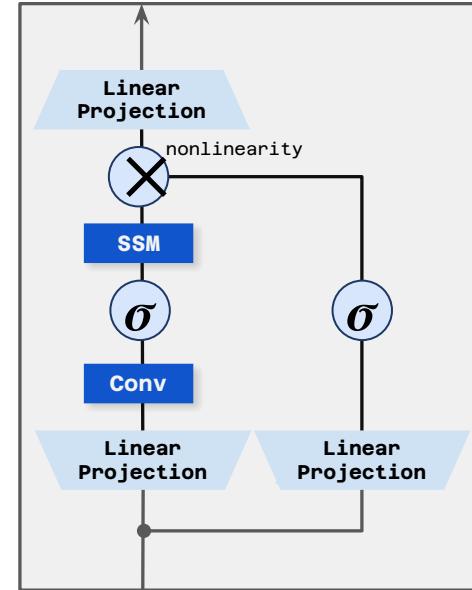
 Sum operator
 Element-wise product
 Nearest Neighbour interpolation



S4M: Neural Speech Separation

[1] Gu, Albert, "Efficiently Modeling Long Sequences with Structured State Spaces", ICLR 2022

Chen, Chen, Chao-Han Huck Yang, Kai Li, Yuchen Hu, Pin-Jui Ku, and Eng Siong Chng. "A Neural State-Space Model Approach to Efficient Speech Separation.", Interspeech 2025

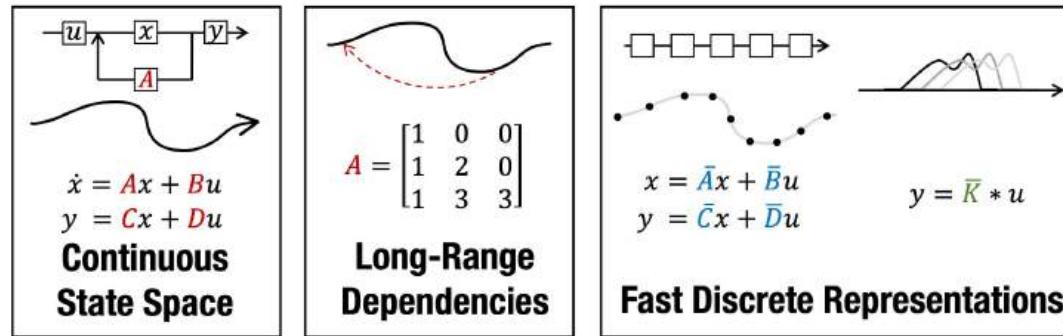


- SSMs were later popularized with Mamba[2], a specialized architecture built on the SSM framework.

[2] Gu, Albert, and Tri Dao. "Mamba: Linear-Time Sequence Modeling with Selective State Spaces." COLM 2024.

Alternative Architectures for Long Context ASR

- State-Space Models: SSM in a nutshell



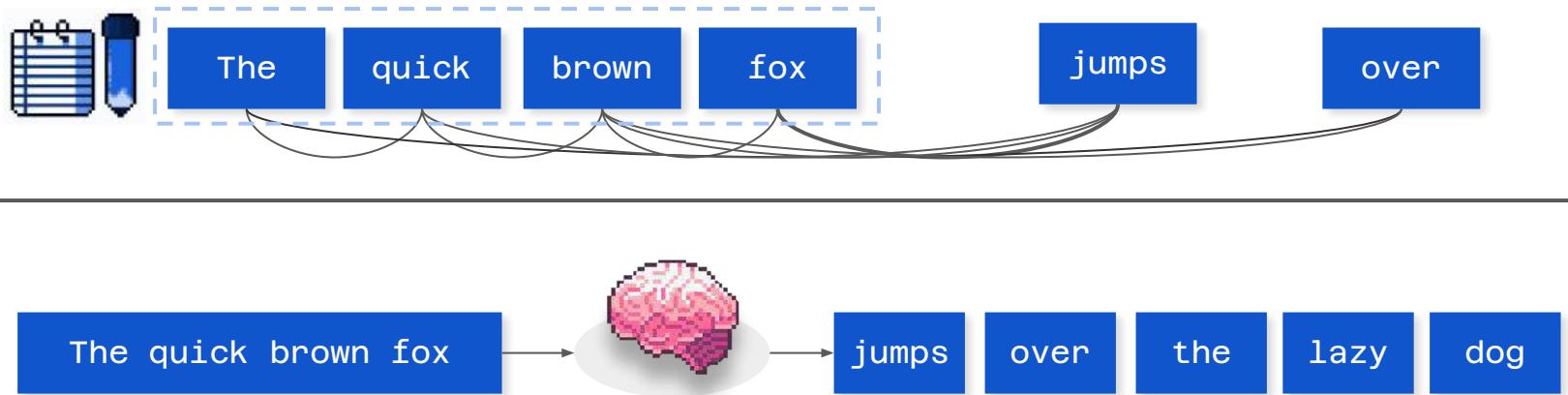
- Sequence modeling struggles with **long-range dependencies (LRD)**.
- SSMs have **linear memory scaling** while having a good **LRD**.
- Natural inductive bias for sequential and temporal data. Thus, widely used **for modeling time-series**.

Alternative Architectures for Long Context ASR

- State-Space Models: Quoting Albert Gu's analogy [1] ...

A Coarse Analogy by Albert Gu: Attention vs SSM

Transformers are like a "**database**"



State space models are like a "**brain**"

[1] Gu, Albert. "On the Tradeoffs of State Space Models and Transformers." *AI Heard That! ICML 2025 Workshop on Machine Learning for Audio*, 27 July 2025

Alternative Architectures for Long Context ASR

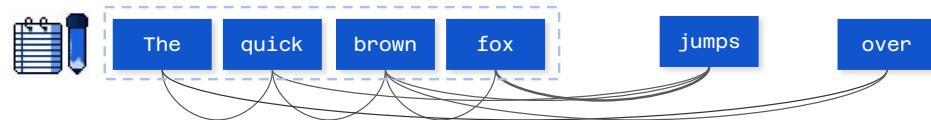
- State-Space Models: Quoting Albert Gu's analogy [1] ...

Tradeoffs of Attention and Transformer

👍 Pros:

Fine-grained attention over past context

Strong at **recall and retrieval**



👎 Cons:

Known to be **Efficient?**: quadratic scaling training, linear time inference

→ But Dependent on resolution and semantic content of data

Reality: Attention is only effective on pre-compressed data at the "**right level of abstraction**"

[1] Gu, Albert. "On the Tradeoffs of State Space Models and Transformers." *AI Heard That! ICML 2025 Workshop on Machine Learning for Audio*, 27 July 2025

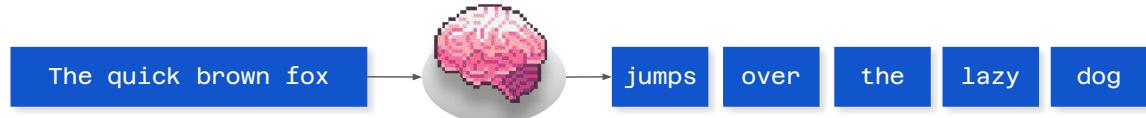
Alternative Architectures for Long Context ASR

- State-Space Models: Quoting Albert Gu's analogy [1] ...

Tradeoffs of State Space Models

👍 Pros:

Stateful, compressive model



👎 Cons:

Lacks fine-grained recall and retrieval abilities

Associative recall, needle-in-a-haystack, general QA.. (Recall and Retrieval)

[1] Gu, Albert. "On the Tradeoffs of State Space Models and Transformers." *AI Heard That! ICML 2025 Workshop on Machine Learning for Audio*, 27 July 2025

Alternative Architectures for Long Context ASR

- State-Space Models: Quoting Albert Gu's examples [1]

Tokenization is "the problem" of attention



...

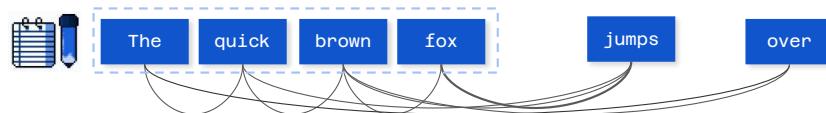
We will see that a lot of weird behaviors and problems of LLMs actually trace back to tokenization. We'll go through a number of these issues, discuss why tokenization is at fault, and why someone out there ideally finds a way to delete this stage entirely.

Tokenization is at the heart of much weirdness of LLMs. Do not brush it off.

- Why can't LLM spell words? **Tokenization**.
- Why can't LLM do super simple string processing tasks like reversing a string? **Tokenization**.
- Why is LLM worse at non-English languages (e.g. Japanese)? **Tokenization**.
- Why is LLM bad at simple arithmetic? **Tokenization**.
- Why did GPT-2 have more than necessary trouble coding in Python? **Tokenization**.
- Why did my LLM abruptly halt when it sees the string "<|endoftext|>"? **Tokenization**.
- What is this weird warning I get about a "trailing whitespace"? **Tokenization**.
- Why does the LLM break if I ask it about "SolidGoldMagikarp"? **Tokenization**.
- Why should I prefer to use YAML over JSON with LLMs? **Tokenization**.
- Why is LLM not actually end-to-end language modeling? **Tokenization**.
- What is the real root of suffering? **Tokenization**.

9:40 AM · Feb 20, 2024 · 747.4K Views

Effective Tokens for Attention



(sub)word tokens ✓

- Semantically meaningful
- Modular, composable

character tokens ✗

DNA tokens ✗

visual "tokens" ?

- Does **hard attention** make sense?
- Does caching a representation for every "token" of data make sense?

Albert Gu says:

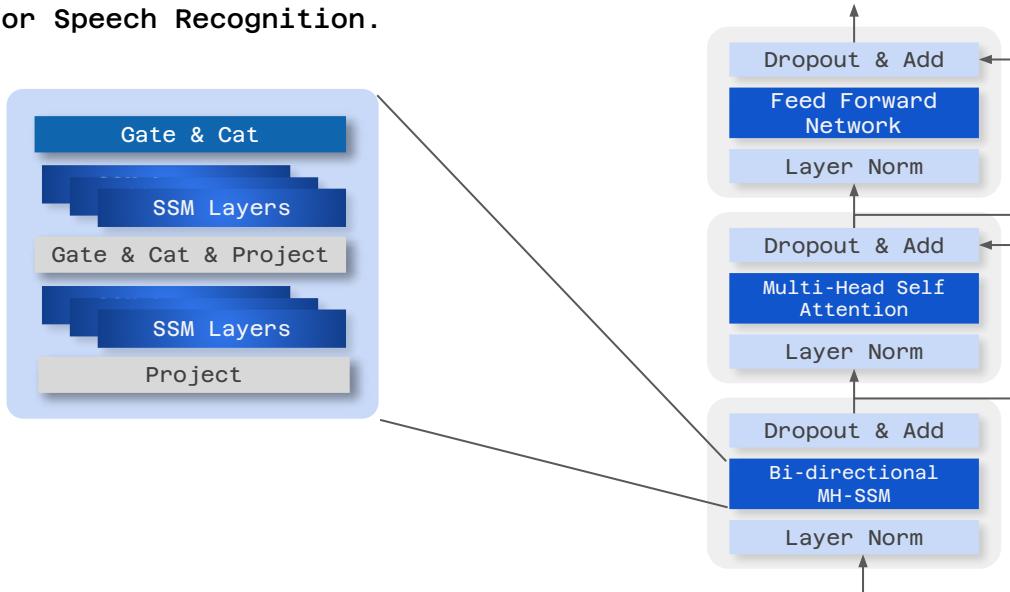
Attention is only effective on
pre-compressed data at the
"right level of abstraction"

[1] Gu, Albert. "On the Tradeoffs of State Space Models and Transformers." *AI Heard That! ICML 2025 Workshop on Machine Learning for Audio*, 27 July 2025

Alternative Architectures for Long Context ASR

- State-Space Models: SSM for Speech Recognition

Multi-Head SSM for Speech Recognition.



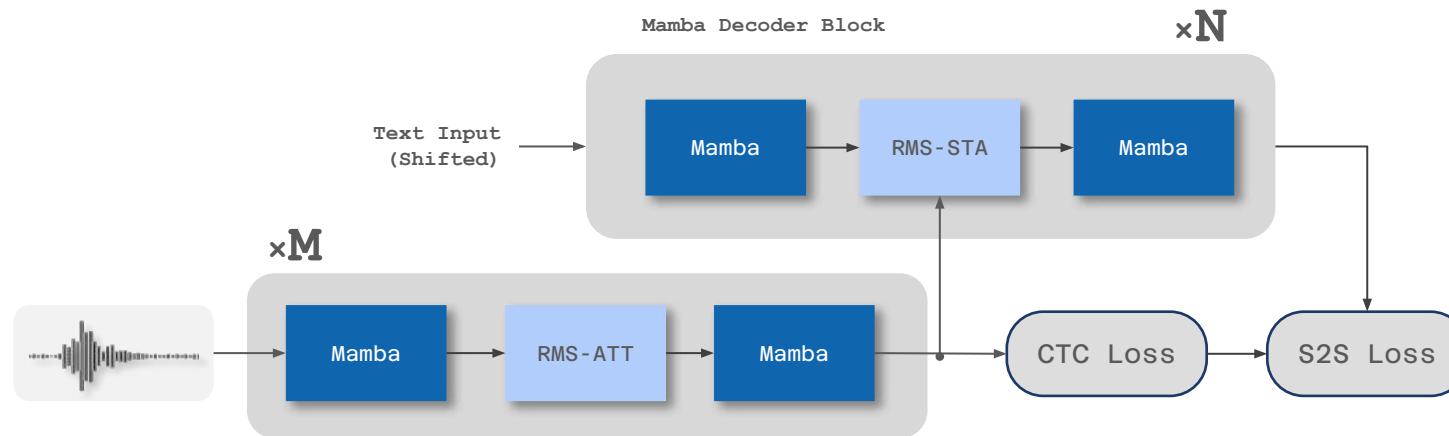
- Drop-in replacement for multihead attention in transformer encoders
- Outperforms the same size transformer transducer

Alternative Architectures for Long Context ASR

- State-Space Models: SSM for Speech Recognition

*RMS-STA: RMS-Norm and source-target multi-head attention

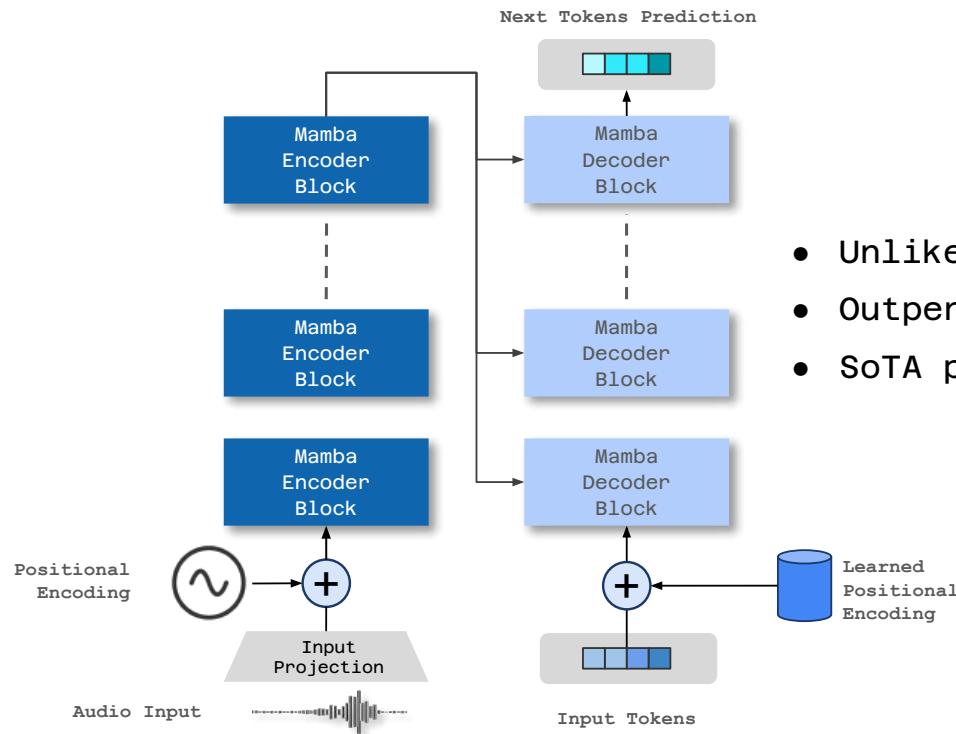
*RMS-ATT: RMS-Norm and multi-head attention



- Incorporates selective SSMs in Transformer architectures with CTC-Loss.
- Outperforms the same size transformer-CTC/Transformer

Alternative Architectures for Long Context ASR

- State-Space Models: SSM for Speech Recognition



- Unlike previous work, fully SSM based model.
- Outperforms the same size Transformer models.
- SoTA performance on public benchmark

Alternative Architectures for Long Context ASR

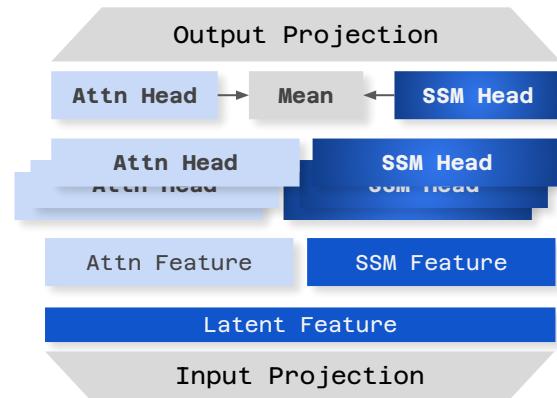
- Hybrid Models? Attention + SSM

1. Mix Mamba-2, Transformer, MLP and self-attentions.
Ablations[1] (130M, 25 Layers) show:

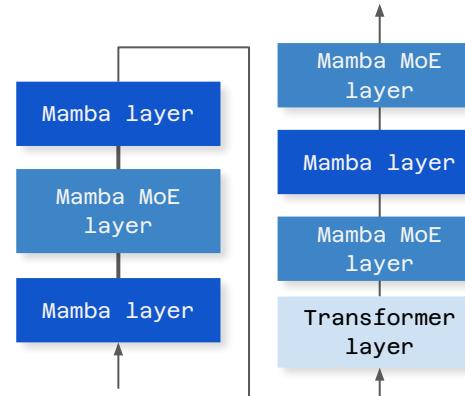
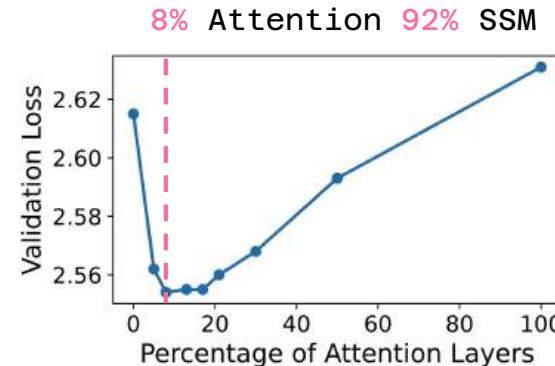
~8% self-attention layers yields the best result.

[1] Waleffe, Roger, et al. "An empirical study of mamba-based language models." arXiv preprint arXiv:2406.07887 (2024).

2. Hybrid Approaches: Attention + SSM



[2] Dong, Xin, et al. "Hymba: A hybrid-head architecture for small language models." arXiv preprint arXiv:2411.13676 (2024).



[3] Lenz, Barak, et al. "Jamba: Hybrid transformer-mamba language models." *The Thirteenth International Conference on Learning Representations*. 2025

Alternative Architectures for Long Context ASR

- Takeaways from SSM

👍 Pros

- 👍 Strengths in time-series data (speech) or non-tokenized data
- 👍 Linear memory scaling - especially efficient at runtime
- 👍 Parameter efficiency in certain types of tasks

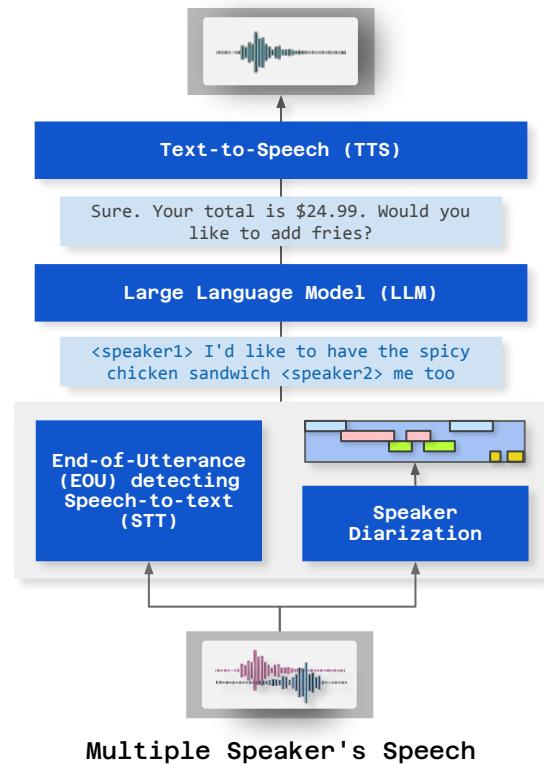
👎 Cons

- 👎 Weak retrieval and recall task performance
- 👎 Underperforms with tokenized data (text) (e.g., Q&A tasks)
- 👎 Less mature; fewer optimized models, tools and silicons than attention-based ones

Voice-agent , Speech-LLM and Acoustic context

Voice-agent, Speech-LLM and Acoustic Context

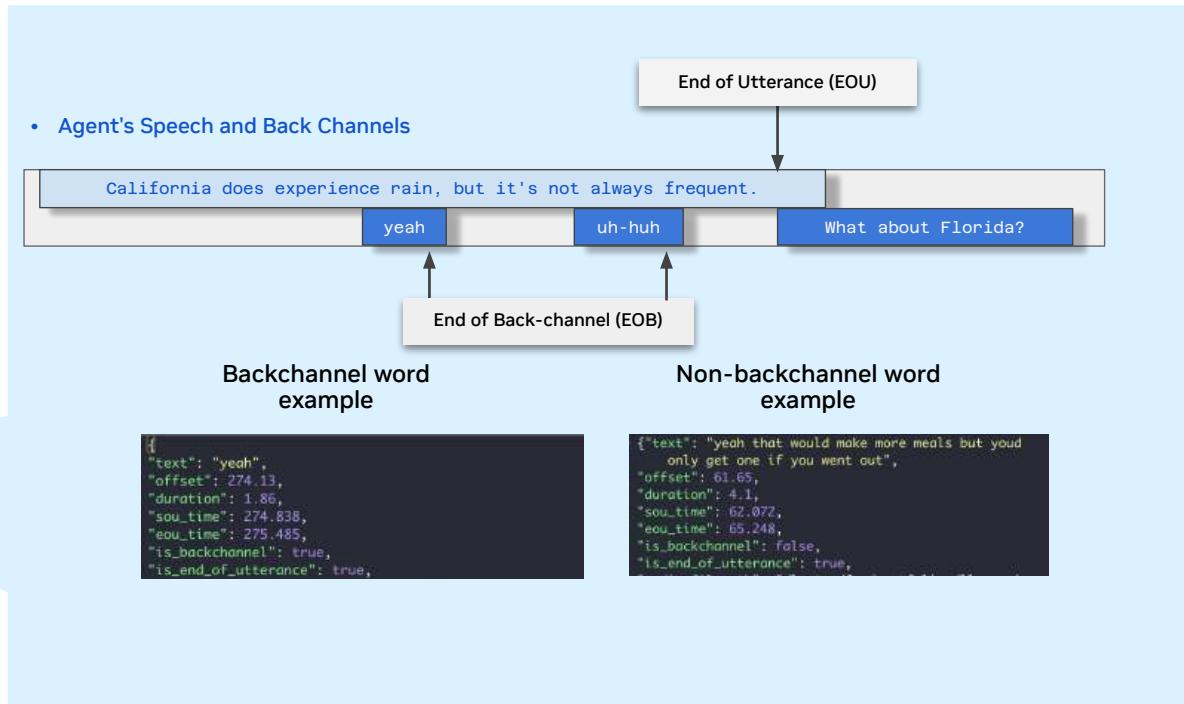
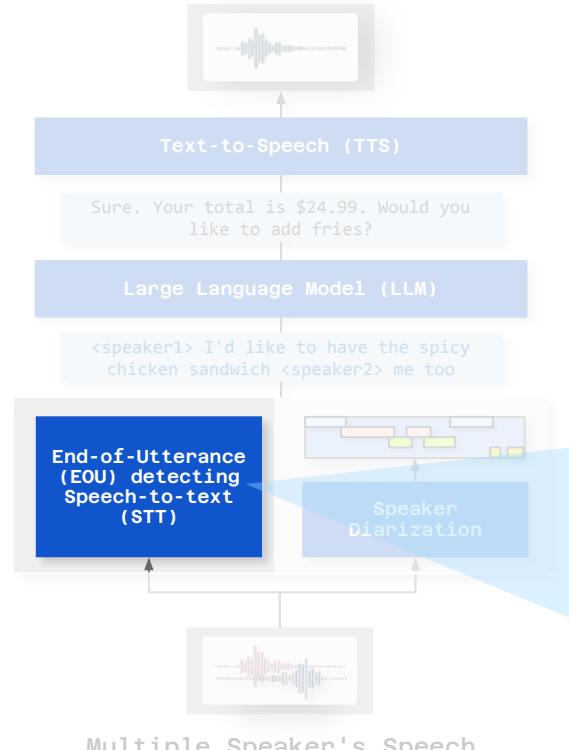
- Modular (EOU-ASR + LLM + TTS) Systems



Voice AI agent Framework : [Pipecat](#)
STT : Speechmatics (ASR + Diarization)
LLM : OpenAI
TTS : Elevenlabs

Voice-agent, Speech-LLM and Acoustic Context

- Modular (EOU-ASR + LLM + TTS) Systems

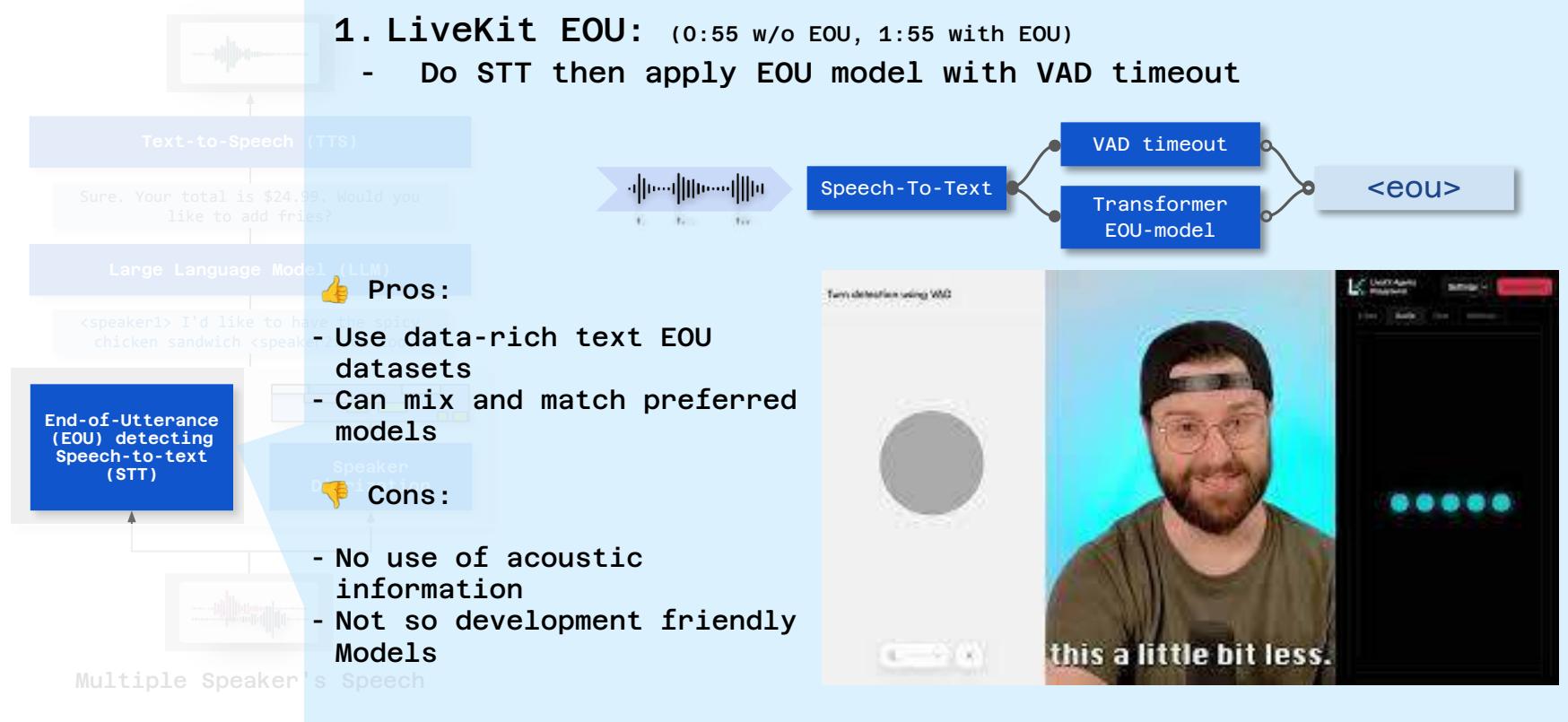


Voice-agent, Speech-LLM and Acoustic Context

- Modular (EOU-ASR + LLM + TTS) Systems

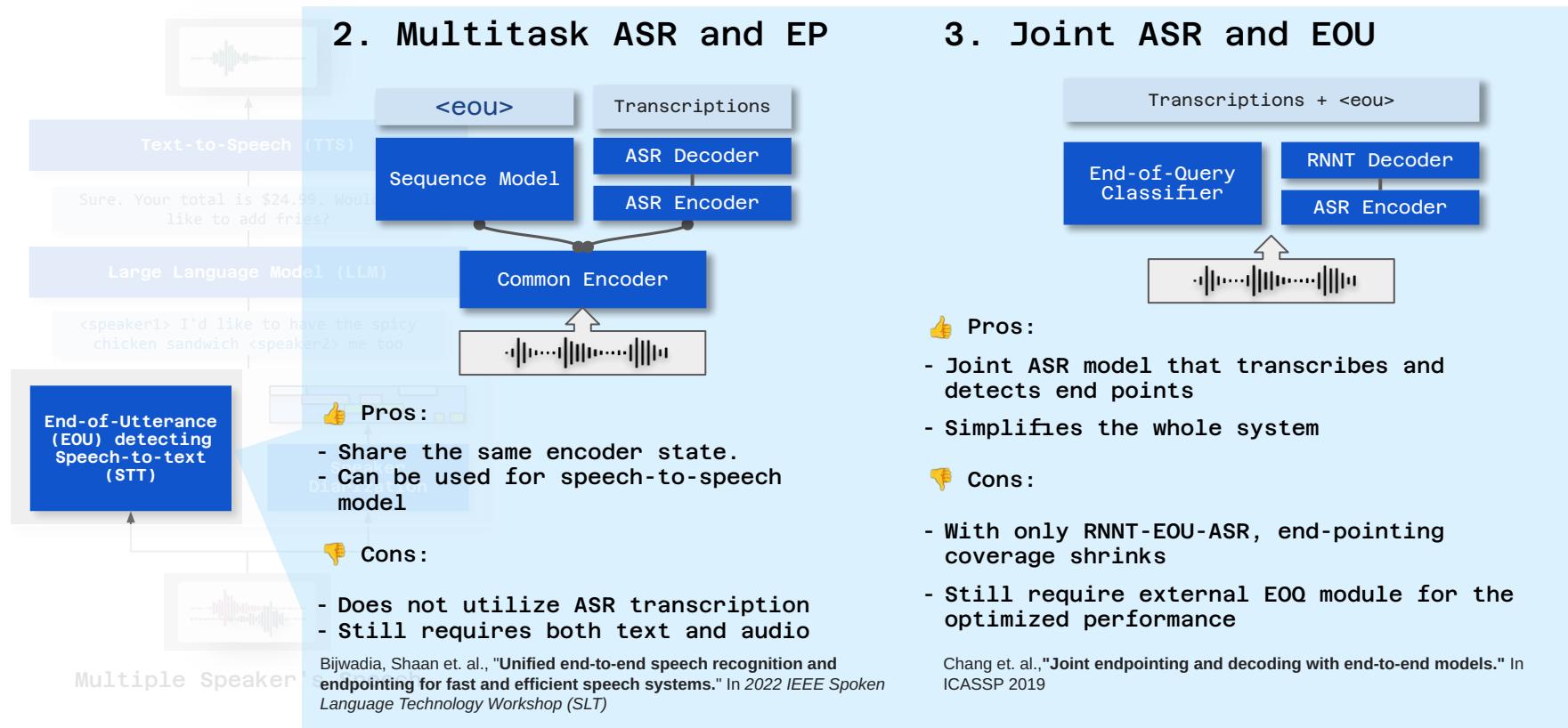
1. LiveKit EOU: (0:55 w/o EOU, 1:55 with EOU)

- Do STT then apply EOU model with VAD timeout



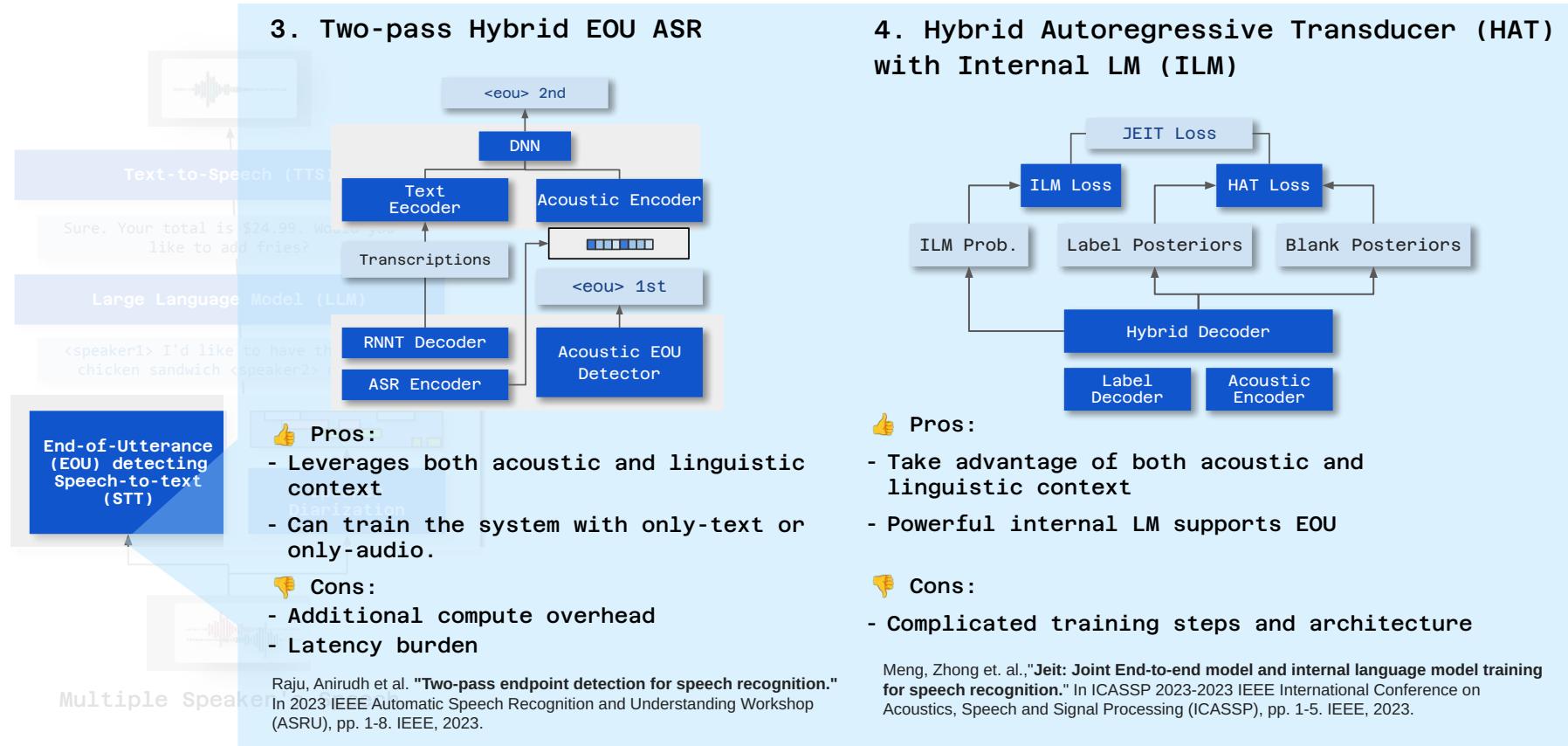
Voice-agent, Speech-LLM and Acoustic Context

- Modular (EOU-ASR + LLM + TTS) Systems



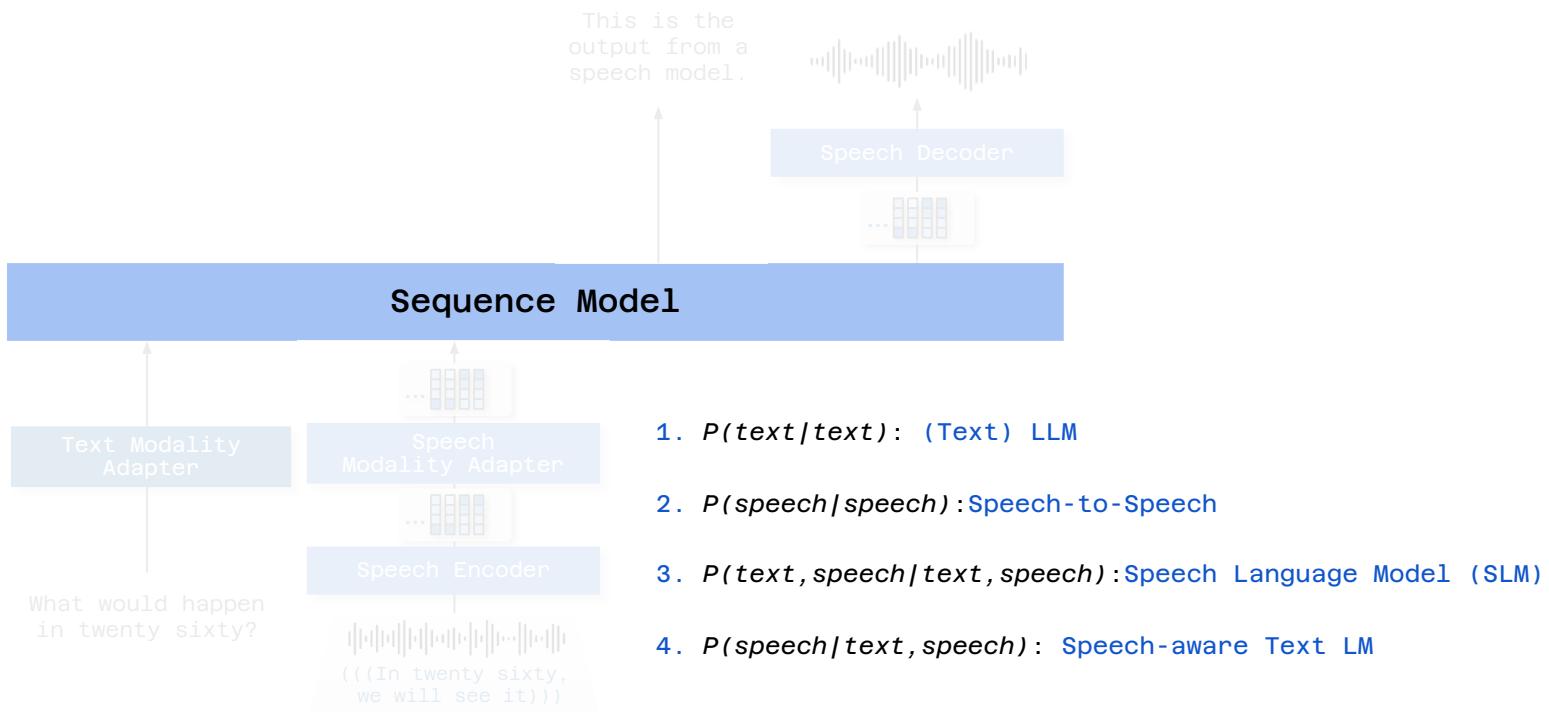
Voice-agent, Speech-LLM and Acoustic Context

- Modular (EOU-ASR + LLM + TTS) Systems



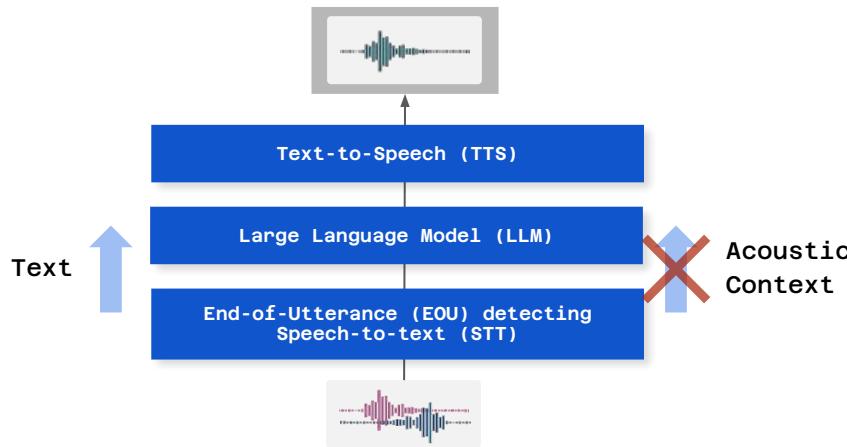
Voice-agent, Speech-LLM and Acoustic Context

- Jointly trained duplex Speech LMs



Voice-agent, Speech-LLM and Acoustic Context

- Jointly trained duplex Speech LMs

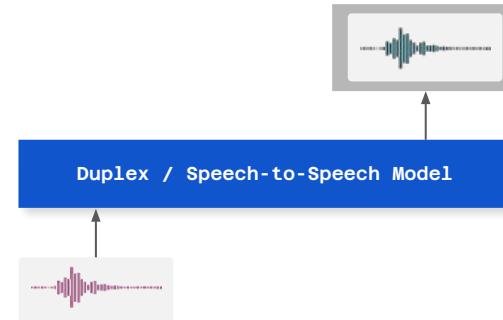


👍 Pros:

- Easily customize LLMs with prompting
- Plug-in different modules (e.g. Diarization)

👎 Cons:

- Compounding errors from ASR → LLM → TTS
- Lack of channel for acoustic and paralinguistic information
- Relatively high latency



👍 Pros:

- Leverages both acoustic and linguistic context
- Relatively Low latency

👎 Cons:

- Hard to customize for the specific need
- Scarcity of the training dataset

Voice-agent, Speech-LLM and Acoustic Context

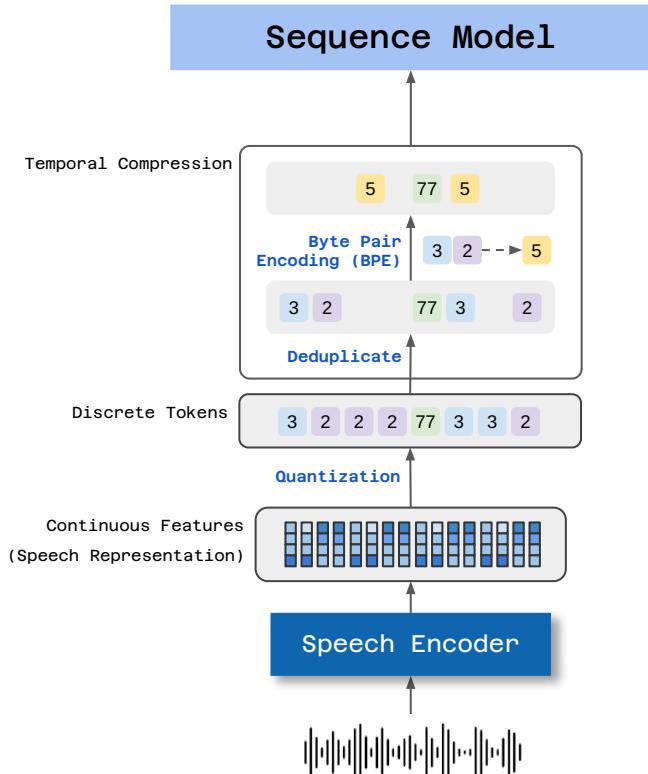
- Jointly trained duplex Speech LMs: Speech Encoder

Continuous Features

1. Spectrogram Features
 - a. Mel-Spec Feature
2. Hidden representations from SSL
 - a. WavLM, Wav2Vec 2.0, HuBERT
3. Hidden representations from ASR models
 - a. Whisper ASR, USM (ASR)
4. Neural audio codecs
 - a. EnCodec, SoundStream

Discrete Tokens

1. Phonetic Tokens - Clustering based
2. Audio Codec Tokens: For more detailed acoustic context
 - a. Vector Quantization



Défossez, Alexandre, et al. "High Fidelity Neural Audio Compression." *Trans. Mach. Learn. Res.* (2023).

Arora, Siddhant, et al. "On the landscape of spoken language models: A comprehensive survey." arXiv preprint arXiv:2504.08528 (2025).

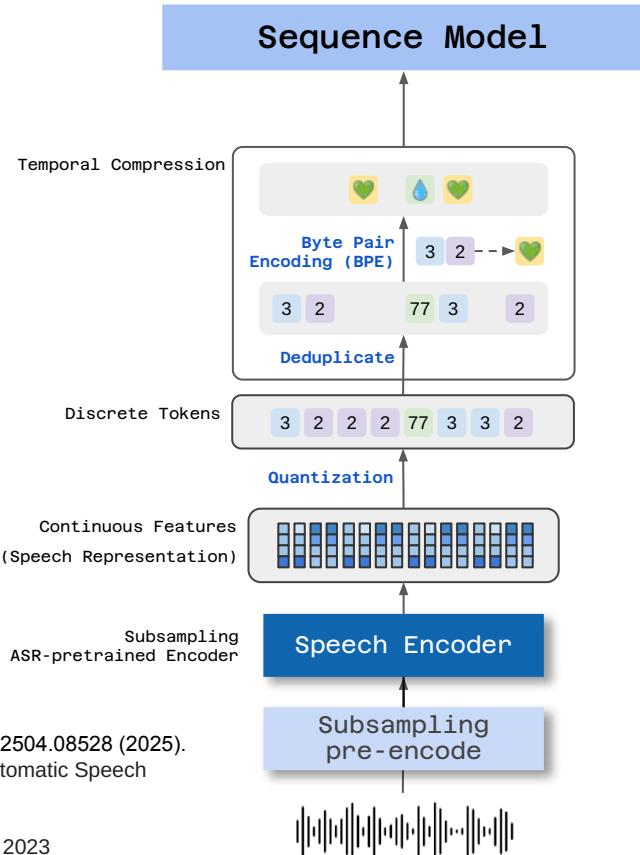
Voice-agent, Speech-LLM and Acoustic Context

- Jointly trained duplex Speech LMs: Speech Encoder

Dealing with a long temporal context

- Speech features have lower information density than text tokens. [1].
- Temporal compression:** efficiency in runtime speed and memory footprint.
- Techniques for reducing the sequence length.
 - Use **subsampling ASR**[2] model as a speech encoder:
→ Use convnet to increase the frame length (10ms → 80ms)
 - Deduplication:** Merges consecutive identical tokens
 - Byte Pair Encoding (BPE):**
 - Merges common co-occurring characters into newly created tokens
 - leverages the morphological information
 - Acoustic BPE[3], Wav2Seq[4]

Diagram from [1]



[1] Arora, Siddhant, et al. "On the landscape of spoken language models: A comprehensive survey." arXiv preprint arXiv:2504.08528 (2025).

[2] Rekesh, Dima, et al. "Fast conformer with linearly scalable attention for efficient speech recognition." 2023 IEEE Automatic Speech Recognition and Understanding Workshop (ASRU). IEEE, 2023.

[3] Shen, Feiyu, et al. "Acoustic bpe for speech generation with discrete tokens." ICASSP 2024

[4] Wu, Felix, et al. "Wav2seq: Pre-training speech-to-text encoder-decoder models using pseudo languages." ICASSP 2023

Speaker-attributed ASR and Long-Context

Takeaways

1. ASR endpointing model plays a crucial role for voice agent.
2. For end point detection ASR taking both acoustic and linguistic context simultaneously.
3. Duplex models also have strength in latency and paralinguistic information but much harder to customize to a specific need.

Table of Contents

Introduction (10 mins) 15:30-15:40

Shinji Speech-to-Text Benchmark
(30 min)
15:40-16:10

Taejin Leveraging Long Acoustic Context
(40 min)
16:10-16:50

Recess (10 min) 16:50-17:00

Huck Semantic Context and Speech-Language Modeling
(40 min)
17:00-17:40

Kyu Contextual Biasing and Methods Leveraging
(30 min) Longer Semantic Context for Speech Systems
17:40-18:10

Closing Remark (10 min) 18:10-18:20

Q&A Session (10 min) 18:20-18:30

10min Recess
16:50-17:00

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	Recess (10 min) 16:50-17:00
Huck (40 min) 17:00-17:40	Semantic Context and Speech-Language Modeling
Kyu (30 min) 17:40-18:10	Contextual Biasing and Methods Leveraging Longer Semantic Context for Speech Systems
	Closing Remark (10 min) 18:10-18:20
	Q&A Session (10 min) 18:20-18:30

Semantic Context and Speech-Language Modeling

Huck Yang

SubTitle of talk

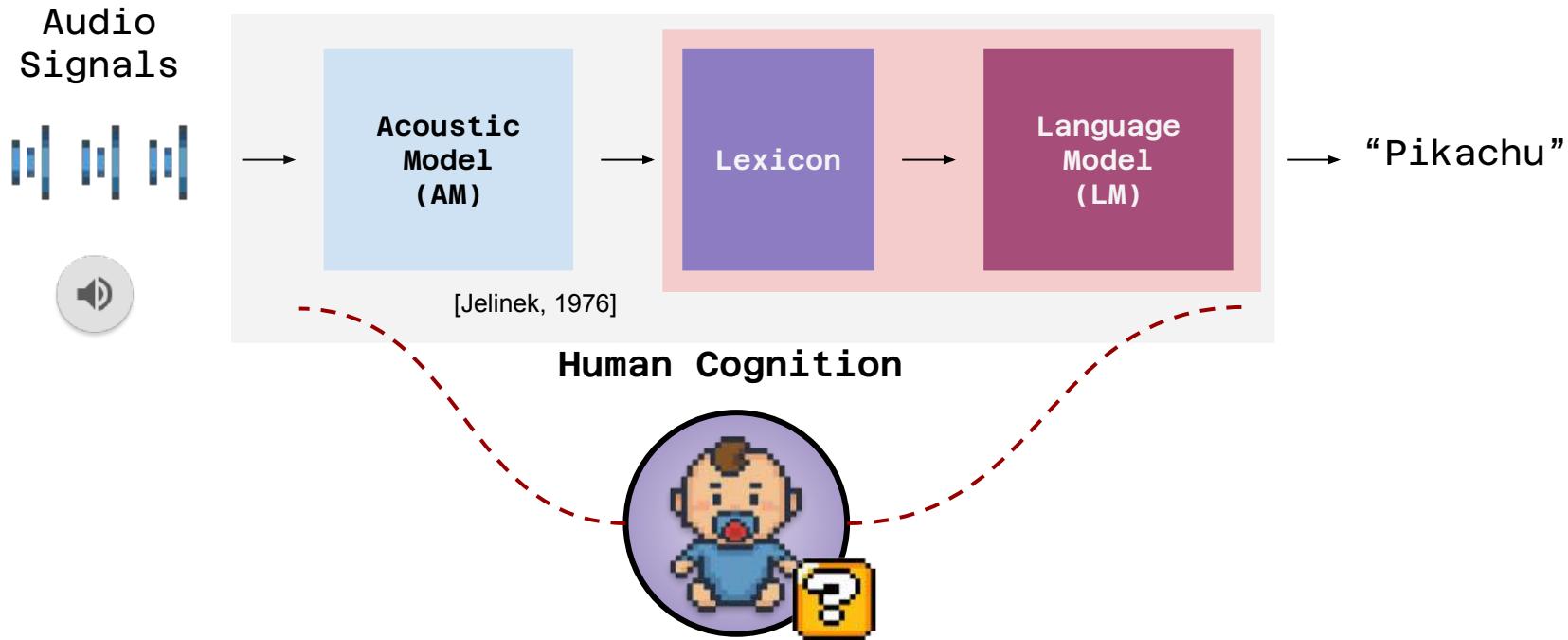
- 1. Semantic Information Modeling in End-to-End ASR**
 - a. Classical ASR-LM
 - b. Post-processing ASR correction mechanism
- 2. Preference-based Semantic Modeling in Post-training**
 - a. LLMs based ASR variants
 - b. Post-training mechanism with RLs
- 3. Semantic Understanding from ASR to Audio Contexts**
 - a. Joint speech and sound semantic modeling (BELU)
 - b. Multimodal QA with non-linguistic semantics
- 4. Limitation and New Evaluation of Semantic Modeling**
 - a. Data Leakage via Text Pre-training
 - b. Agentic and Instruction Evaluation



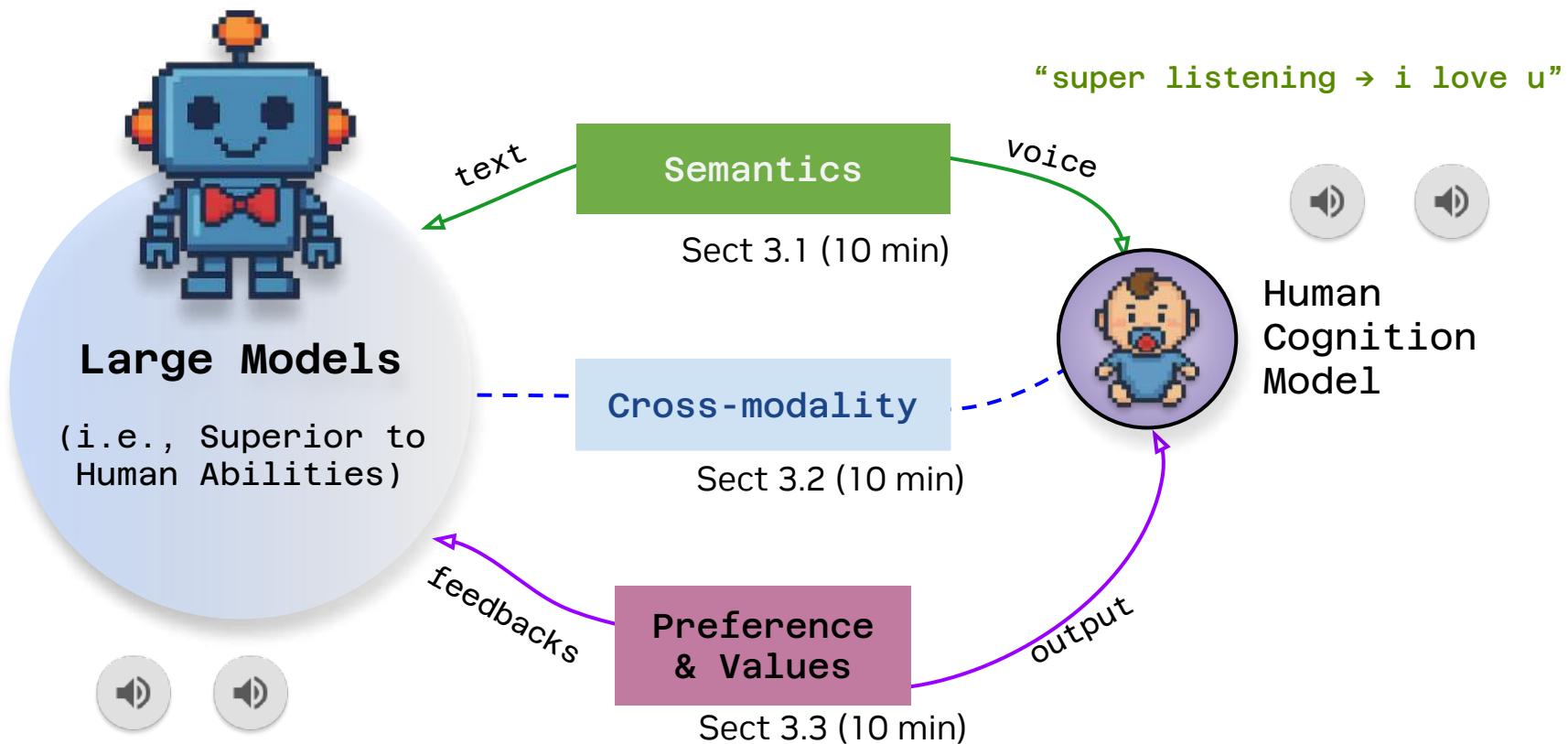
Speech-Language Modeling: background of ASR-LM



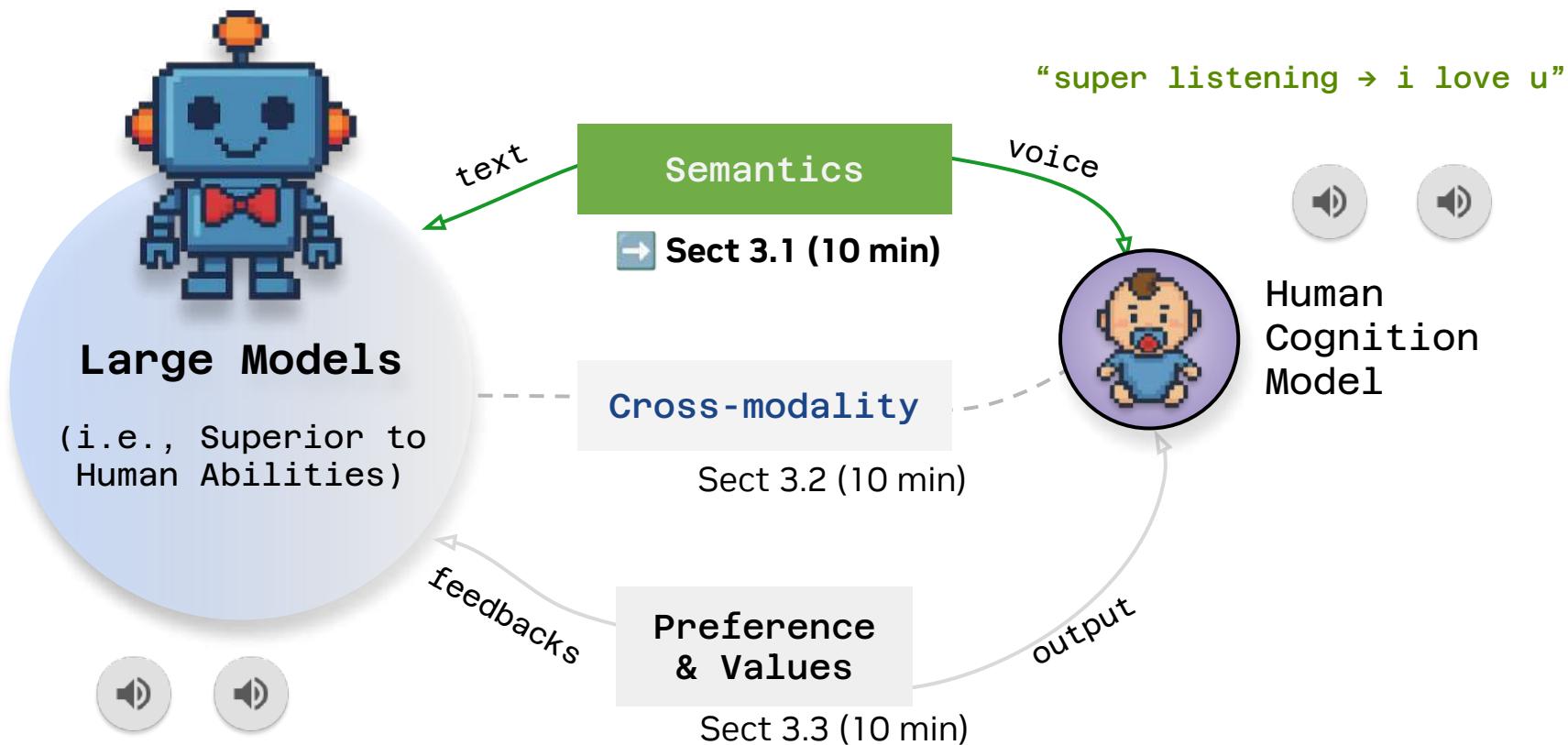
This session with ASR + NLP



Semantic Alignment in Large Models (1/2)

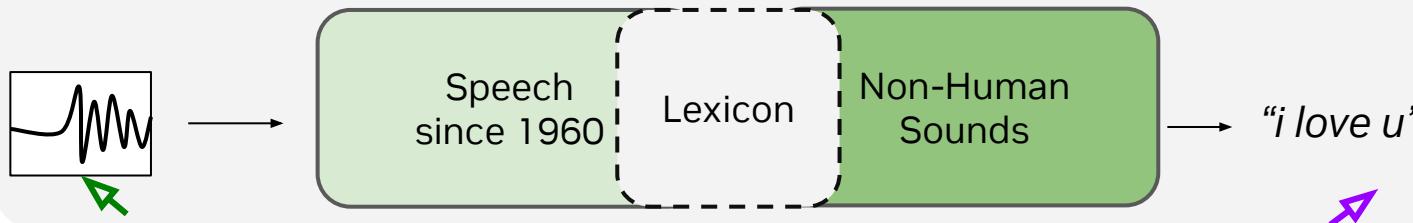


Semantic Alignment in Large Models (1/2)



Semantic Alignment in Large Models (2/2)

From ASR to Voice Understanding & Communication Pipeline



(1) Semantic Modeling

(2) Audio Modality Injection

Large Language
Models (LLMs)

(3) Preference (RL)
Post-Training

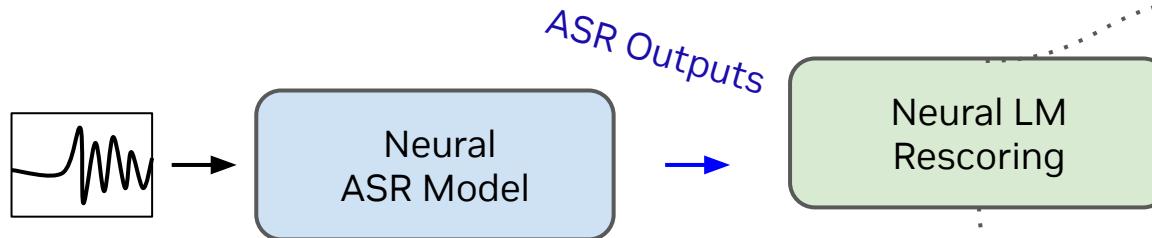
3.1 - Background (1/2) Semantic modeling in ASR-LM

- Language Model (LM) Rescoring over Decoding Outputs (e.g., Utterance Levels)
 - To modify **negative log-likelihood (NLL) scores** from acoustic model (AM)

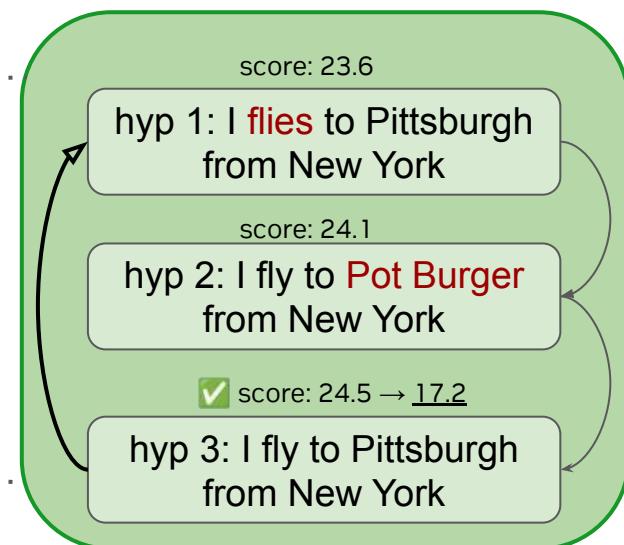
$$\hat{W} = \underset{W}{\operatorname{argmax}} \left[\log P_{\text{AM}}(W|X) + \lambda \cdot \log P_{\text{LM}}(W) \right]$$

ASR words output

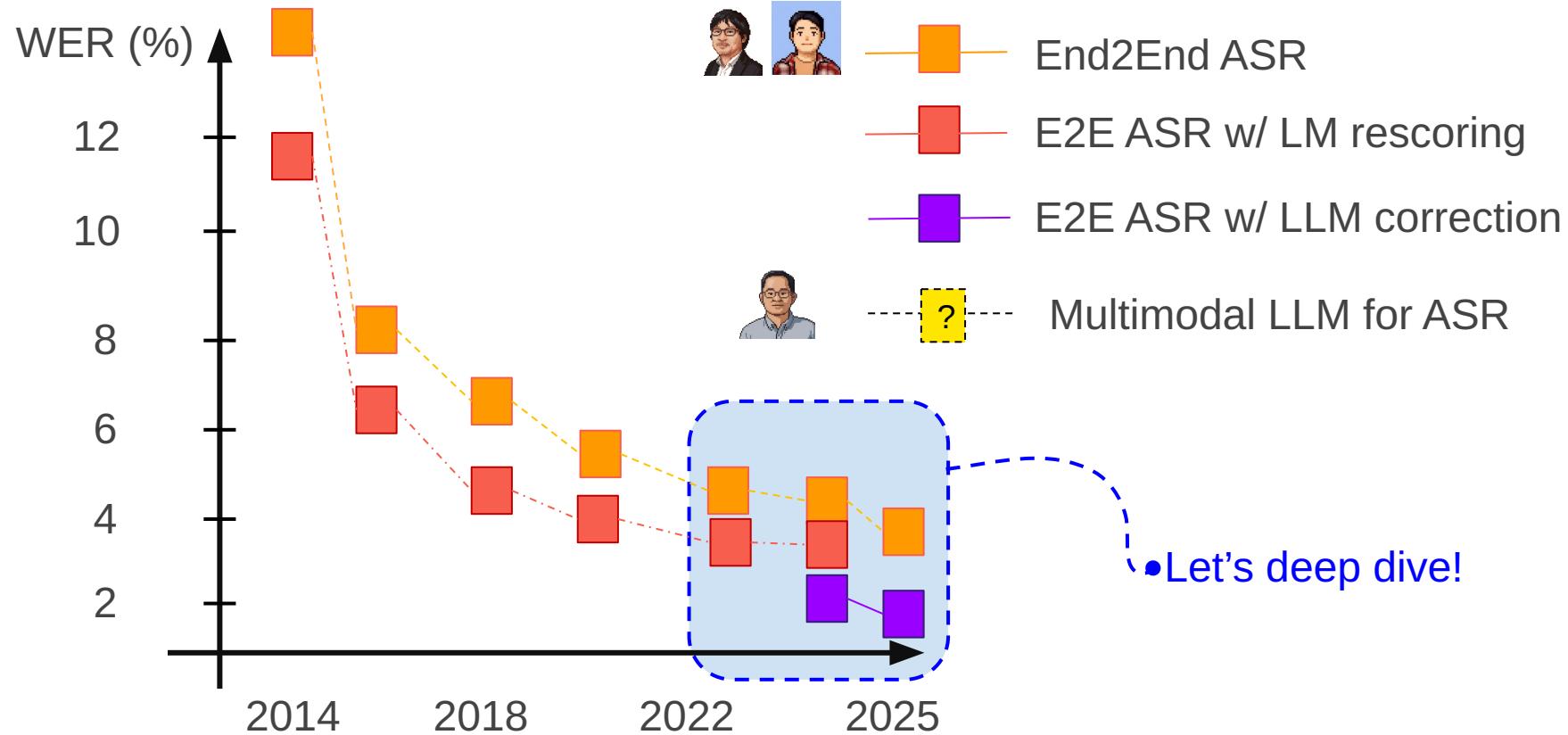
NLL from AM to the word utterance (W)



- Multi-task LM and NLU training for ASR [ASRU 2021]
- Contextualization and Retrieval (see Part 4)



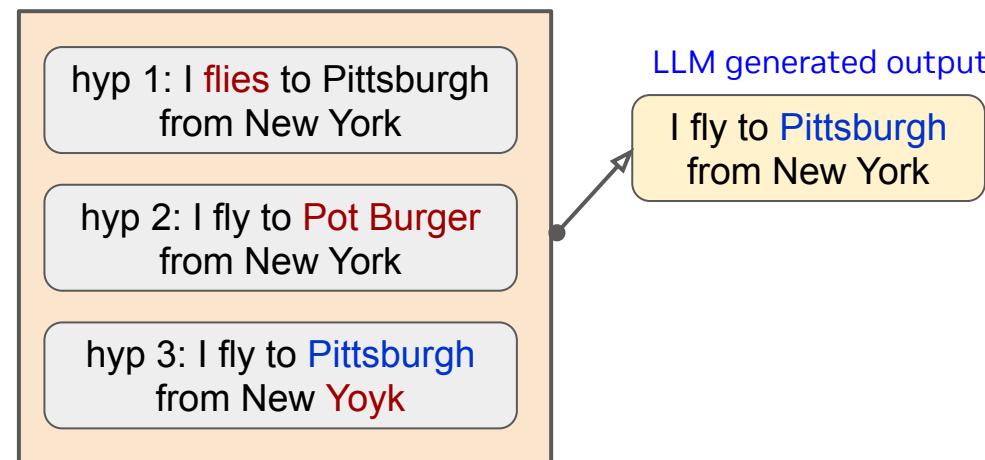
3.1 - Background (2/2) - End2End ASR vs ASR-LM



3.1 - Can ASR-LLM beyond ASR correction?

From human recognition to grounded texts

- Input: N -best decoding hypotheses
 - Output: Re-constructed 1 -*best* transcription (i.e., ASR, MT, OCR)
- **Discriminative** Modeling
- ◆ Utterances Re-Ranking
- **Generative** Modeling (GER)
- ◆ Many-to-One Utterance Generation



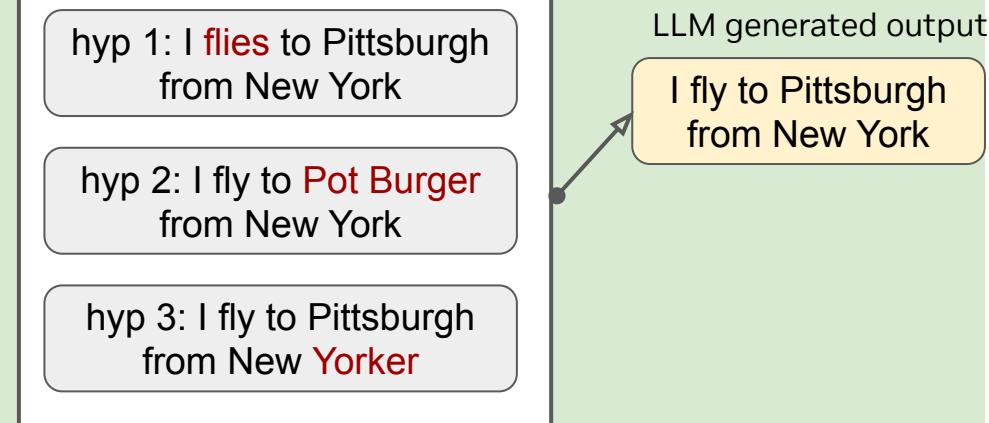
Yang et al. ASRU 23
Chen et al. NeurIPS 23

Generative Semantics Modeling (1/3) Post-ASR LM

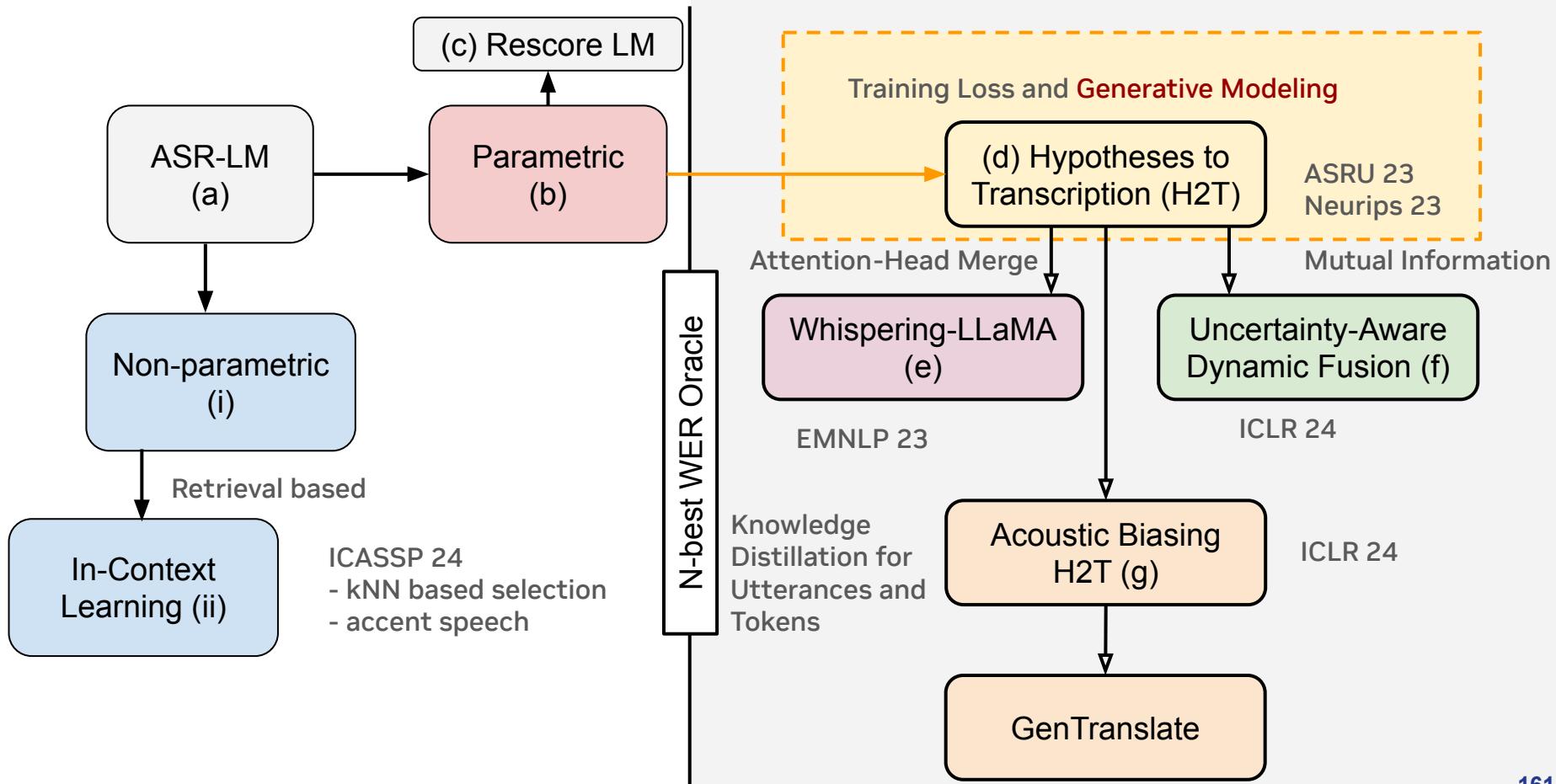
- **Discriminative** Modeling
 - Utterances Re-Ranking



- **Generative** Modeling (ours)
 - Many-to-One Utterance Generation

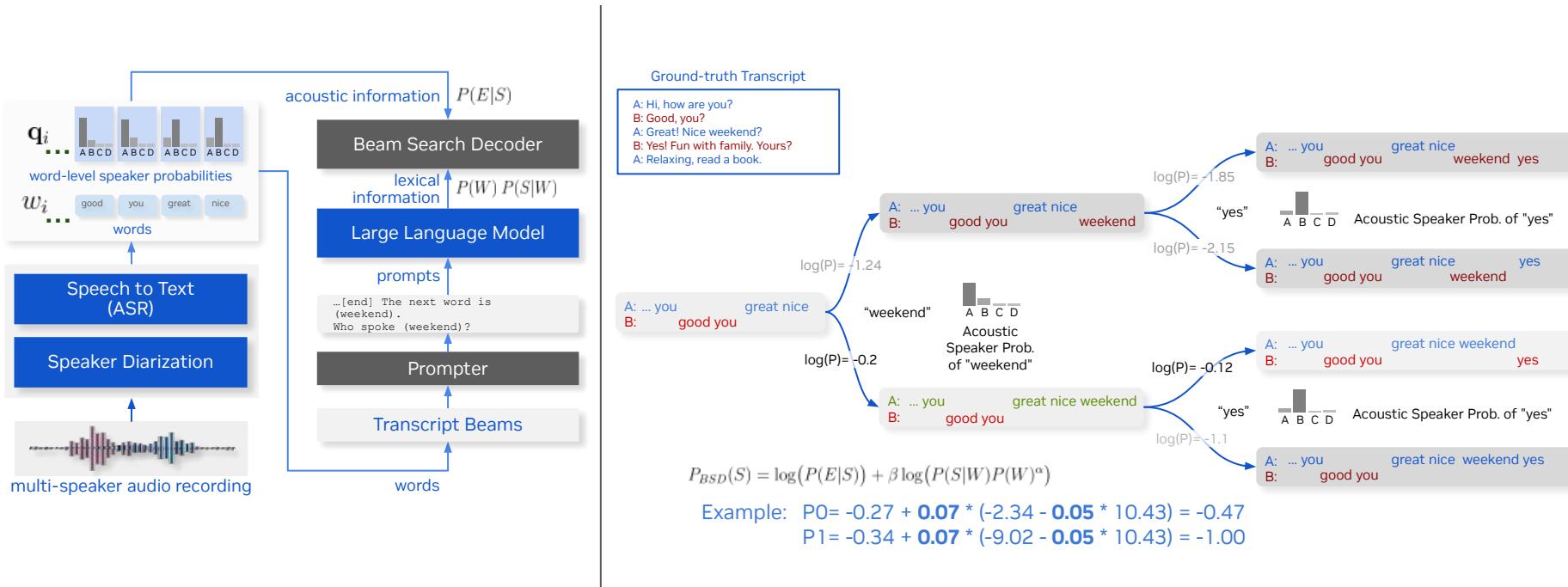


3.2 Roadmap of ASR-LLM (2022 to 24)



Post-ASR Correction (2/3) Multi-Speakers

- Multi-speaker ASR Correction with LLM - Without Fine-tuning LLMs



Post-ASR Correction (3/3) Multi-Speakers LMs

- Multi-speaker ASR Correction with LM - By Fine-tuning LLMs

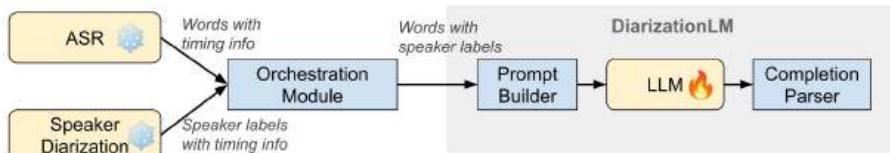
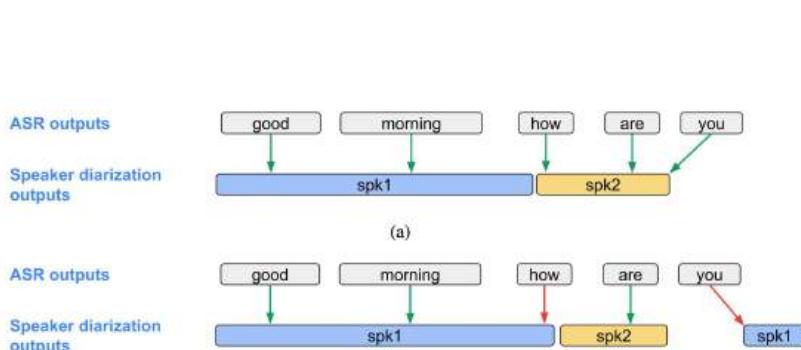


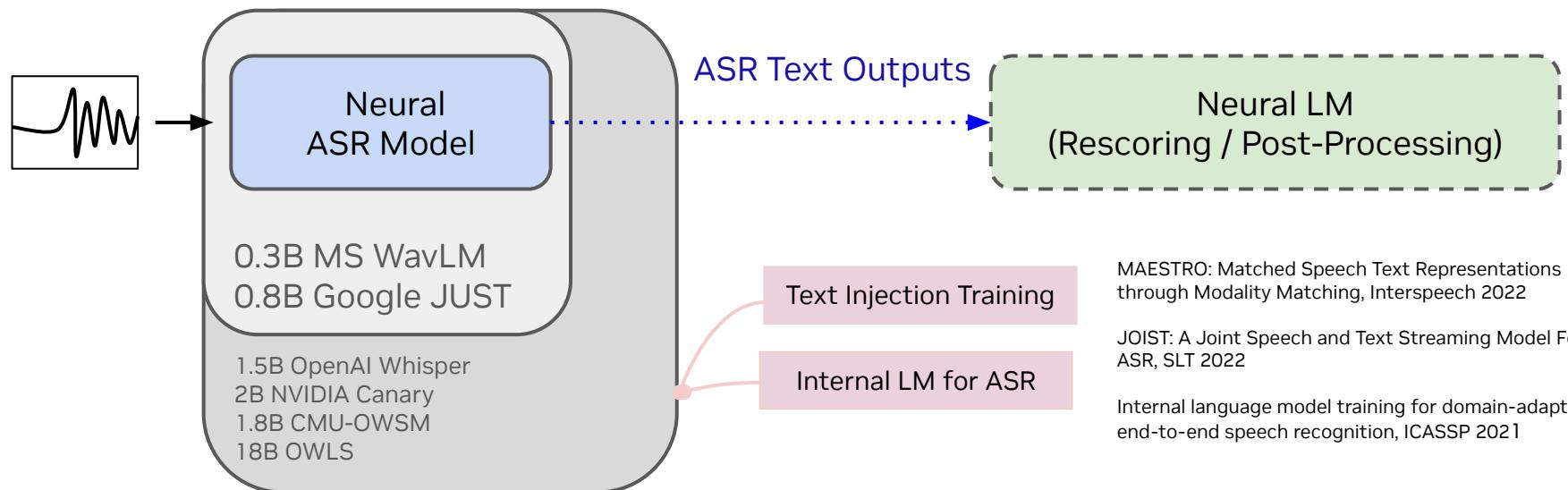
Figure 2: Diagram of the proposed DiarizationLM framework.

Example text representation of the prompt

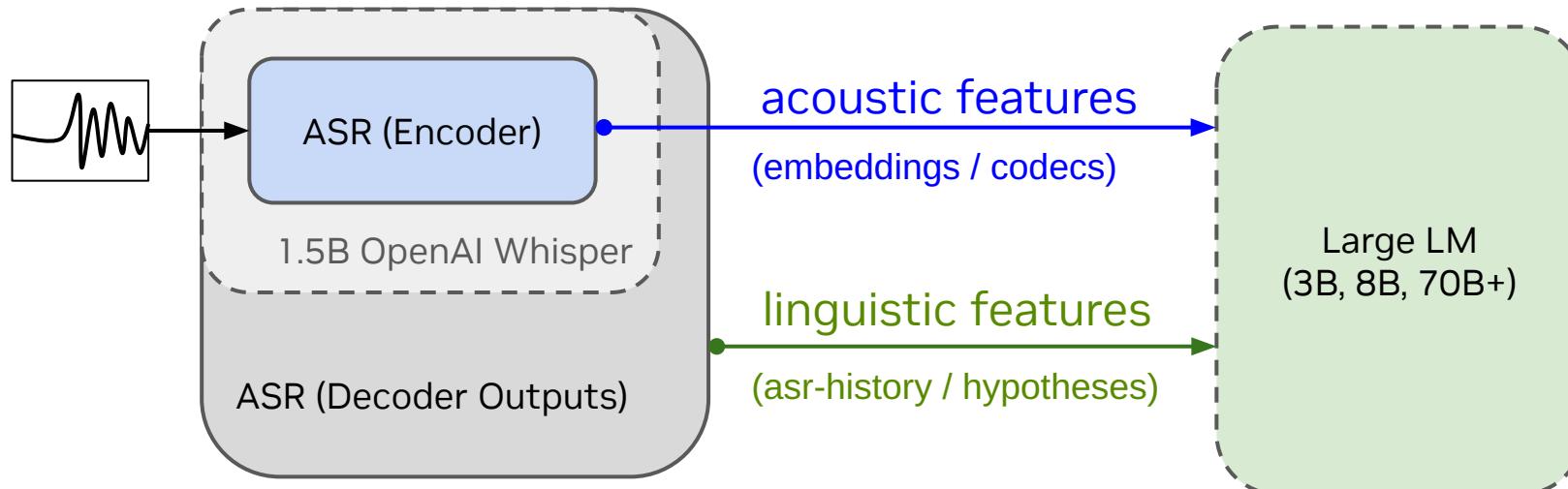
```
Word sequence: ["good", "morning", "how", "are", "you"]
Speaker sequence: [1, 1, 2, 2, 2]
Text representation: "<spk:1> good morning <spk:2> how are you"
```

3.1 - ASR-LM Designs (1/2) from 2017 to 2023

- Do we really need a cascaded LM in end-to-end **streaming ASR** model?
 - **Arguments:** “*Transformer-Transducer based ASR-decoder already contains contextual information*”



3.1 - ASR-LLM Designs (2/2) from 2023 to now



Agentic ASR-LLM
→ best performance

Task-activating ASR-LLM [ASRU 23]
Whispering-LLaMA [EMNLP 23]
GenTranslate [ACL 24]
NeKo MoE [ACL 25]

Duplex SpeechLM
→ real time interaction

SoundStorm, Google 2023
Moshi, Kyutai 2024
Synchronous LLMs [EMNLP 24]

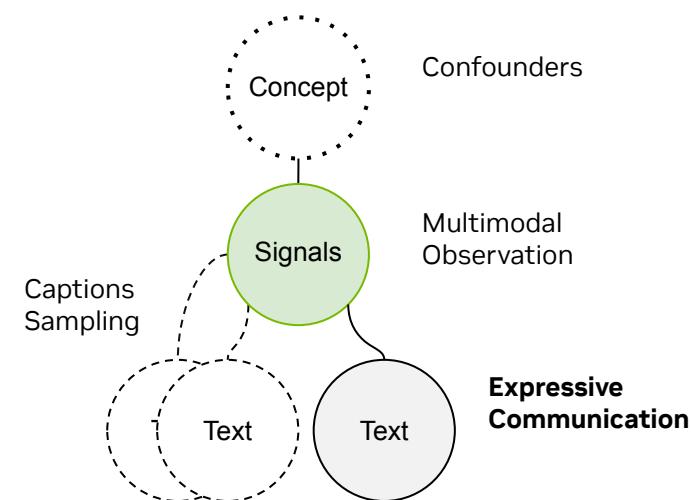
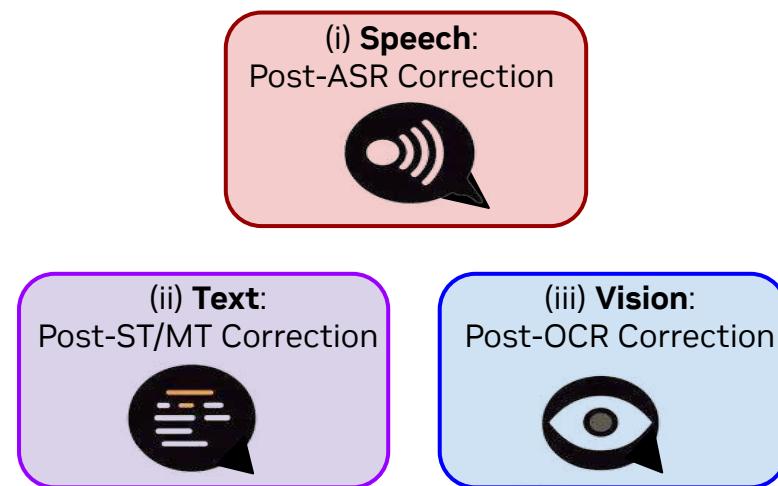
Audio-Injector LM
→ multi-task modeling

SALMON [ICLR 24]
AudioFlamingo [ICML 24]
LLaMA-3.1, Meta 2024
Gemma, Google 2024
Canary-Qwen, NVIDIA 2025

3.1 - Can ASR-LLM beyond ASR correction?

- X-to-Text Communication Tasks with “**Grounded Transcription**”
 - Automatic Speech Recognition (**ASR**)
 - Multilingual Speech Translation (**ST**) and Machine Translation (**MT**)
 - Optical character recognition (**OCR**)

Generalized Cross-modal N-best correction



EMNLP 24 Y. Hirota et al.
EMNLP 23 D. Chan et al.

ACL 24 Y. Hu et al.
ASRU 23 C.-H. Yang et al.

3.1 - Can ASR-LLM beyond ASR correction?

- Input: N -best decoding hypotheses
- Output: Re-constructed 1-best transcription (i.e., ASR, MT, OCR)

(a) Human Recognition



(b) Generative Understanding



SC Levinson and N Evans Time for a sea-change in linguistics: Response to comments on
“The myth of language universals”, Lingua, 2010

3.1 - Can ASR-LLM beyond ASR correction?

→ Word Error Rate (the lower; the better)

(i) Speech to Text



Domain Shift	Test Set	Baseline	GPT-3.5 Turbo		Claude-Opus		0-shot w/ NEKO			Oracle N-best
			0-shot	5-shot	0-shot	5-shot	NEKO-FFT	NEKO-BTX	NEKO-MoE	
Specific Scenario	WSJ-dev93	9.0	8.5 _{-5.6%}	7.7 _{-14.4%}	8.2 _{-8.9%}	7.4 _{-17.8%}	8.6 _{-4.4%}	7.5 _{-16.7%}	6.8 _{-24.4%}	6.5
	WSJ-eval92	7.6	7.3 _{-3.9%}	6.6 _{-13.2%}	7.0 _{-7.9%}	6.3 _{-17.1%}	7.4 _{-2.6%}	6.4 _{-15.8%}	5.8 _{-23.7%}	5.5
	ATIS	5.8	5.5 _{-5.2%}	5.0 _{-13.8%}	5.2 _{-10.3%}	4.7 _{-19.0%}	5.6 _{-3.4%}	4.8 _{-17.2%}	4.2 _{-27.6%}	3.5
Common Noise	CHiME4-bus	18.8	17.6 _{-6.4%}	16.2 _{-13.8%}	17.1 _{-9.0%}	15.7 _{-16.5%}	17.7 _{-5.9%}	15.9 _{-15.4%}	14.5 _{-22.9%}	16.8
	CHiME4-caf	16.1	14.7 _{-8.7%}	13.7 _{-14.9%}	14.2 _{-11.8%}	13.2 _{-18.0%}	14.8 _{-8.1%}	13.4 _{-16.8%}	12.2 _{-24.2%}	13.3
	CHiME4-ped	11.5	10.9 _{-5.2%}	9.7 _{-15.7%}	10.5 _{-8.7%}	9.3 _{-19.1%}	11.0 _{-4.3%}	9.5 _{-17.4%}	8.6 _{-25.2%}	8.5
	CHiME4-str	11.4	10.9 _{-4.4%}	9.7 _{-14.9%}	10.5 _{-7.9%}	9.3 _{-18.4%}	11.0 _{-3.5%}	9.4 _{-17.5%}	8.5 _{-25.4%}	9.0
Speaker Accent	MCV-af	25.3	24.9 _{-1.6%}	23.6 _{-6.7%}	24.4 _{-3.6%}	23.0 _{-9.1%}	25.0 _{-1.2%}	23.3 _{-7.9%}	21.0 _{-17.0%}	23.6
	MCV-au	25.8	25.1 _{-2.7%}	24.0 _{-7.0%}	24.6 _{-4.7%}	23.4 _{-9.3%}	25.2 _{-2.3%}	23.7 _{-8.1%}	21.4 _{-17.1%}	24.9
	MCV-in	28.6	27.6 _{-3.5%}	25.0 _{-12.6%}	27.0 _{-5.6%}	24.3 _{-15.0%}	27.8 _{-2.8%}	24.6 _{-14.0%}	22.2 _{-22.4%}	27.1
	MCV-sg	26.4	26.5 _{+0.4%}	25.1 _{-4.9%}	25.9 _{-1.9%}	24.5 _{-7.2%}	26.6 _{+0.8%}	24.7 _{-6.4%}	22.3 _{-15.5%}	25.5

3.1 - Can ASR-LLM beyond ASR correction?

(i) **Speech to Text**



→ Word Error Rate (the lower; the better)

Model	Inference Para.	Avg. ↓	AMI	Earnings22	Gigaspeech	LS Clean	LS Other	SPGI	Tedium	Voxp.	MCV9
ASR or SpeechLMs: End-to-end Voice Understanding Models											
Distil-Whisper-V2-L (Gandhi et al., 2023)	0.75B	8.31	14.65	12.12	10.31	2.95	6.39	3.28	4.30	8.22	12.60
Whisper-V2-L (Radford et al., 2022)	1.5B	8.06	16.82	12.02	10.57	2.56	5.16	3.77	4.01	7.50	10.11
Canary (NVIDIA, 2024)	2B	6.67	14.00	12.25	10.19	1.49	2.49	2.06	3.58	5.81	7.75
Bestow Speech LM (Chen et al., 2024c)	1.8B	6.50	12.58	12.86	10.06	1.64	3.07	2.11	3.41	5.84	6.97
Qwen2-Audio (Chu et al., 2024)	8B	7.43	-	-	-	1.6	3.6	-	-	-	-
Gemini-2.0-Flash	-	8.56	-	-	-	-	-	-	-	-	-
ASR+LLM: Frozen Whisper-v2-L (1.5B) + Voice Correction LMs											
+ Gemma 2B (Team et al., 2024) FFT	3.5B (2B)	6.61	13.20	12.30	10.40	1.60	2.60	2.20	3.70	6.00	7.50
+ Gemma 8x2B FFT	3.5B (2B)	6.51	13.10	12.20	10.30	1.50	2.50	2.10	3.60	5.90	7.40
+ NEKO (Ours) Gemma 8x2B	3.5B (2B)	6.41	13.00	12.10	10.20	1.40	2.40	2.00	3.50	5.80	7.30
+ NEKO (Ours) Qwen1.5-MoE	4.2B (2.7B)	5.90	12.60	11.82	9.95	1.30	2.32	1.94	3.20	5.80	7.30
+ Mistral 7B (Jiang et al., 2023) FFT	8.5B (7B)	6.40	13.07	11.87	10.09	1.48	2.46	2.04	3.55	5.75	7.29
+ Mixtral 8x7B (Jiang et al., 2024b) FFT	8.5B (7B)	6.51	12.91	12.19	10.34	1.54	2.55	2.12	3.64	5.89	7.43
+ Mixtral 8x7B Lora	8.5B (7B)	6.60	12.96	12.24	10.38	1.55	2.56	2.13	3.66	5.92	7.47
+ Mistral 8x7B BTM (Sukhbaatar et al., 2024)	8.5B (7B)	6.43	13.13	11.93	10.14	1.49	2.47	2.05	3.57	5.78	7.33
+ NEKO (Ours) Mixtral 8x7B	8.5B (7B)	6.34	12.55	11.82	10.02	1.49	2.47	2.05	3.52	5.76	7.25
+ NEKO (Ours) Mixtral 8x22B	23.5B (22B)	6.40	12.61	11.93	10.15	1.52	2.51	2.09	3.58	5.82	7.33

3.1 - Can ASR-LLM beyond ASR correction?

(ii) Text to Text



Cascaded agentic LLMs

En→X	FLEURS							CoVoST-2				MuST-C			
	Es	Fr	It	Ja	Pt	Zh	Avg.	Fa	Ja	Zh	Avg.	Es	It	Zh	Avg.
End-to-end ST Methods															
SeamlessM4T-Large (Barrault et al., 2023a)	23.8	41.6	23.9	21.0	40.8	28.6	30.0	18.3	24.0	34.1	25.5	34.2	29.9	16.2	26.8
GenTranslate (Hu et al., 2024c)	25.4	43.1	25.5	28.3	42.4	34.3	33.2	21.1	29.1	42.8	31.0	33.9	29.4	18.5	27.3
SeamlessM4T-Large-V2 (Barrault et al., 2023b)	23.8	42.6	24.5	21.7	43.0	29.5	30.9	16.9	23.5	34.6	25.0	32.1	27.5	15.6	25.1
GenTranslate-V2 (Hu et al., 2024c)	25.5	44.0	26.3	28.9	44.5	34.9	34.0	19.4	29.0	43.6	30.7	32.2	27.3	18.1	25.9
Cascaded ASR+MT Methods															
Whisper + NLLB-3.3b (Costa-jussà et al., 2022)	25.1	41.3	25.0	19.0	41.5	23.5	29.2	13.6	19.0	32.0	21.5	35.3	29.9	13.5	26.2
SeamlessM4T-Large (ASR+MT) (Barrault et al., 2023a)	24.6	44.6	25.4	22.5	41.9	31.2	31.7	18.8	24.0	35.1	26.0	35.1	30.8	17.7	27.9
SeamlessM4T-V2 (ASR+MT) (Barrault et al., 2023b)	24.7	44.1	25.1	20.6	43.6	30.6	31.5	17.4	23.8	35.4	25.5	33.0	27.8	14.5	25.1
Cascaded ASR+GEC Methods															
GenTranslate	26.8	45.0	26.6	29.4	43.1	36.8	34.6	21.8	30.5	43.3	31.9	35.5	31.0	19.6	28.7
GenTranslate-V2	27.0	44.3	26.4	27.8	44.5	36.1	34.4	20.8	29.7	43.5	31.3	33.2	28.3	16.9	26.1
NEKO-Gemma-2B-FT	26.9	44.2	26.3	27.7	44.4	36.0	34.3	20.7	29.6	43.4	31.2	33.1	28.2	16.8	26.0
NEKO-Gemma-8x2B-BTX	27.2	44.5	26.7	28.0	44.7	36.3	34.6	21.0	29.9	43.8	31.6	33.4	28.5	17.1	26.3
NEKO-Gemma-8x2B-MoE	28.5	46.2	28.0	30.1	46.3	38.7	36.3	23.4	32.6	46.5	34.2	37.2	32.8	21.5	30.5

NeKo

→ GPT-4o-mini-2411 BLEU CoVoST-2 (~33.2) | MuST-C (~29.2)

3.1 - Vision - OCR Correction

Cascaded agentic LLMs

(iii) **Vision:**

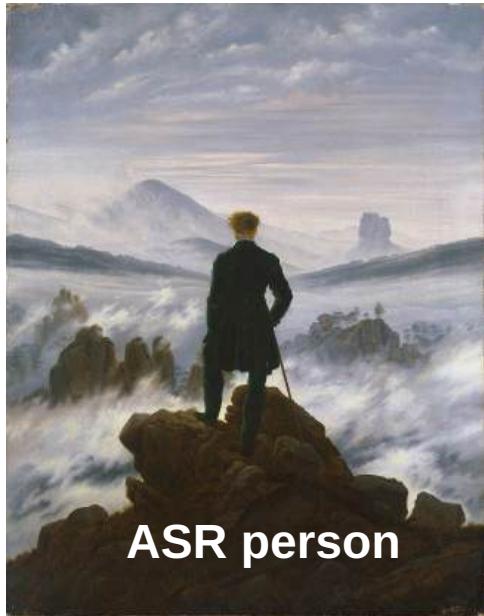
Post-OCR Correction



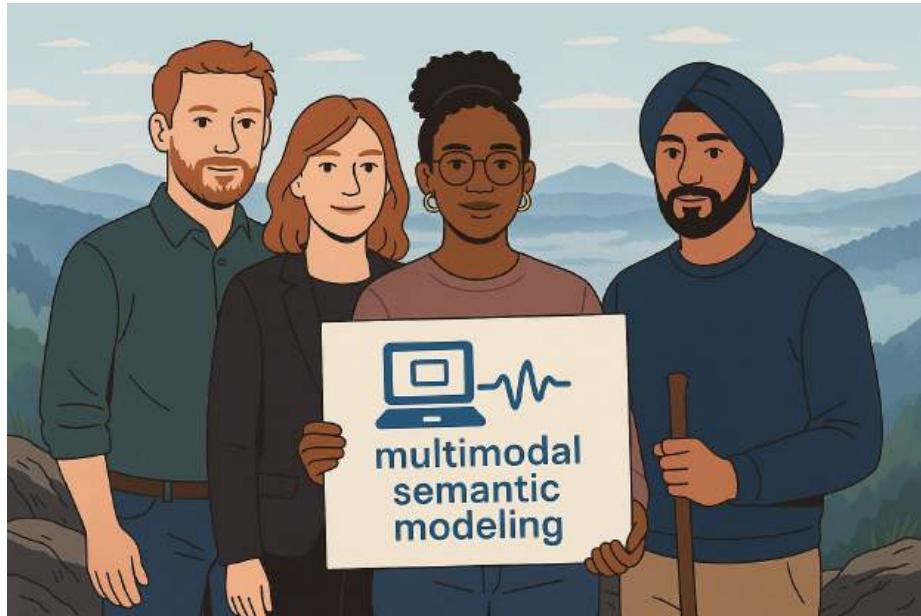
Task / WER ↓	Grammar Correction	Coherence Improv.	OCR
Mixtral-MoE (frozen)	31.41	13.48	71.03
GPT-3.5-turbo	17.43	12.25	39.45
Mixtral-MoE-FFT	10.73	12.05	45.32
NEKO-Mixtral-MoE	9.42	9.71	14.43

NeKo 

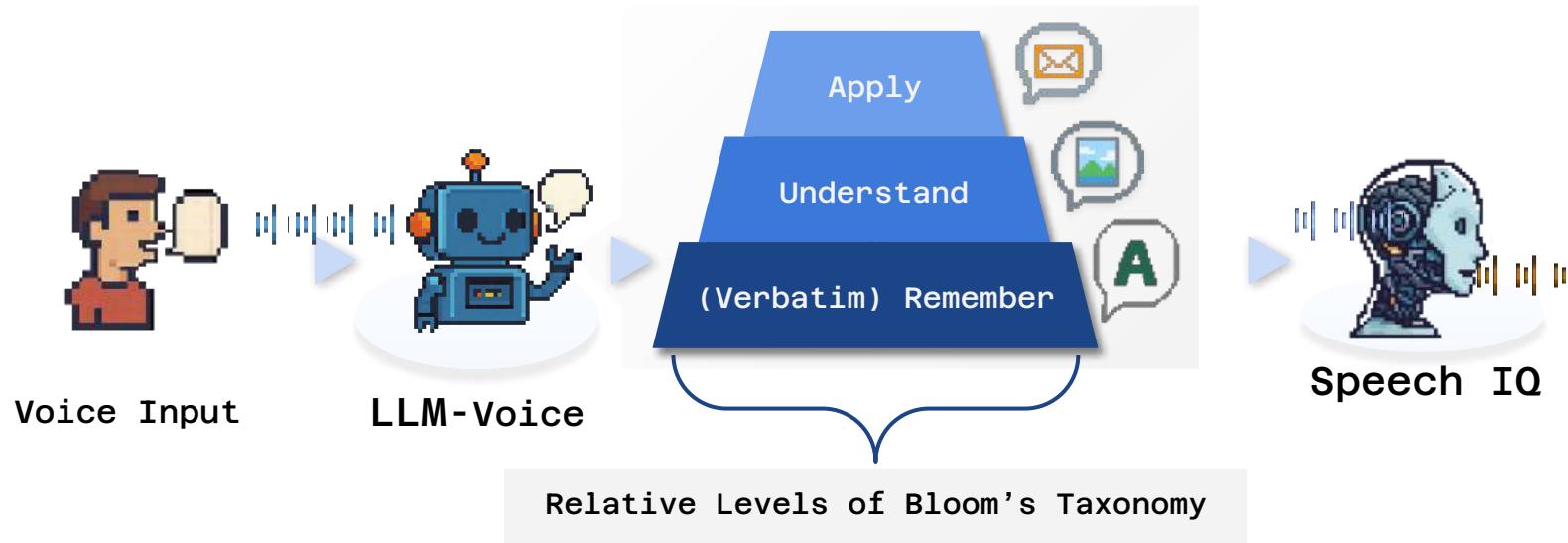
3.1 semantic ASR-LM: what's the next



Der Wanderer über dem Nebelmeer

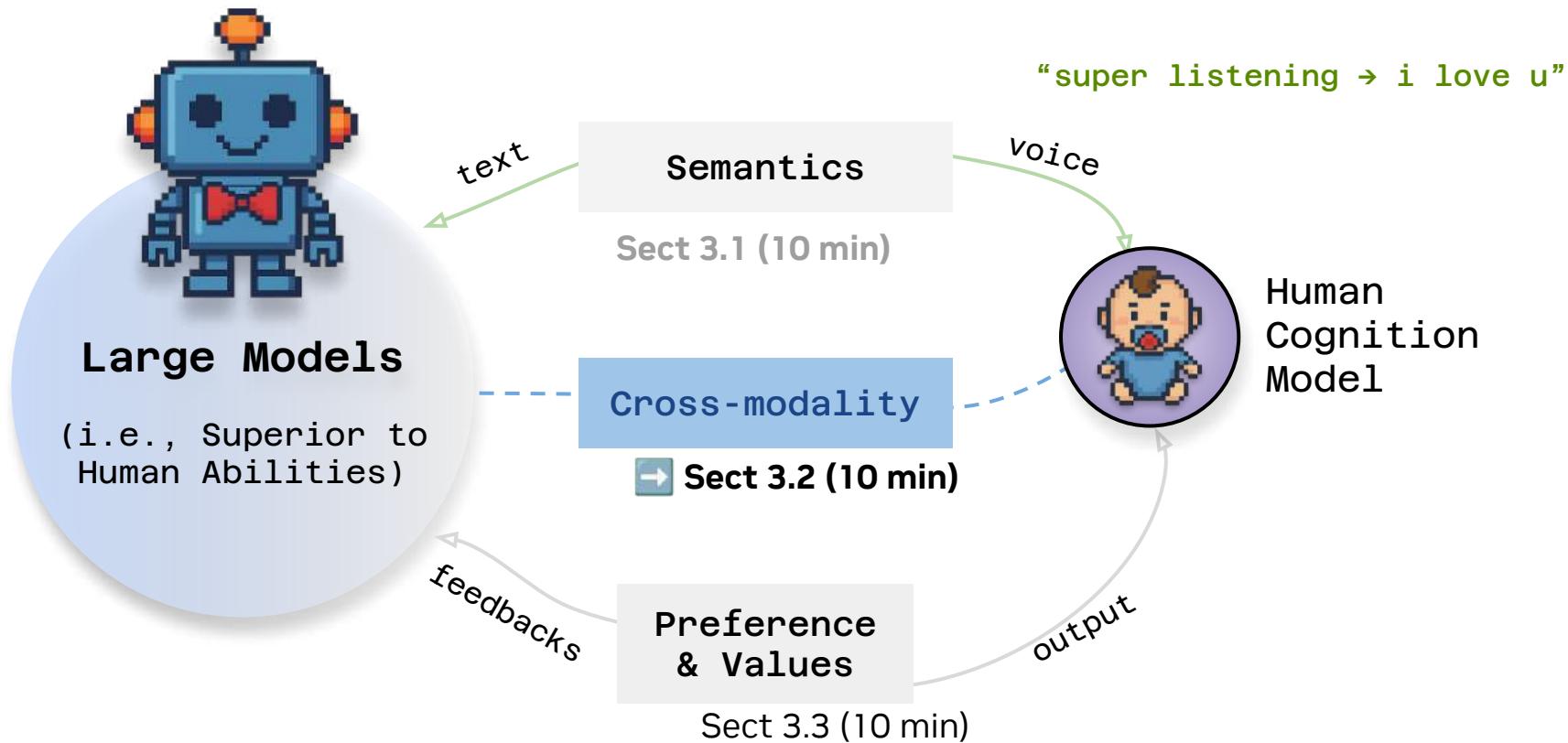


Recent Benchmark-LLM Responses



- **SpeechIQ:** Speech Intelligence Quotient Across Cognitive Levels in Voice Understanding Large Language Models, ACL 2025
- **Dynamic-superb phase-2:** A collaboratively expanding benchmark for measuring the capabilities of spoken language models with 180 tasks, ICLR 2025

Semantic Alignment in Large Models II



3.2 How to Inject Acoustic Info into LLM?

- Hidden **semantic information** in the **audio modality**
 - How to ground sound, accent speech, and music into text?

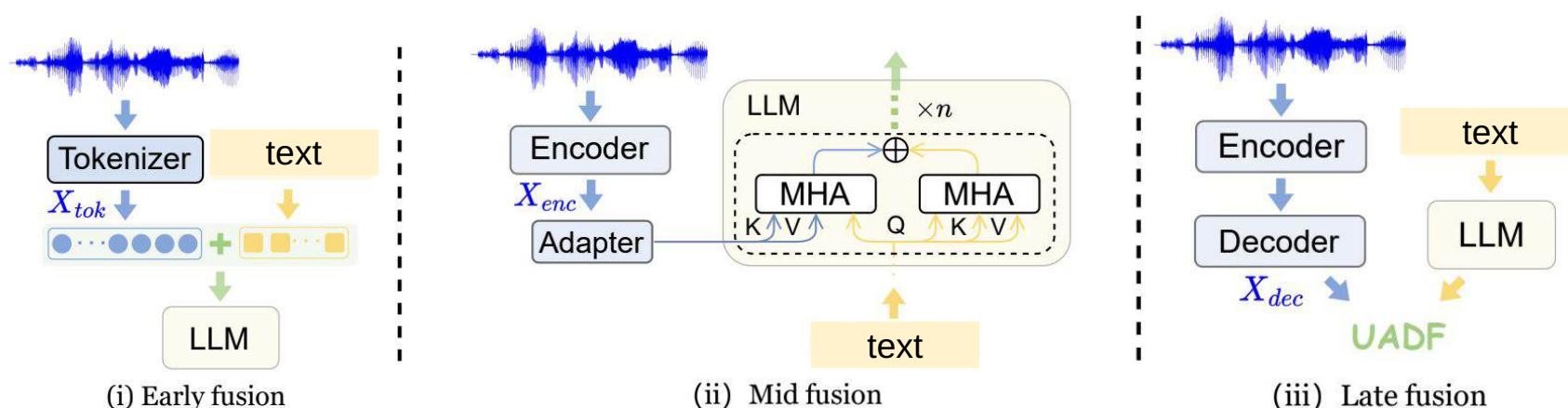
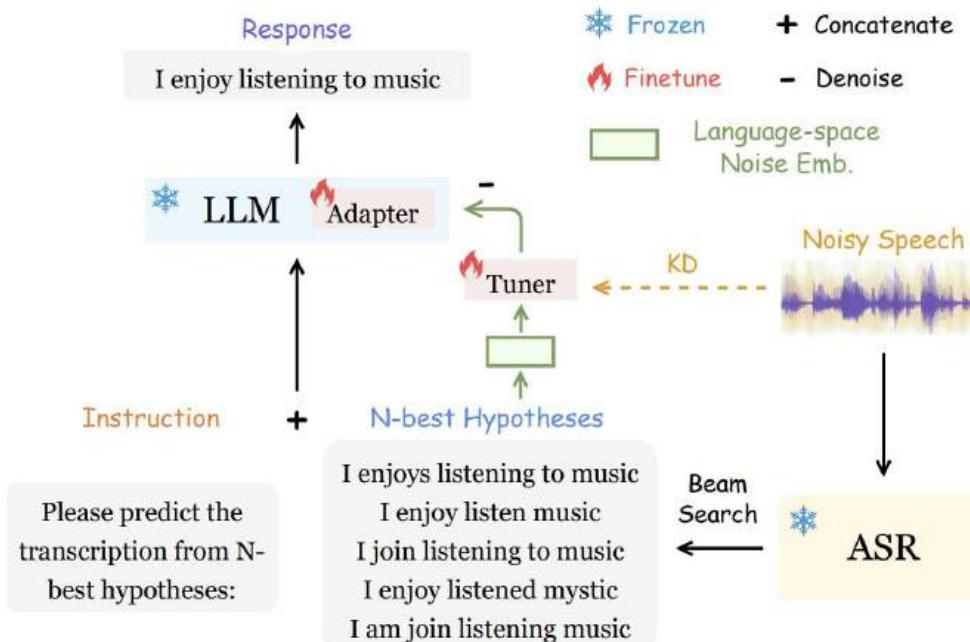


Image Source: It's Never Too Late: Fusing Acoustic Information into Large Language Models for Automatic Speech Recognition, ICLR 24

3.2 Different Semantic Aligned Speech-LMs

- **early fusion:** audio embedding injection into text space
 - Qwen-audio, and most of the audioLMs
 - more post-training fusion methods
- **codec based:** compressing signals into discrete codecs
- **cascaded agent:** audio model chained LM

Generative Semantics Modeling (2/3) Language Denoising



Utterance-level Noise Emb.

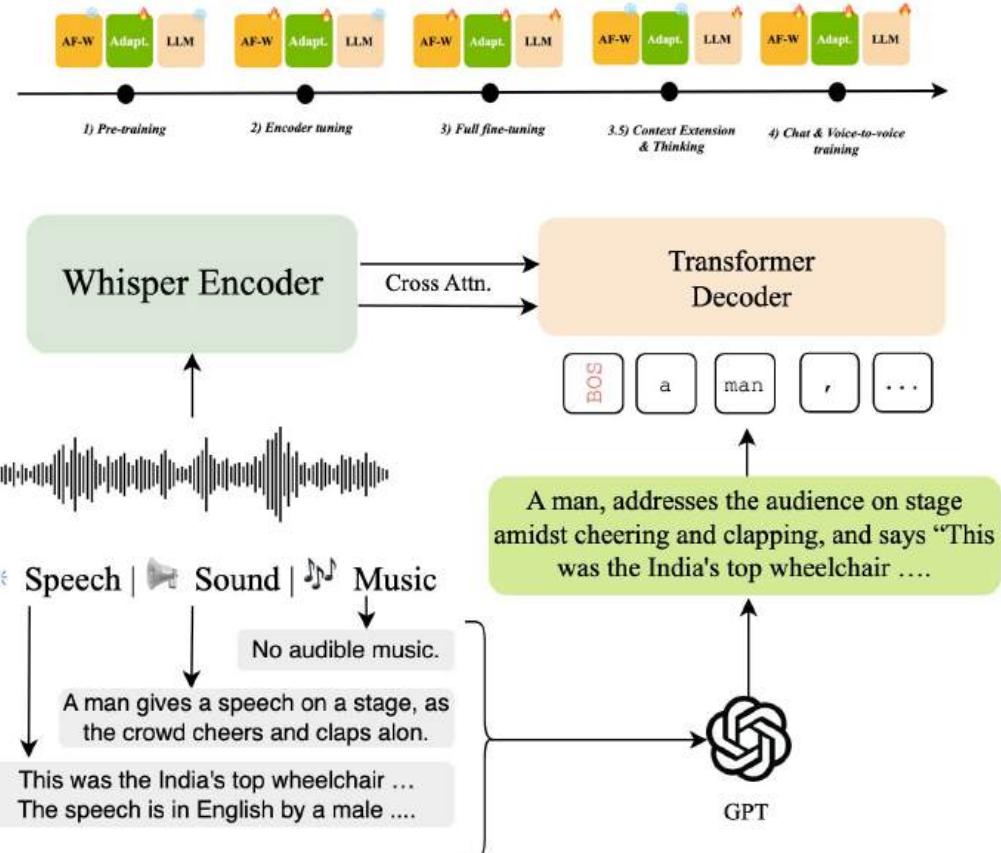
I enjoys listening to music
I enjoy listen music
I join listening to music
I enjoy listened mystic
I am join listening music

Token-level Noise Emb.

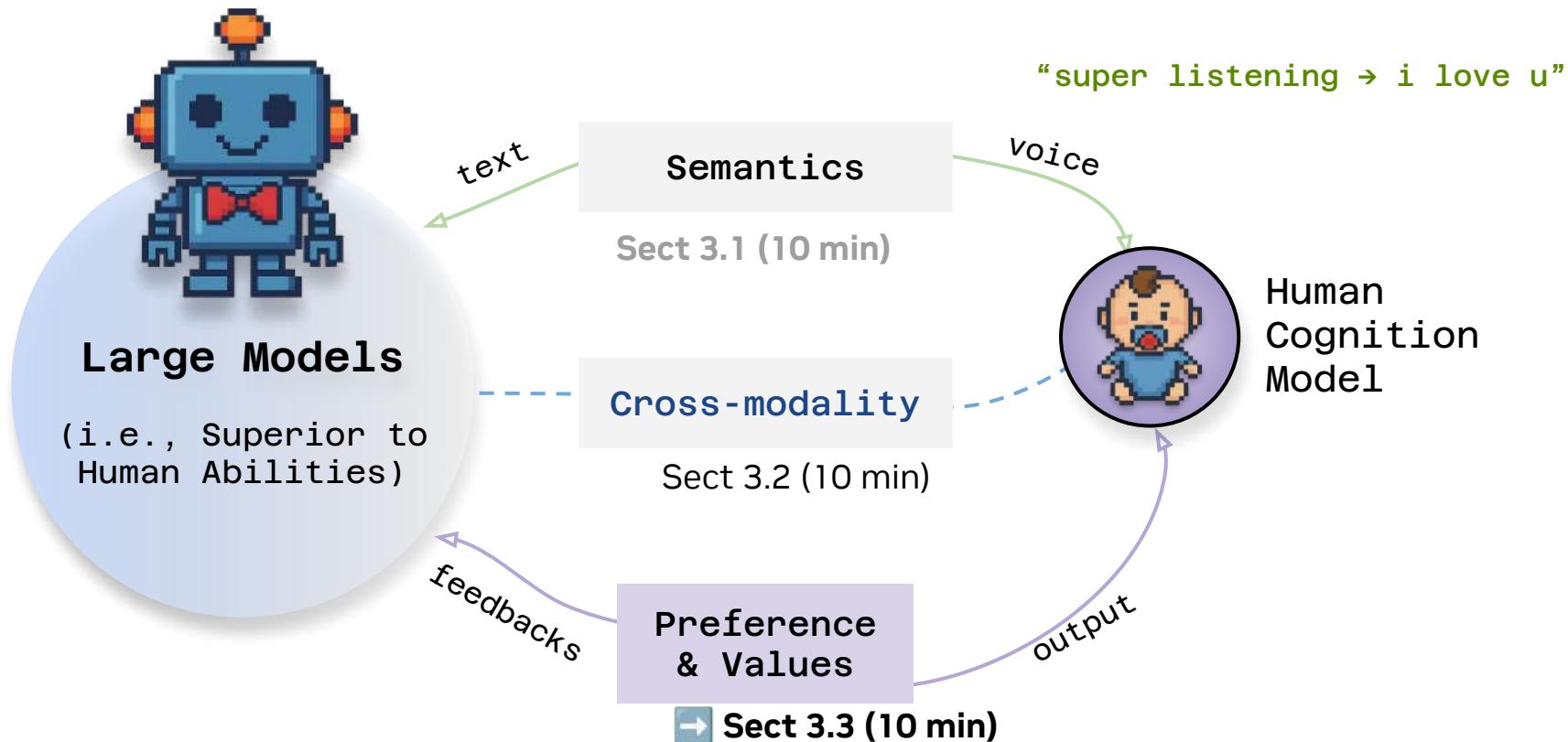
I Ø enjoys listening to music
I Ø enjoy listen Ø music
I Ø join listening to music
I Ø enjoy listened Ø mystic
I am join listening Ø music

Generative Semantics Modeling (3/3) Audio-LMs

- Audio Flamingo 3
 - Applied Deep Learning Research (ADLR)
 - Arushi Goel, Sreyan Ghosh, et al.
 - Open AudioLM
 - <https://huggingface.co/nvidia/audio-flamingo-3>

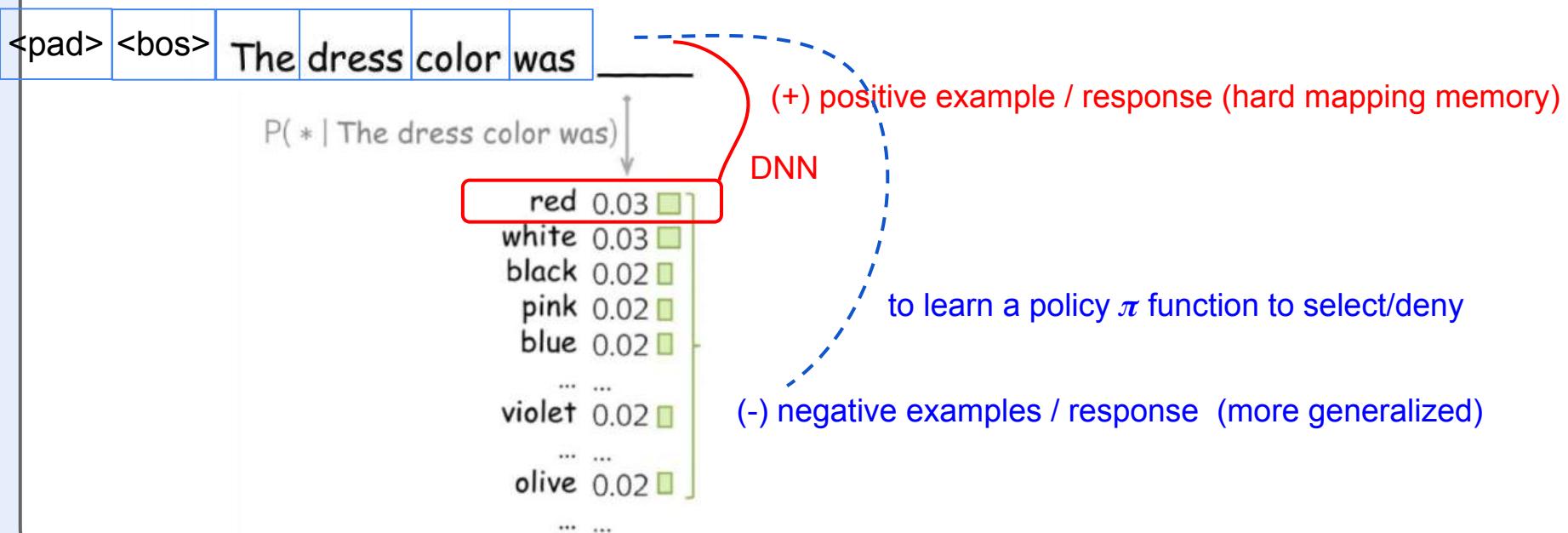


Semantic Alignment in Large Models III



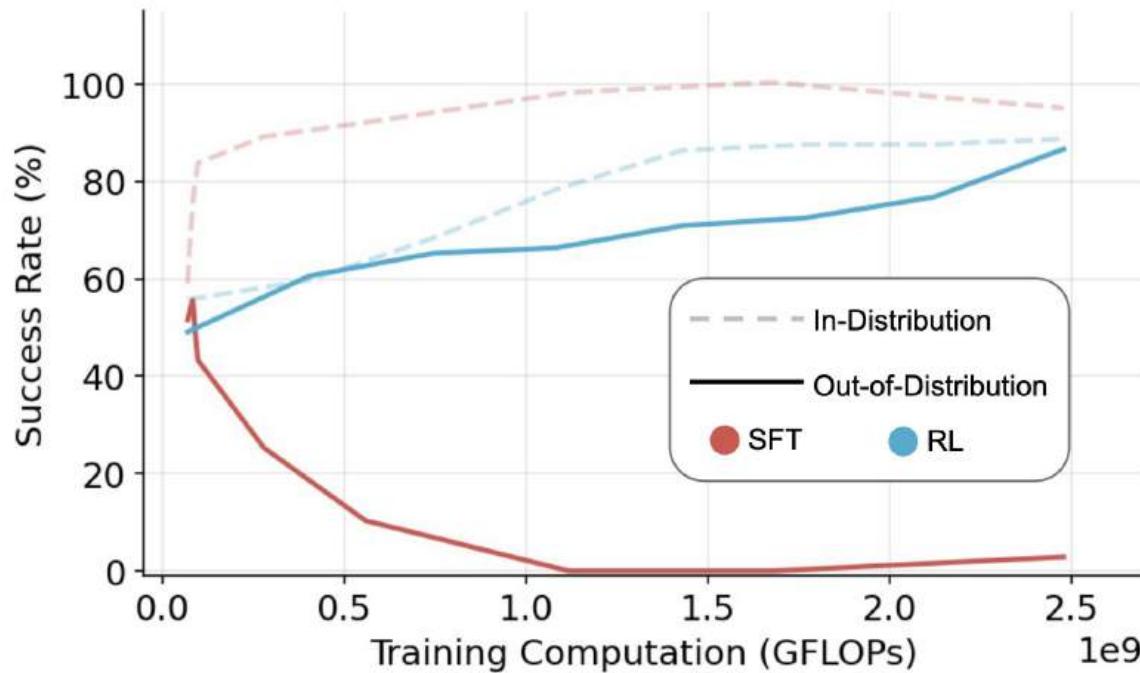
Supervised Fine-Tuning (SFT) (1/3): positive examples

- SFT has “limit” on predicting the next token only on “positive examples”
 - an example on causal LM training



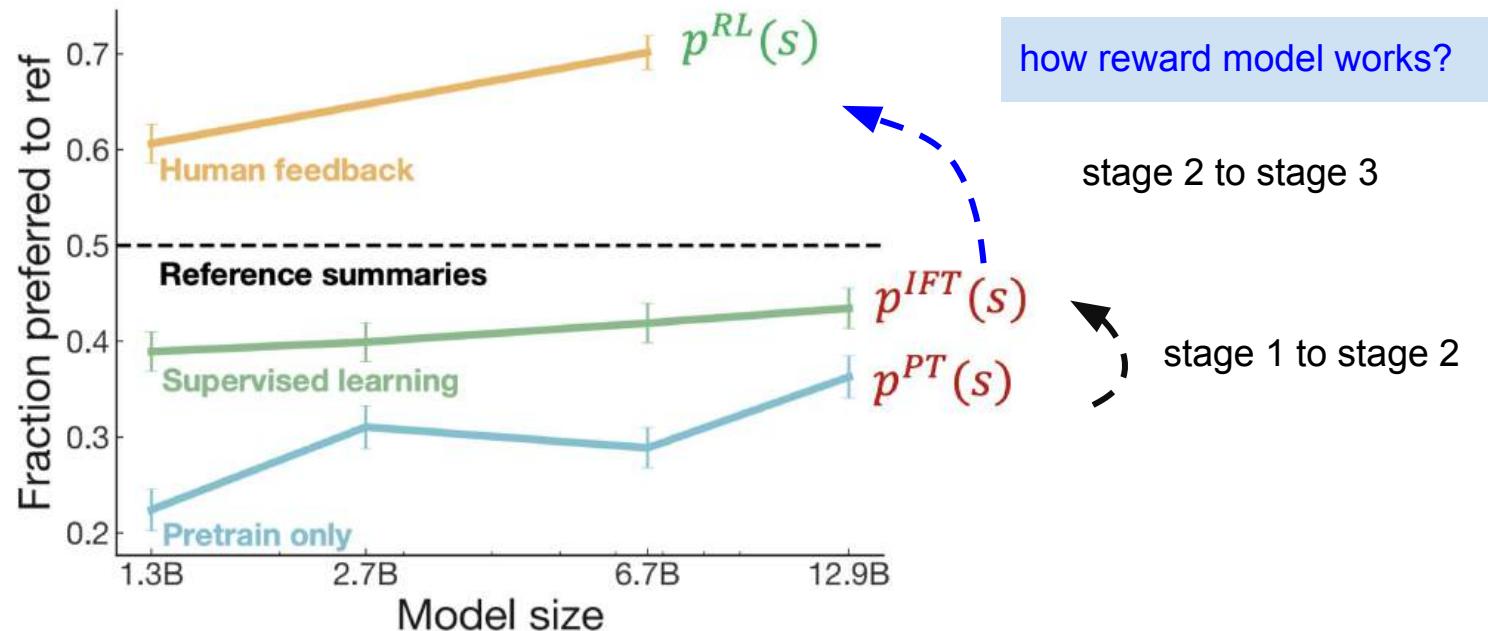
Causal LM Training (2/3): negative examples

- SFT Memorizes, RL Generalizes [ICML 25]
 - We need both SFT and RL, which generalizes in SFT-DPO or SFT-GRPO.



Causal LM Training (3/3): stage-wise training

- “Learning to summarize from human feedback [NeurIPS 20]” OpenAI
 - stage-wise training is essential before RL-stage



How Reward Model (RM) works in reasoning LMs?

- How preference information can be learned from negative information.

$$J_{RM}(\phi) = -\mathbb{E}_{(s^w, s^l) \sim D} [\log \sigma(RM_\phi(s^w) - RM_\phi(s^l))]$$


“winning” sample “losing” sample

s^w should score higher than s^l

→ Reward Model needs preference data but how data further generalizes the reasoning ability

How Data work in the Reasoning LMs



gpt-o1-preview

deepseek-r1

Sep 24: unknown method

Jan 25: <thinking> format compresses CoTs and GRPO

Congrats to DeepSeek on producing an o1-level reasoning model! Their research paper demonstrates that they've independently found some of the core ideas that we did on our way to o1.

1:11 PM · Jan 28, 2025 · 8.1M Views

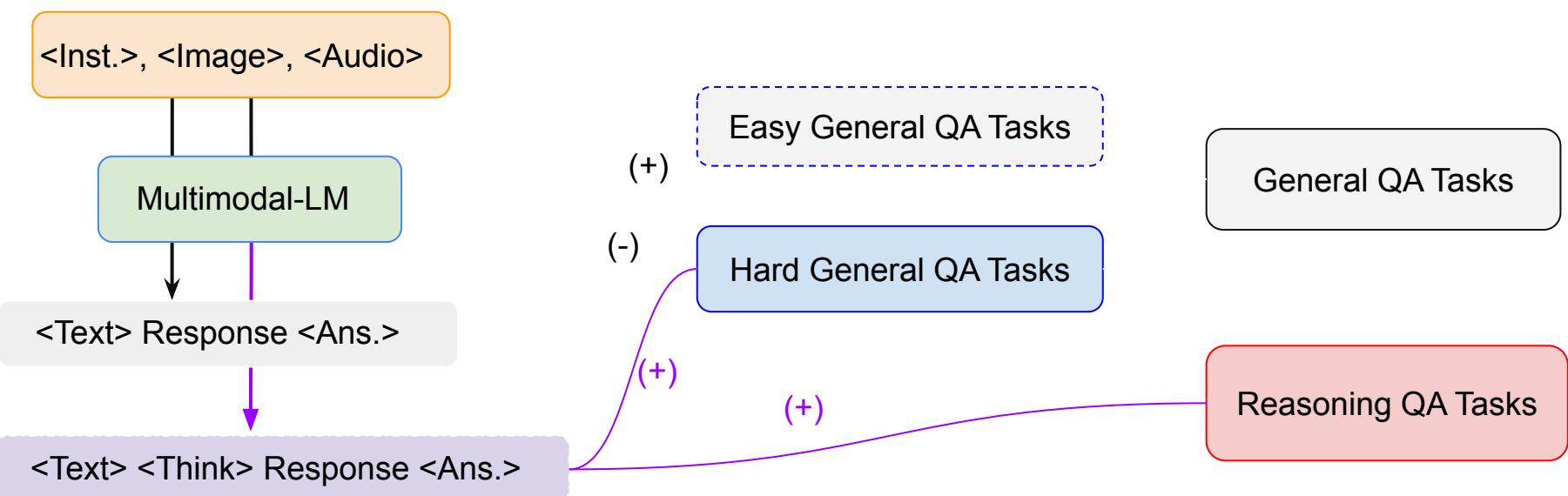
A conversation between User and Assistant. The user asks a question, and the Assistant solves it. The assistant first thinks about the reasoning process in the mind and then provides the user with the answer. The reasoning process and answer are enclosed within <think> </think> and <answer> </answer> tags, respectively, i.e., <think> reasoning process here </think> <answer> answer here </answer>. User: **prompt**. Assistant:



Compressing Chain of Thoughts (CoTs; demo searching traces)

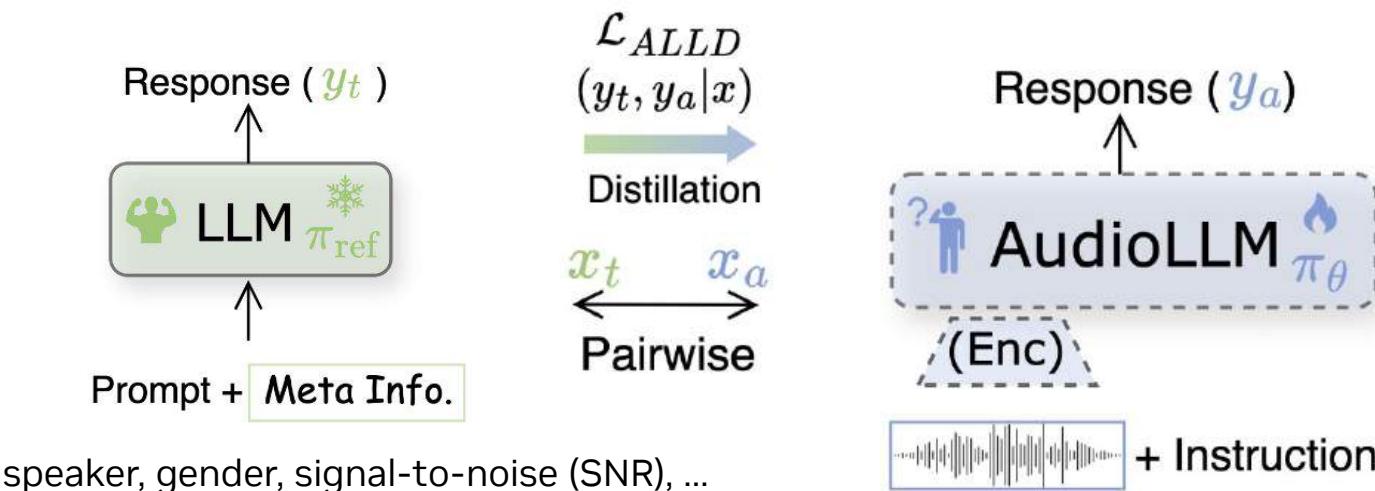
Why we need “Reasoning Ability”?

- Training Objectives
 - (1) Long <think> responses helps on hard and reasoning QA tasks
 - (2) When generate <think> token



Audio LLMs can be Voice Quality Descriptors (1/4)

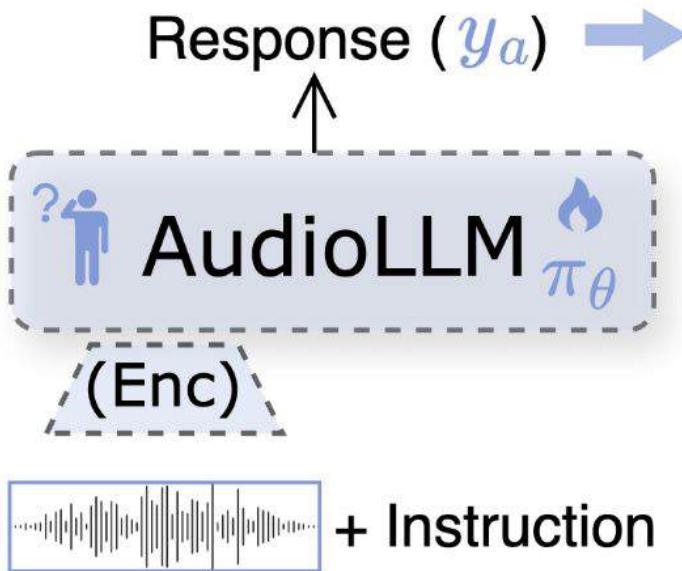
- Can Audio LLM learning from synthesized feedback data
 - Textual Caption view of audio signals
 - A/B testing for reward format data



Source: Audio Large Language Models Can Be Descriptive Speech Quality Evaluators, ICLR 25

Audio LLMs can be Voice Quality Text Descriptors (2/4)

- How to make proper data format?



SFT-target

Exp1: Evaluate the quality of [audio waveform]

Res1: This given speech has slight distortion, but the, the overall MOS score is about 2.4.

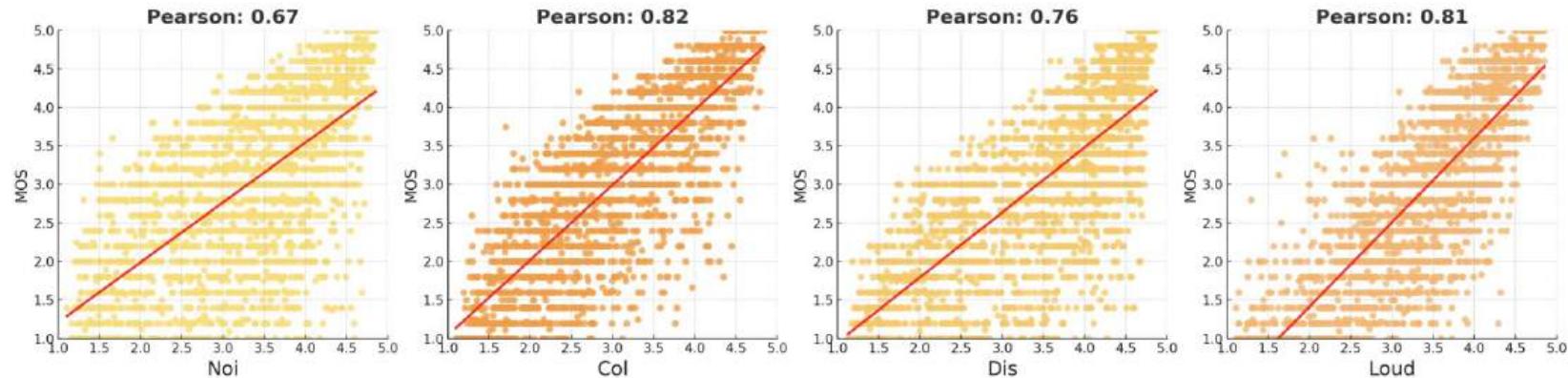
DPO-target

Exp2: A/B test for [audio waveform] and [audio waveform]

Res2: The noise level of Speech A is slighter than, Therefore, I think Speech A has better quality.

Audio LLMs can be Voice Quality Descriptors

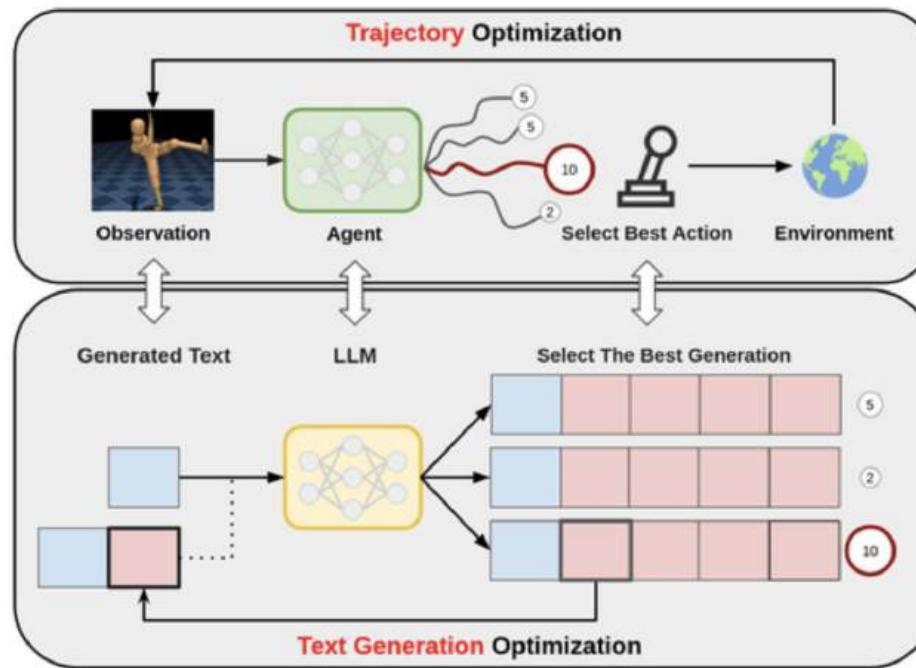
- How Audio LLM correlates to human Mean opinion score (MOS)?



Joint Training	A/B Test		MOS			
	BLEU	Acc (%)	LCC	SRCC	MSE	BLEU
✗	29.02	95.6	0.92	0.92	0.20	25.22
✓	30.17	98.6	0.92	0.91	0.20	26.08

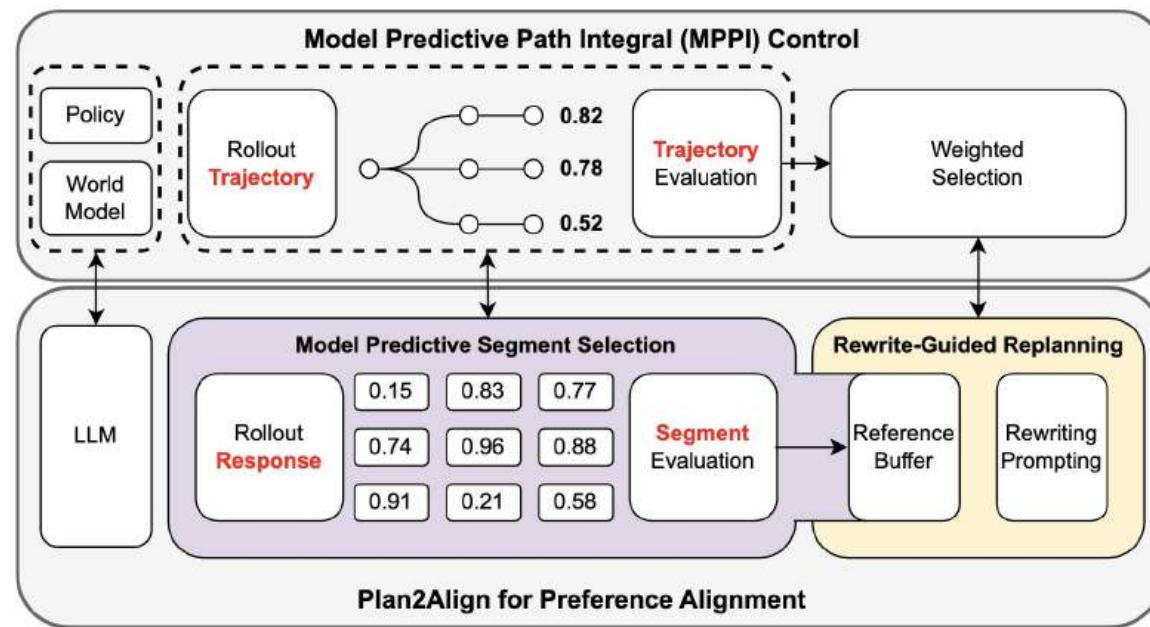
Test-Time Adaptation with Semantic Modeling (1/3)

- Plan2Align: Semantic Trajectory Modeling During Test-Time
 - Improved Machine Translation Results by X%



Test-Time Adaptation with Semantic Modeling (2/3)

- Plan2Align: Semantic Trajectory Modeling During Test-Time
 - Improved Machine Translation Results by X%



Test-Time Adaptation with Semantic Modeling (3/3)

- Plan2Align: Semantic Trajectory Modeling During Test-Time
 - Improved Machine Translation Results by X%

Methods	Test-Time	zh → en		zh → ru		zh → de	
		CW-COMET ↑	CW-KIWI ↑	CW-COMET ↑	CW-KIWI ↑	CW-COMET ↑	CW-KIWI ↑
GPT-4o 2024-08-06	-	94.58	73.06	93.74	54.20	94.54	54.55
Qwen-2.5 (14B)	-	94.43	72.44	90.47	50.13	92.98	50.02
Llama-3.1 (8B)	×	84.36	58.27	86.28	34.32	88.97	39.49
Llama-3.1 _{SFT}	×	93.54	67.16	89.11	43.99	93.47	47.39
Llama-3.1 _{SimPO}	×	91.74	62.31	84.56	41.66	93.40	46.47
Llama-3.1 _{DPO}	×	90.23	62.09	82.15	38.91	93.48	46.09
Llama-3.1 _{RAIN}	✓	58.52	36.39	66.29	31.75	67.43	31.69
Llama-3.1 _{ARGS}	✓	63.99	41.62	43.03	19.57	51.97	23.23
Llama-3.1 _{Best-of-60}	✓	90.97	65.41	84.86	48.93	82.74	38.55
Llama-3.1 _{Vanlia MPC}	✓	88.50	57.06	73.84	31.45	90.32	42.20
Llama-3.1 _{Plan2Align}	✓	94.62	68.00	91.53	41.62	91.73	41.50

Takeaways: Semantic Modeling beyond E2E-ASR

- Semantic models can recover meaning from noisy or partially corrupted speech by leveraging both text and audio cues.
- Large language models (LLMs) improve ASR outputs with post-ASR correction, speaker attribution, and emotion tagging—even without clean input.
- Contextual and multi-modal retrieval bridges gaps in ASR, supporting domain adaptation and code-switching.
- Integration of semantic modeling with **retrieval-augmented** approaches could be further explored for context-aware speech understanding.

Table of Contents

	Introduction (10 mins) 15:30-15:40
	Shinji Speech-to-Text Benchmark (30 min) 15:40-16:10
	Taejin Leveraging Long Acoustic Context (40 min) 16:10-16:50
	Recess (10 min) 16:50-17:00
	Huck Semantic Context and Speech-Language Modeling (40 min) 17:00-17:40
	Kyu Contextual Biasing and Methods Leveraging (30 min) Longer Semantic Context for Speech Systems 17:40-18:10
	Closing Remark (10 min) 18:10-18:20
	Q&A Session (10 min) 18:20-18:30

Contextual Biasing and Methods Leveraging Longer Semantic Context for ASR Systems

Kyu J. Han



Contextual Biasing w/ Longer Semantic Context

- 1. Contextual Biasing for E2E ASR**
 - a. Decoder Biasing
 - b. Encoder Biasing
 - c. Hybrid Biasing
 - d. Retrieval Toward Large-Scale Biasing

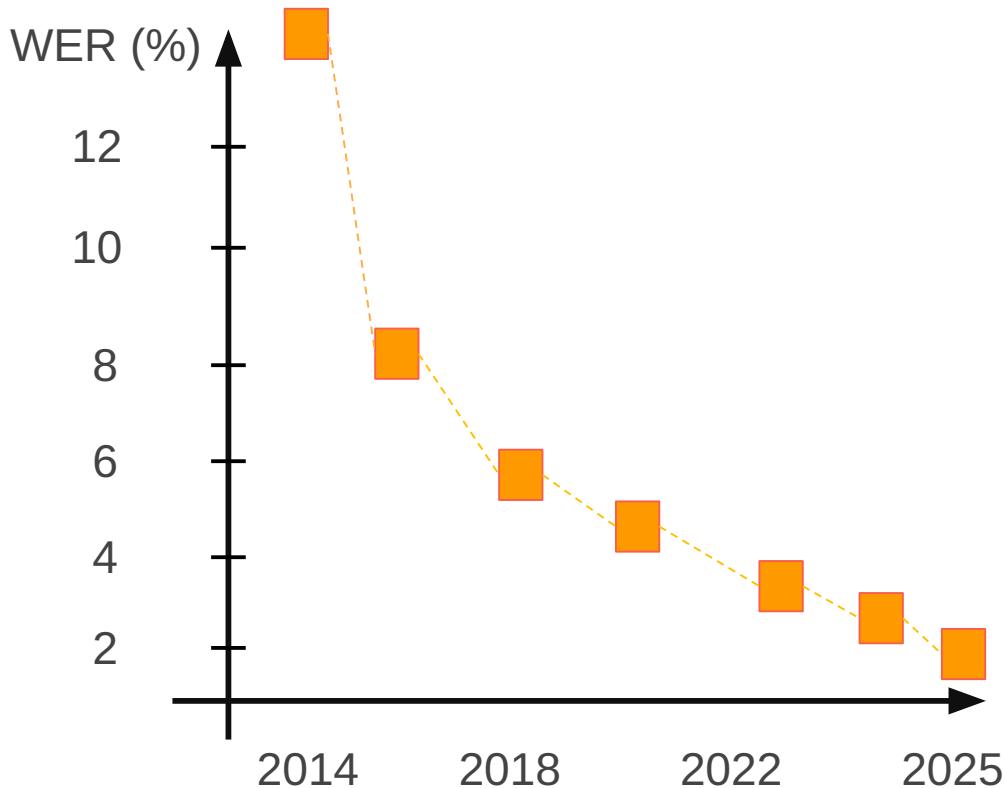
- 2. Retrieval Augmented Generation (RAG)**
 - a. What is RAG?
 - b. RAG for Contextual Biasing

Is ASR a Solved Problem?

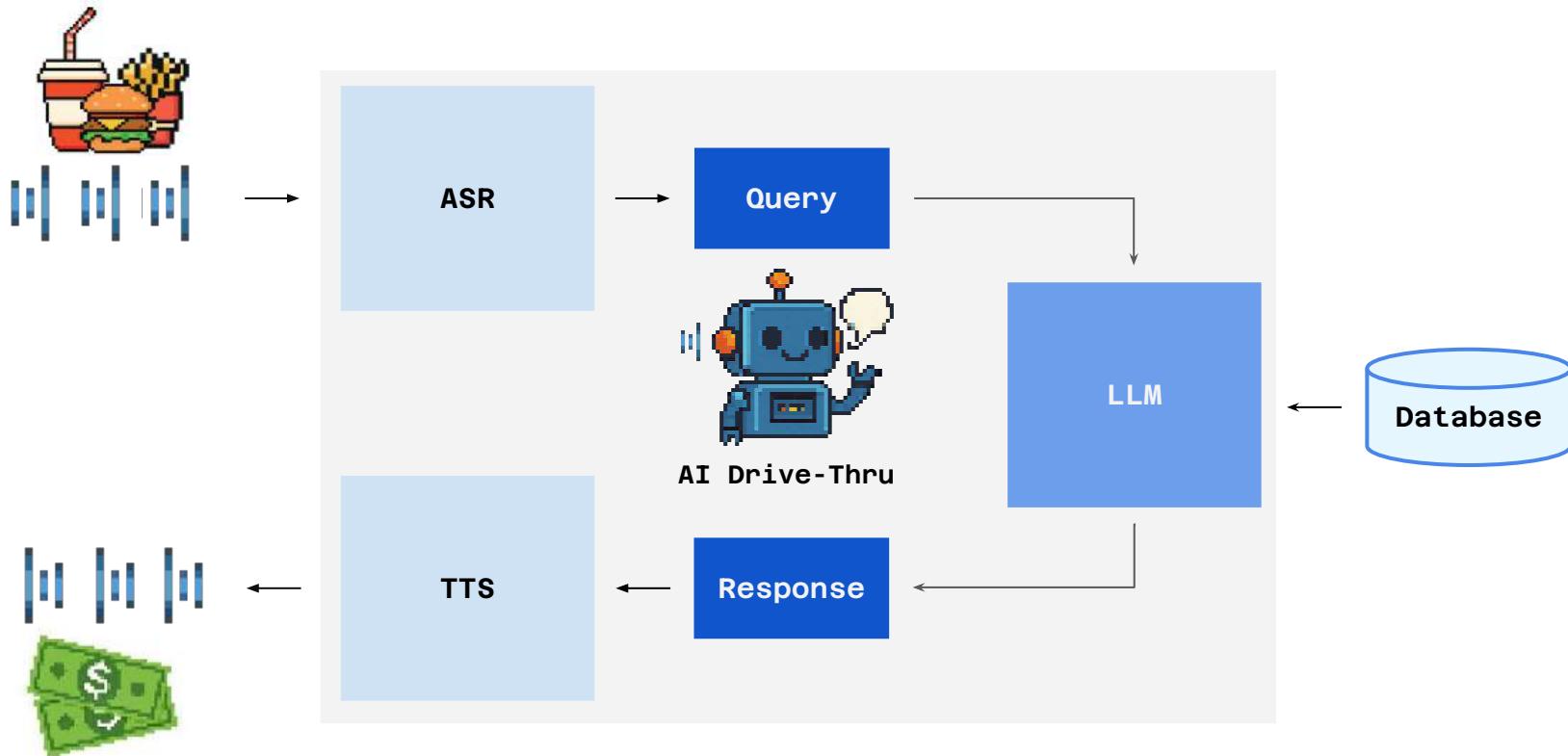


As speech-recognition accuracy goes from 95% to 99%, we'll go from barely using it to using all the time! [theworldin.com/article/12760/...](http://theworldin.com/article/12760/)

6:03 PM · Dec 15, 2016 from Sunnyvale, CA



How Is ASR Used, Any Example?

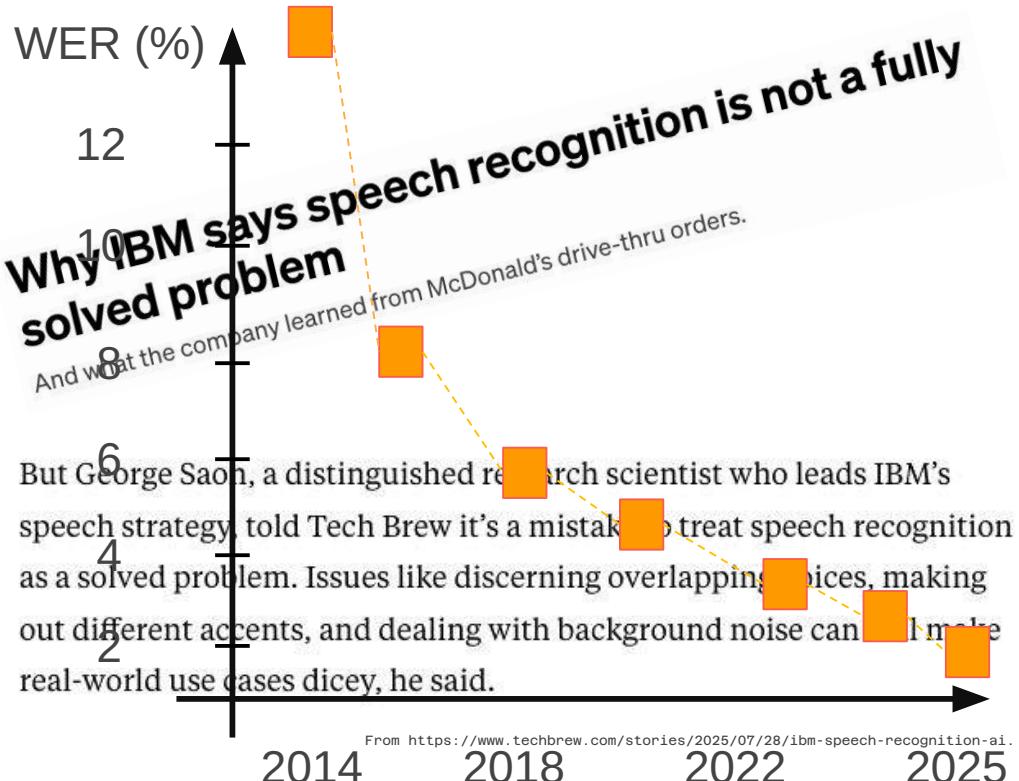


Is ASR a Solved Problem?

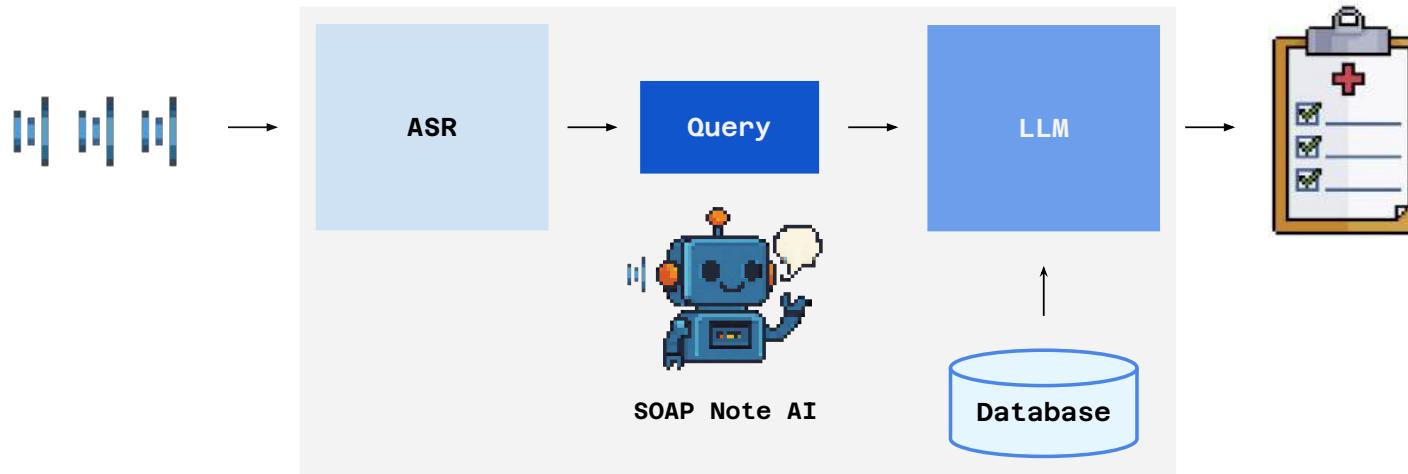


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6:03 PM · Dec 15, 2016 from Sunnyvale, CA



How Is ASR Used, Another Example?



Clinical note generation

- ASR + LLM for post-consultation transcription and clinical note summary
- Could save over 45% of doctors' time.

Is ASR a Solved Problem?

THIS IS A 67 YEAR OLD FEMALE WITH END-STAGE RENAL DISEASE DUE TO DIABETIC NEPHROPATHY ...

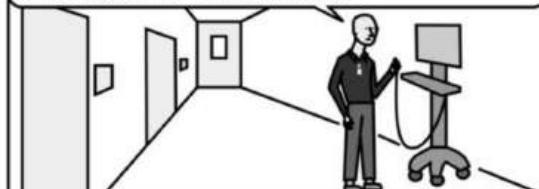
Coalmine Hospital

... ON HEMODIALYSIS THROUGH A FOREARM FISTULA ...

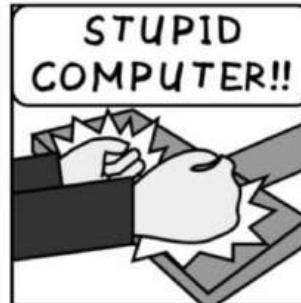
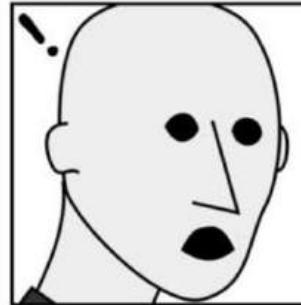
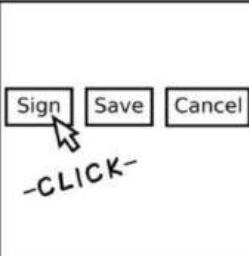
... PRESENTING WITH ACUTE RENAL FAILURE DUE TO MISSING DIALYSIS ...

... FOUND TO HAVE A FISTULA THROMBOSIS.

AND DIALYZE THROUGH A TEMPORARY CATHETER. THANK YOU FOR ALLOWING ME TO PARTICIPATE IN THE CARE OF THIS PATIENT.



WE WILL CONSULT VASCULAR SURGERY FOR MANAGEMENT OF THE FISTULA ...



ASSESSMENT AND PLAN:

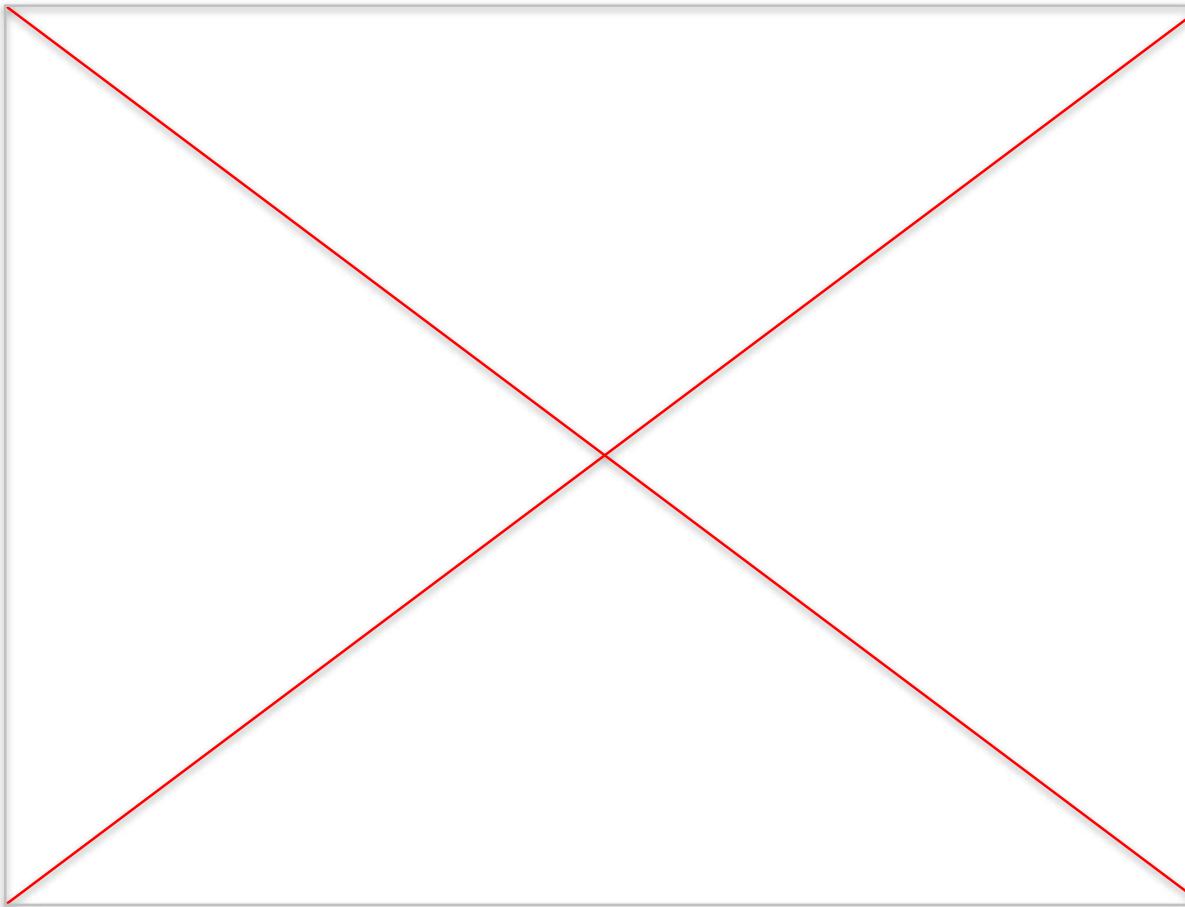
This is a 6-7 year old female with end days real disease due 2 die pathetic nephropathy, on hero dial a sis through a 4-arm fist EULA, presenting with a cute real fail your do 2 missing dial a sis appointments and found to have a fist EULA trombone sis. We will insult vascular surgery for management of the fist EULA and dial eyes through a temp urinary catheter. Thank you for allowing me to produce pain in the care of this patient.

Ian Bean, MD
Nephrologist

Electronically signed by beanian01 on 01/16/2023 at 1930.

WHATEVER. TOO LATE TO CHANGE IT NOW.

Is ASR a Solved Problem? (AWS Transcribe Example)



Contextual Biasing in E2E ASR

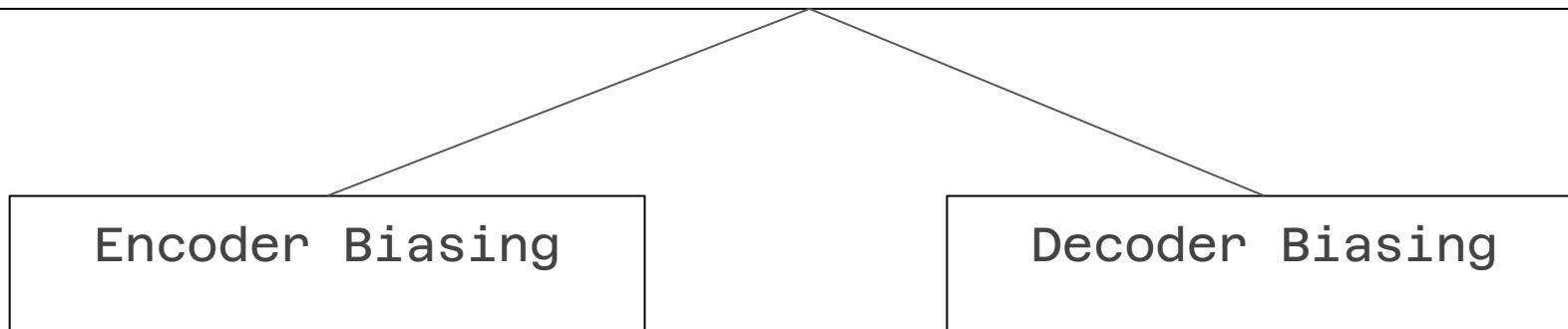
Context Biasing

Technique of influencing an ASR system to favor specific words or phrases during decoding, often because they are relevant to a particular context or user. This is particularly useful when dealing with rare words, named entities, or phrases specific to a domain, which might otherwise be poorly recognized by a general ASR model.

Contextual Biasing in E2E ASR

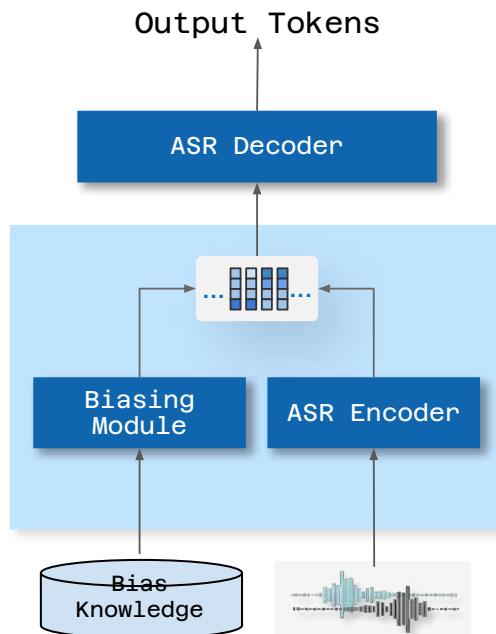
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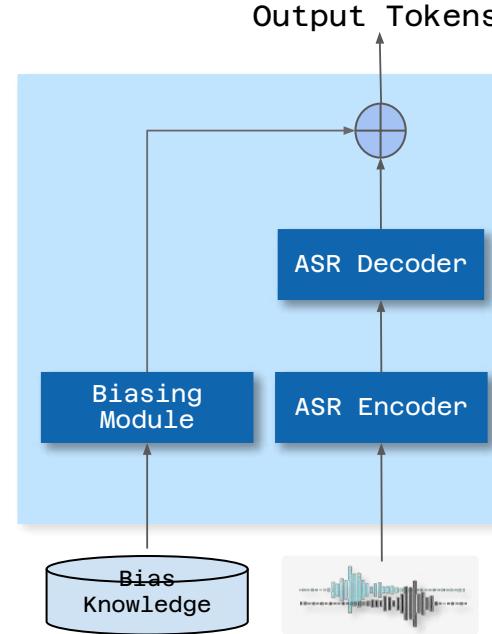


Encoder vs. Decoder Biasing

Encoder biasing



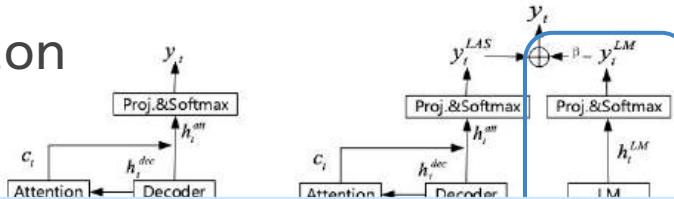
Decoder biasing



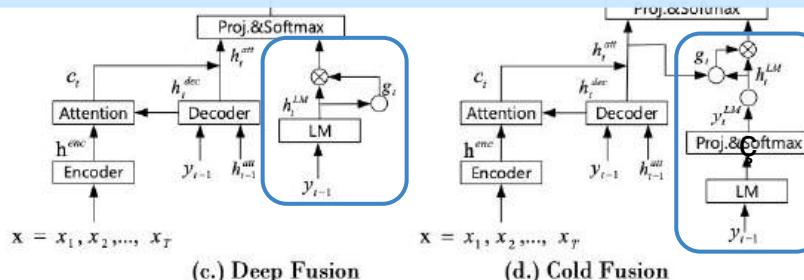
Decoder Biasing

Integrating static knowledge to ASR models to influence decoding scores on bias words

- LM shallow fusion



$$\mathbf{y}^* = \arg \max_{\mathbf{y}} \log P(\mathbf{y} | \mathbf{x}) + \lambda \log P_C(\mathbf{y})$$

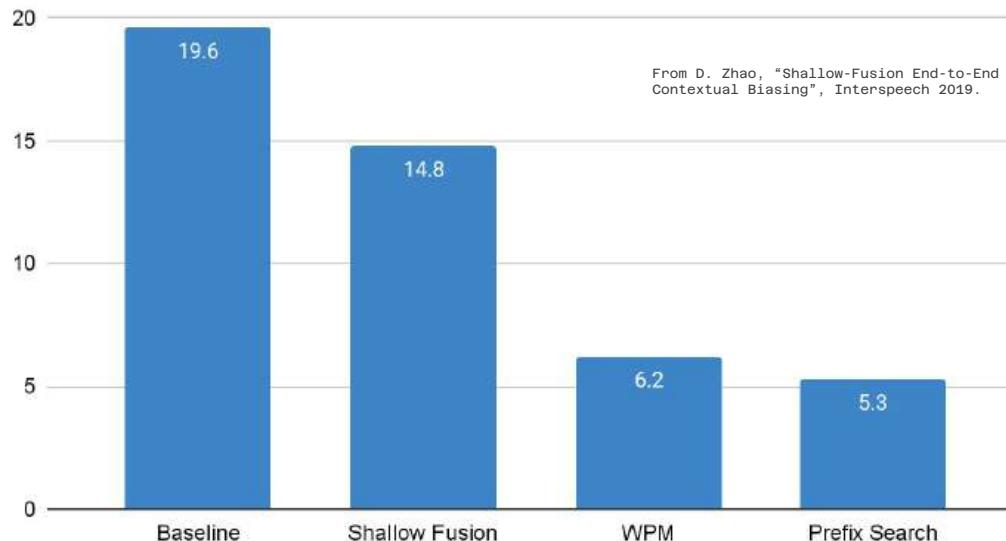


From C. Shan, et al., "Component Fusion: Learning Replaceable Language model component for End-to-End Speech Recognition System", ICASSP 2019.

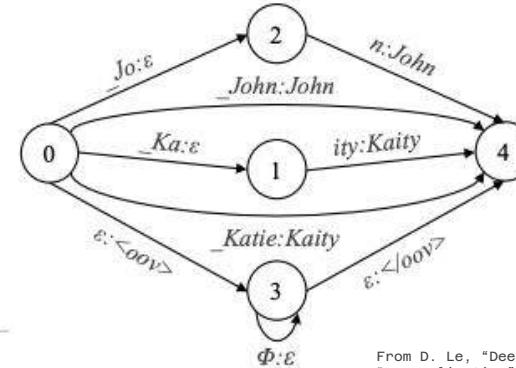
Decoder Biasing

- Class-LM WFST
- Prefix tree search
- Wordpiece modeling (WPM)

WER (%)

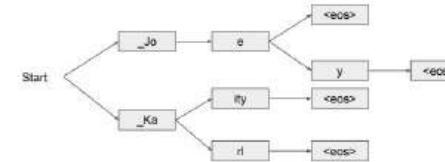


From D. Zhao, "Shallow-Fusion End-to-End Contextual Biasing", Interspeech 2019.



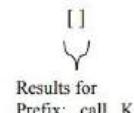
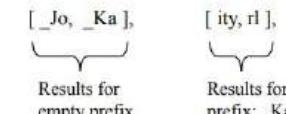
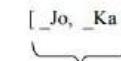
From D. Le, "Deep Shallow Fusion for RNN-T Personalization", SLT 2021.

Prefix tree for bias phrases [Joe, Joey, Kaity, Karl]:



Previously emitted tokens: [_call _Ka]

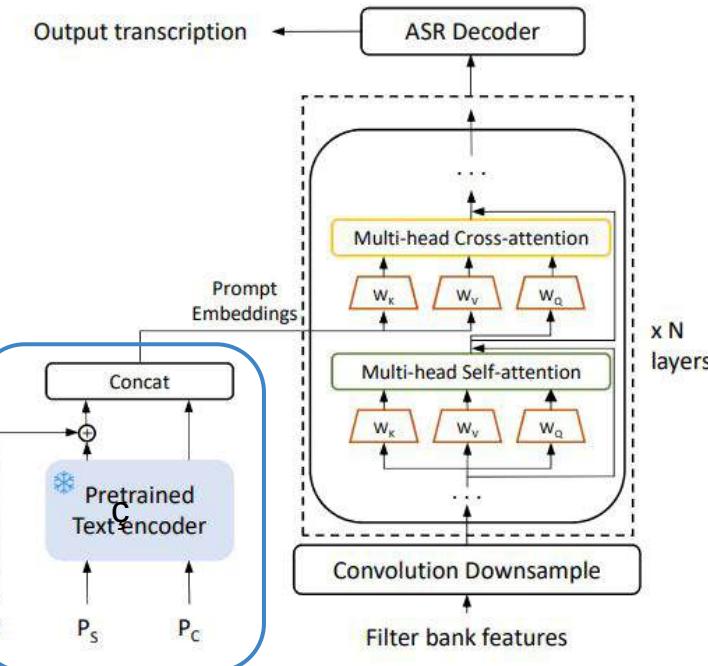
PLM output:



Encoder Biasing

Trying to affect embedding vectors directly to influence posteriori probs on bias words

Bias words	Stella, Froedtert Hospital, fistula, amoxicillin, etc.
Previous transcripts	This is a 67 year old female with end...
Prompts/Context	Today's game is between Real Madrid and Liverpool.



From X. Yang, "PromptASR for Contextualized ASR with Controllable Style", ICASSP 2024.

Context Biasing

Encoder Biasing

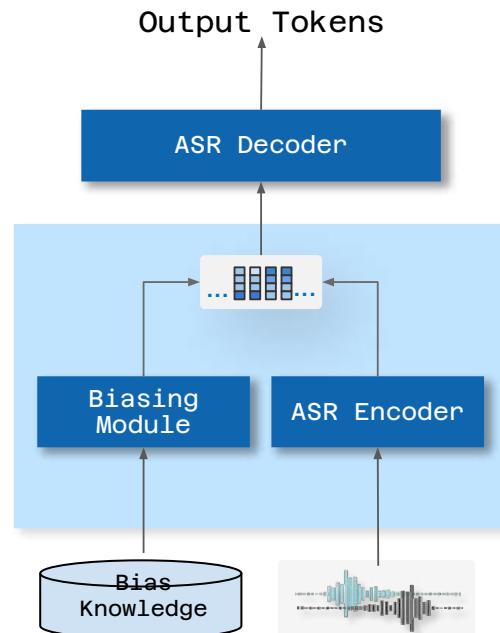
- Intrinsic
- Could lead to more modest accuracy improvement
- Reliable across datasets, languages, etc.

Decoder Biasing

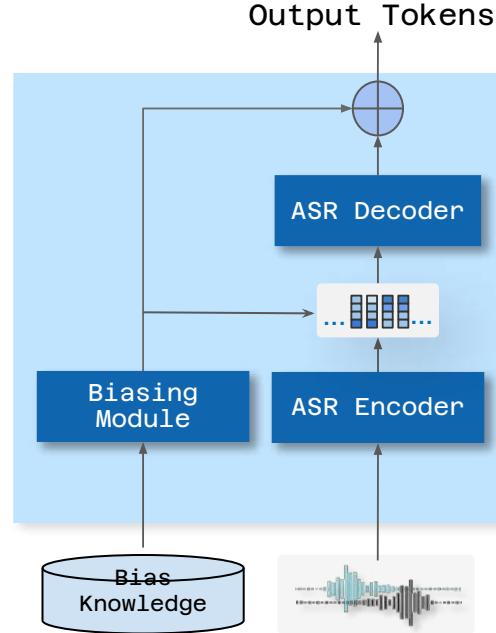
- Extrinsic
- Could result in more false positives
- Could be sensitive to datasets, languages, etc.

Hybrid Biasing

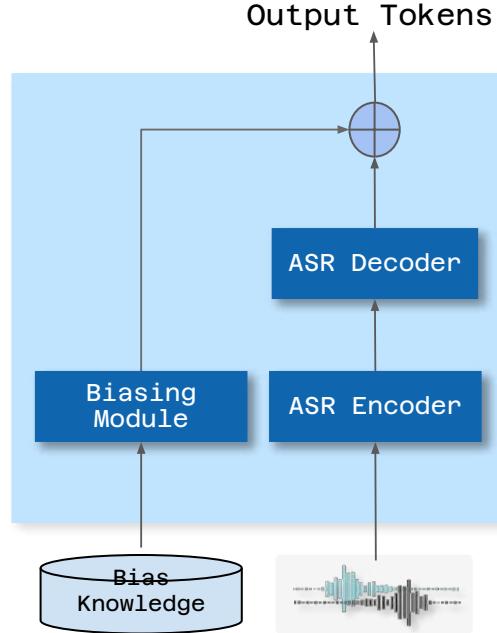
Encoder Biasing



Hybrid Biasing



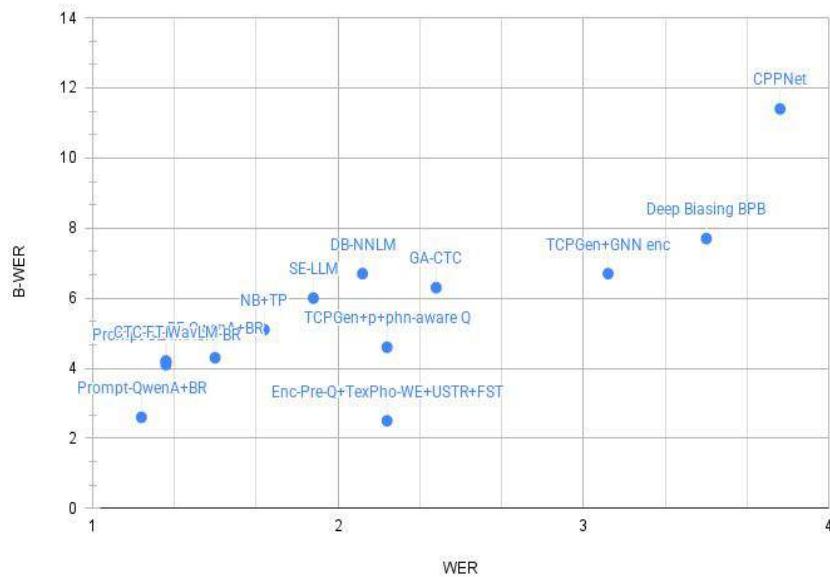
Decoder Biasing



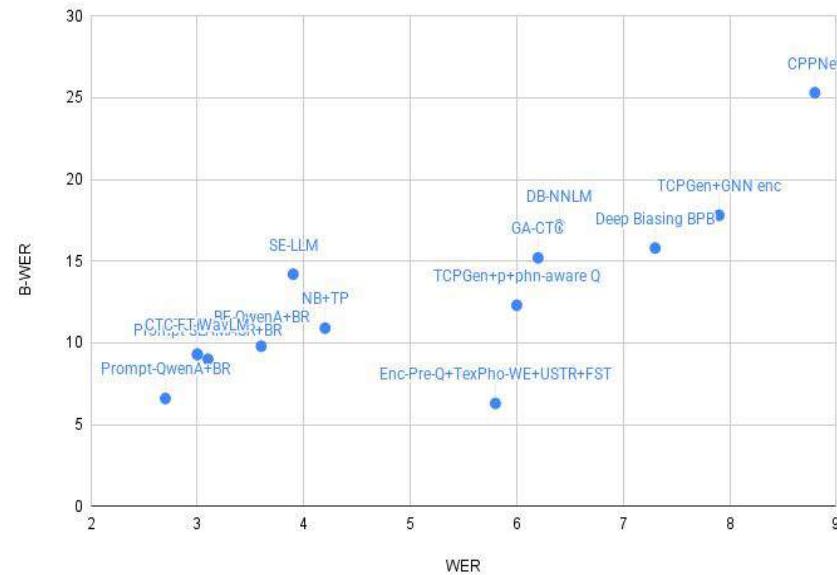
WER vs B-WER Benchmark on Hybrid Biasing (mostly)

B-WER: WER on bias (rare) words (N=1000)

LibriSpeech: test-clean



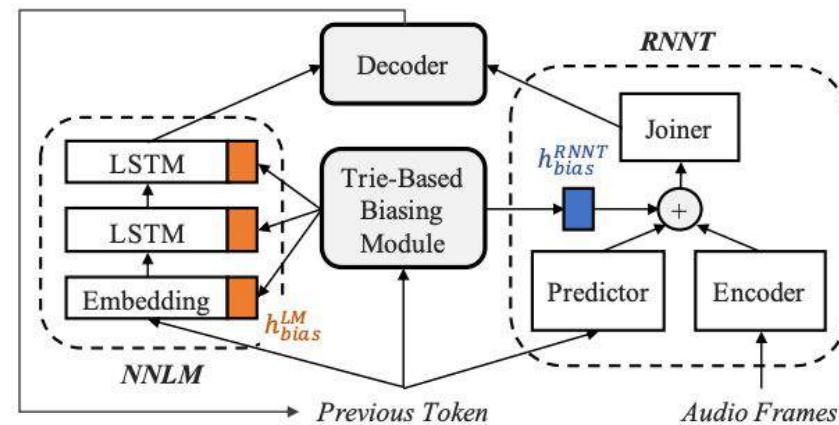
LibriSpeech: test-other



Hybrid Biasing

Leveraging advantages of both encoder and decoder biasing

- Shallow fusion
- Trie-based deep biasing
- Deep integration
 - Biasing module to encoder/LM

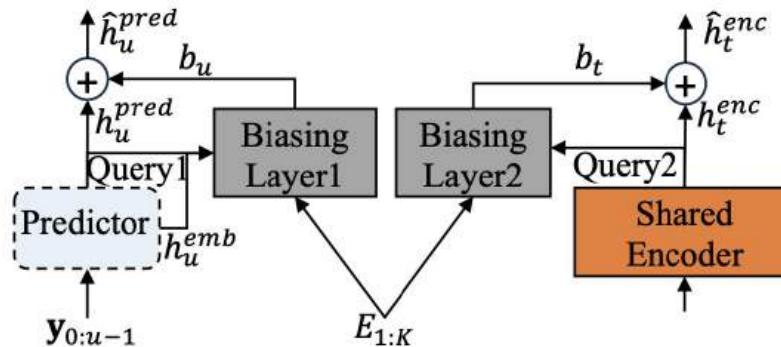
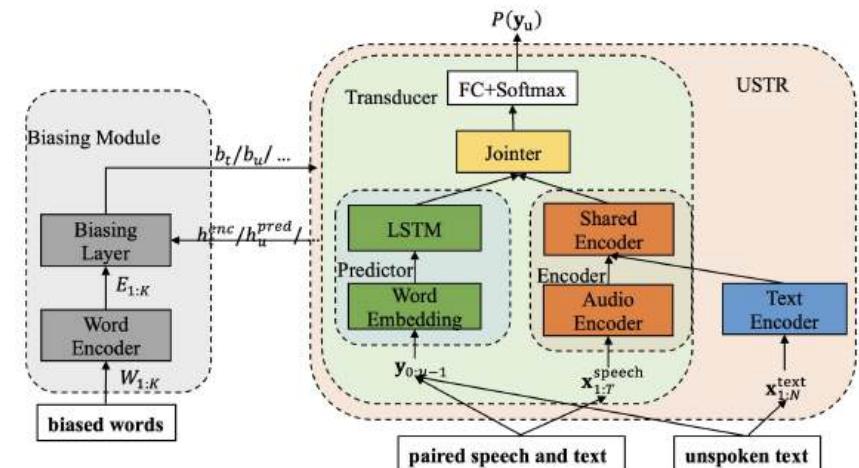


From D. Le, "Contextualized Streaming End-to-End Speech Recognition with Trie-Based Deep Biasing and Shallow Fusion", Interspeech 2021.

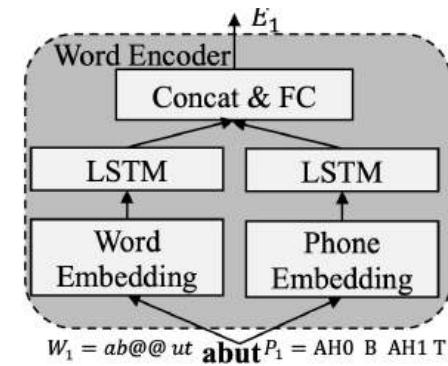
Hybrid Biasing

Leveraging advantages of both encoder and decoder biasing

- Text only domain adaptation
- Text and phoneme embedding
- Encoder-predictor biasing



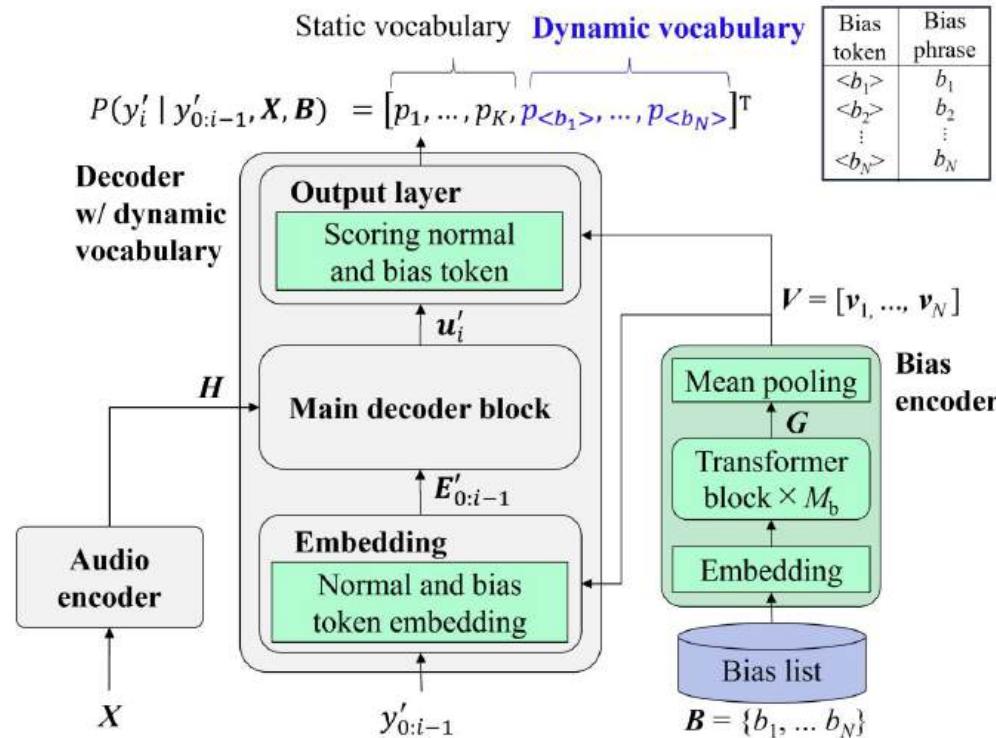
From J. Qiu, "Improving Large-Scale Deep Biasing with Phoneme Features and Text-Only Data in a Streaming Transducer", ASRU 2023.



$$W_1 = ab@@@ut \quad \mathbf{a} \mathbf{b} \mathbf{u} \mathbf{t} \quad P_1 = AH0 \ B \ AH1 \ T$$

Hybrid Biasing

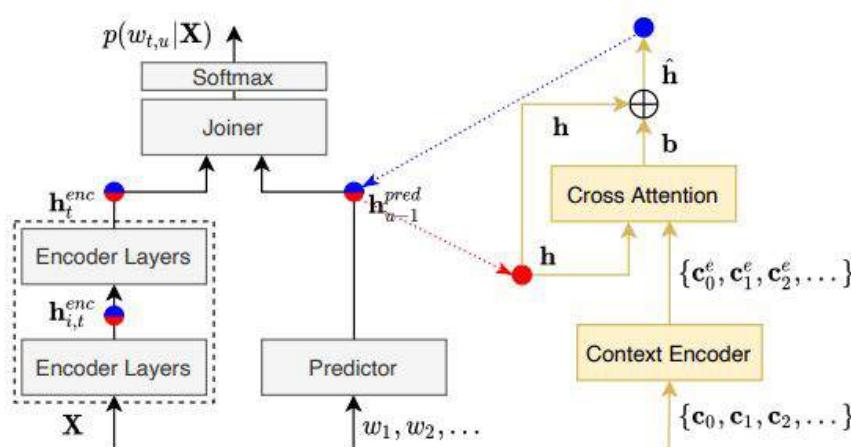
- Expanding output token layer



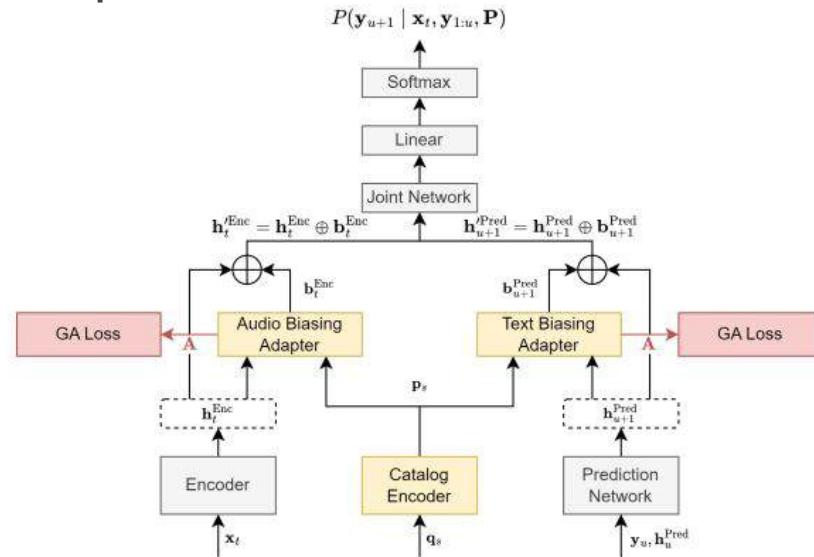
Hybrid Biasing

Applying diverse mechanisms to incorporate external knowledge for bias words to ASR models

- Guided attention on biasing adapters
- Neural biasing w/ attention



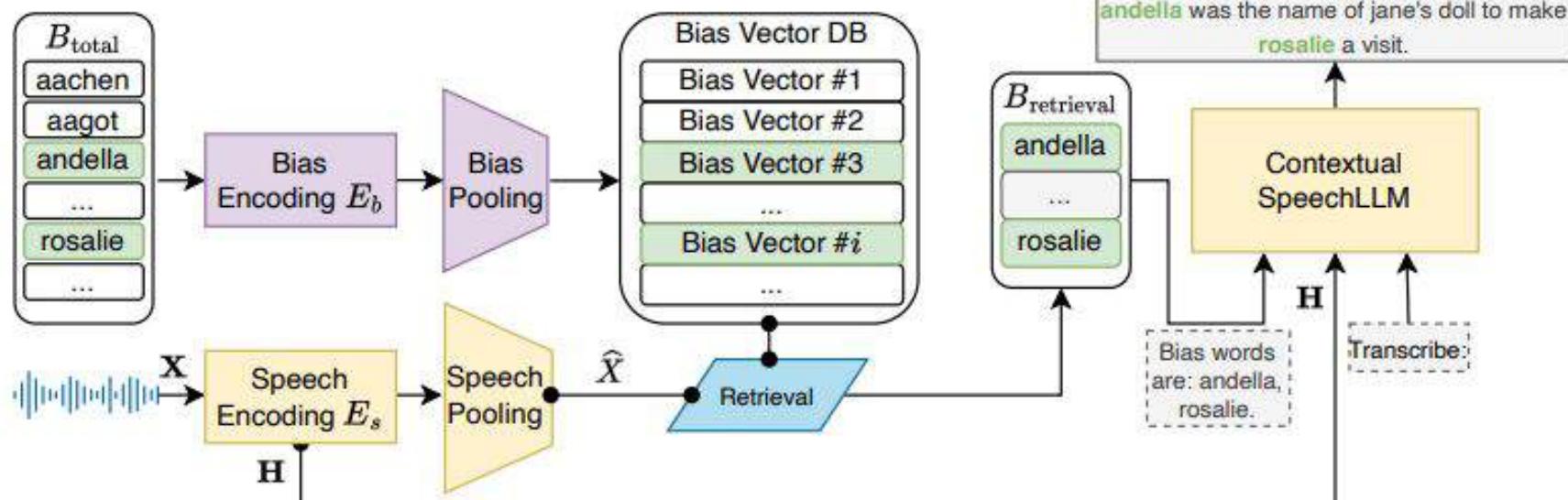
From R. Huang, "Improving Neural Biasing for Contextual Speech Recognition by Early Context Injection and Text Perturbation", Interspeech 2024.



From J. Tang, "Improving ASR Contextual biasing with Guided Attention", ICASSP 2024.

Contextual Biasing for LLMs

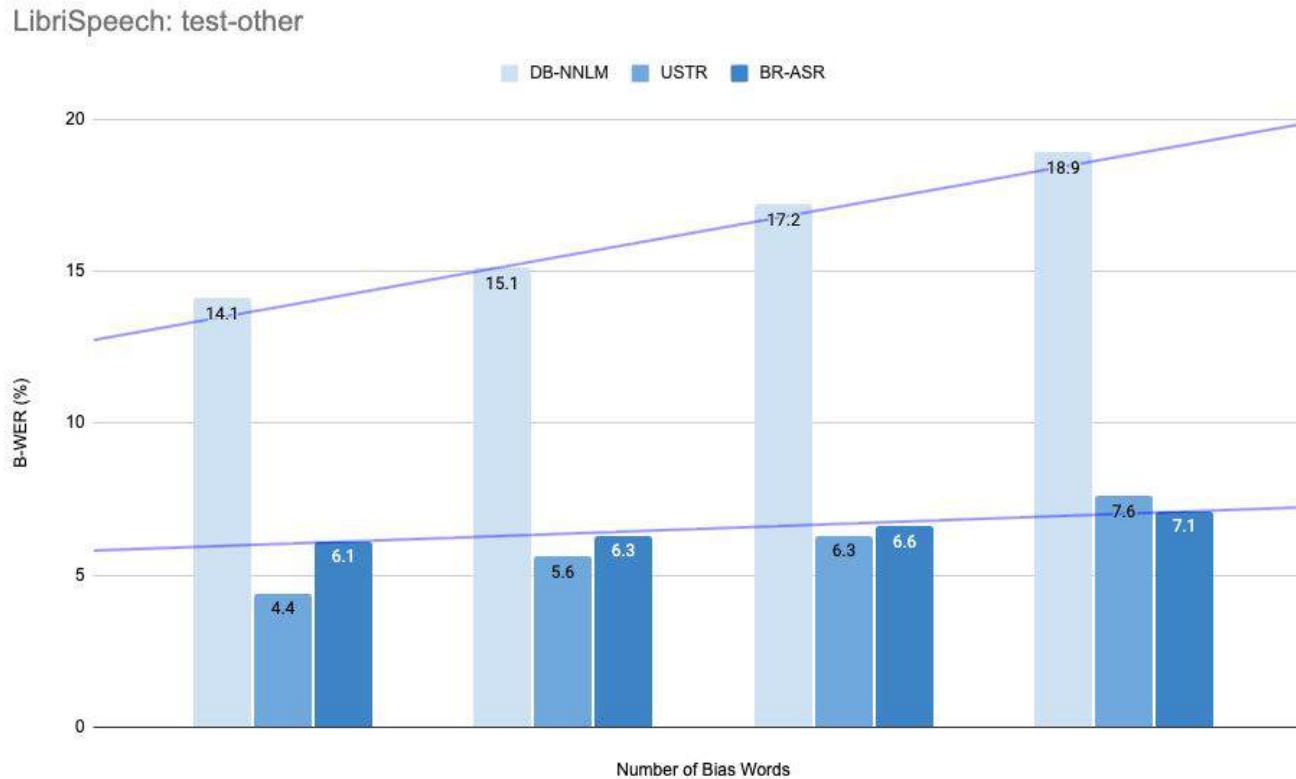
Prompting LLMs to enable contextual biasing



From X. Gong, "BR-ASR: Efficient and Scalable Bias Retrieval Framework for Contextual Biasing ASR in Speech LLM", Interspeech 2025: Wed 13:30-15:30 Area12-Poster3.

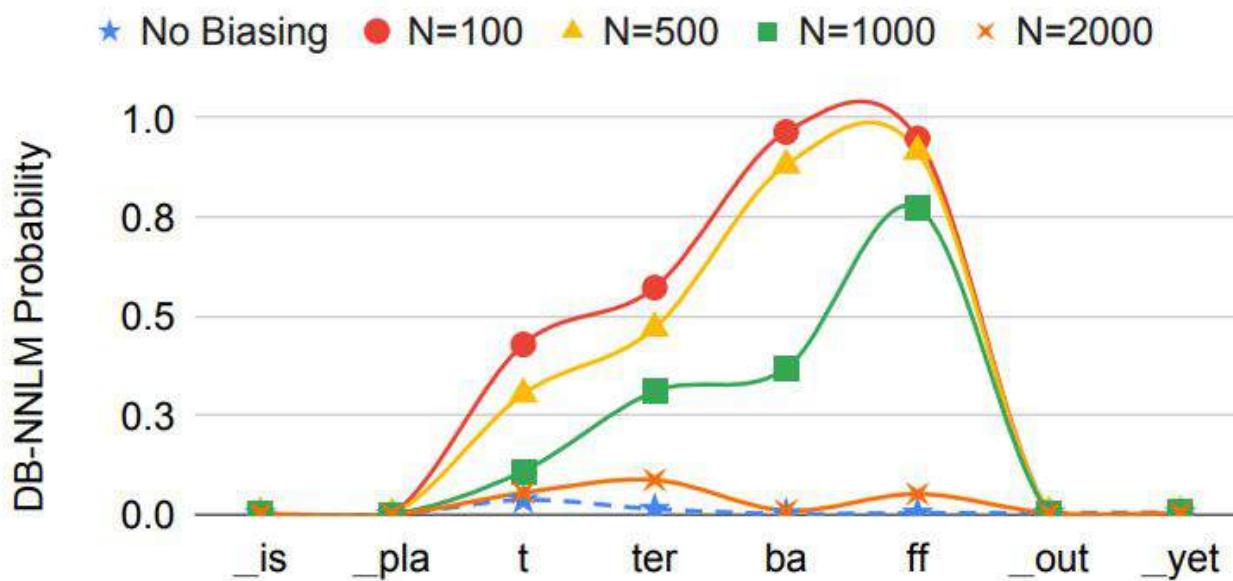
How Scalable is Contextual Biasing?

B-WER, increasing as a list of bias (rare) words gets larger



How Scalable is Contextual Biasing?

B-WER, increasing as a list of bias (rare) words gets larger and w/ more distractors



From D. Le, "Contextualized Streaming End-to-End Speech Recognition with Trie-Based Deep Biasing and Shallow Fusion", Interspeech 2021.

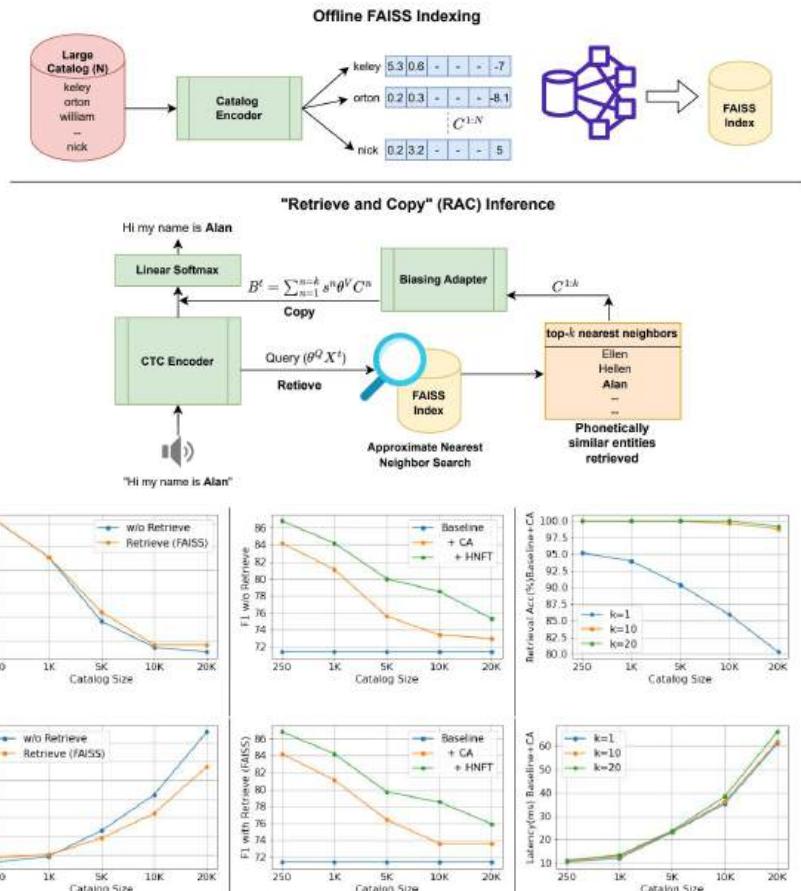
Retrieval Toward Large-Scale Contextual Biasing

Contextual biasing up to 200K

- Nearest search w/ FAISS
- Hard negative fine-tuning
- Encoder biasing w/ CTC

Model	Transcription
Baseline + CA + HNFT	my name is Ruben my name is Ruben my name is Rueben
Baseline + CA + HNFT	my name is Wally yes it's Wy yes it's Wally

From S.Jayanthi, "Retrieve and Copy: Scaling ASR Personalization to Large Catalogs", EMNLP 2023.

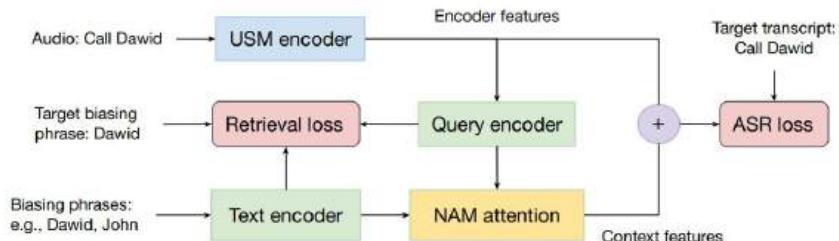
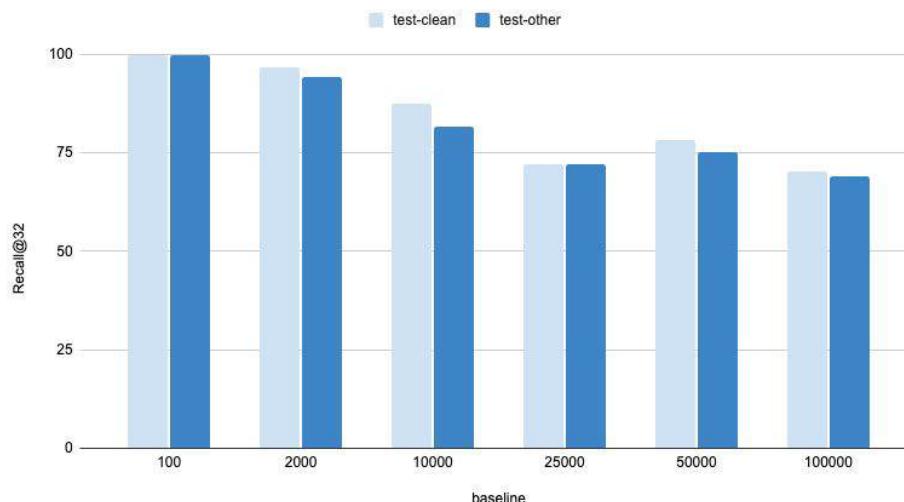


Retrieval Toward Large-Scale Contextual Biasing

Contextual biasing up to 100K

- Neural attention memory

LibriSpeech: Recall@32

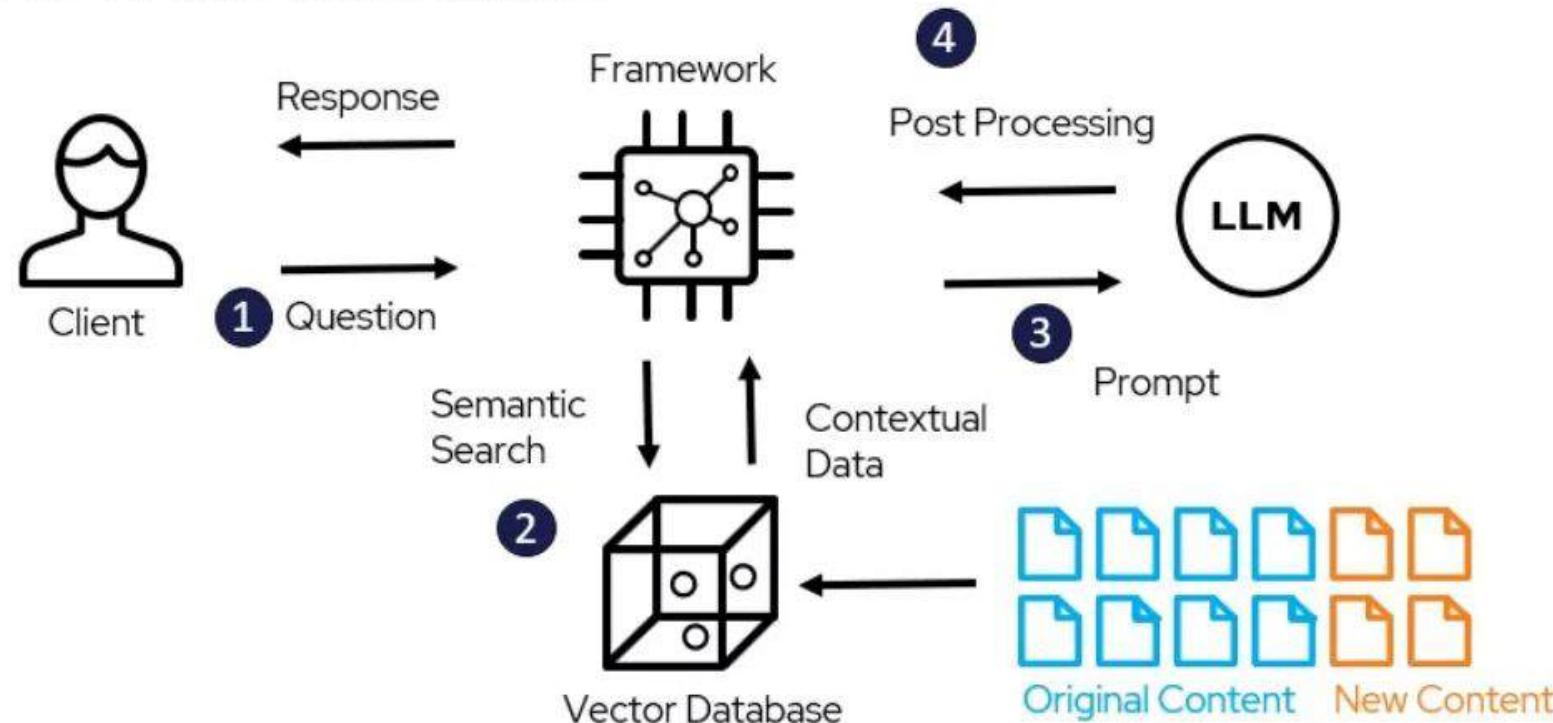


From Z. Huang, "Optimizing Large-Scale Context Retrieval for End-to-End ASR", Interspeech 2024.

Transcript truth	Top 5 phrases
nought worse than many others i reckon	nought, beckon, reckoning, reckoned, more's, er
margaret was collecting her mother's working materials and preparing to go to bed	collecting, milking, mature, marking, lurking
just as she was leaving the room she hesitated she was inclined to make an acknowledgement which she thought would please her father but which to be full and true must include a little annoyance	annoyance, acknowledgement, hesitating, incur, liberal allowance

What is Retrieval Augmented Generation (RAG)?

RAG Architecture Model



What is Retrieval Augmented Generation (RAG)?

Benefits of RAG

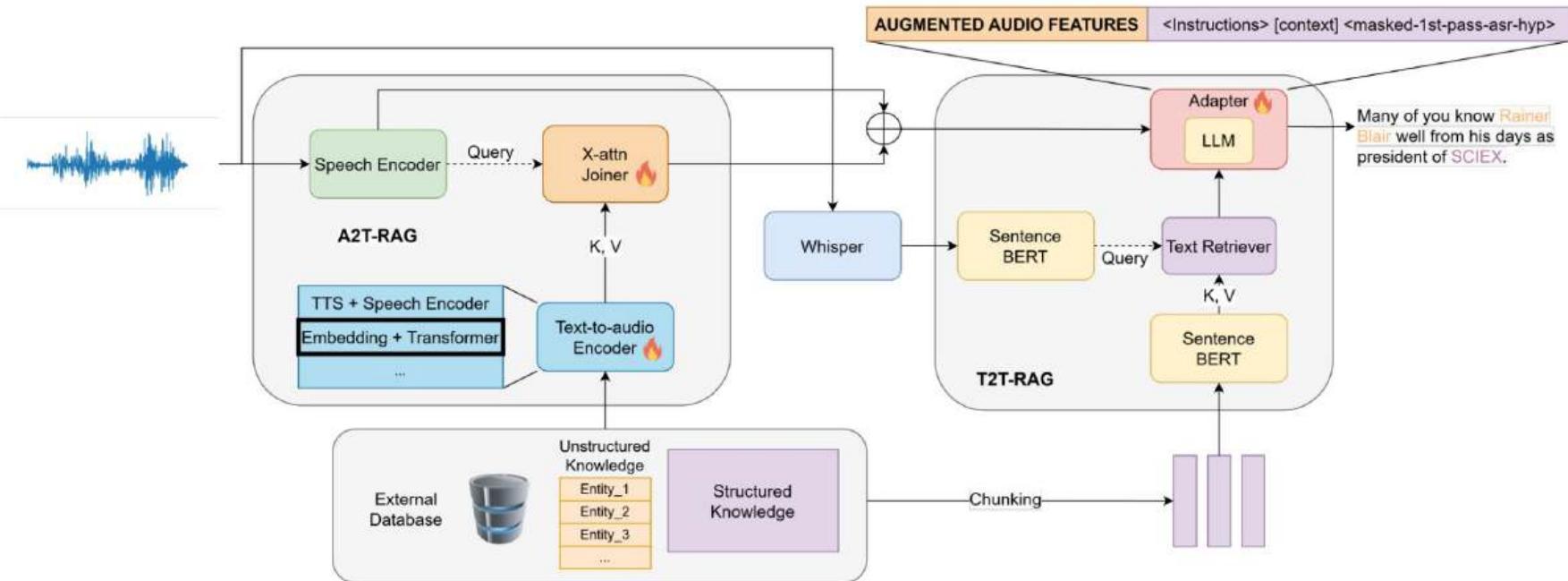
- Cost-effective implementation
- Current information
- Enhanced user trust
- More developer control

Benefits of RAG for contextual biasing for ASR

- Using innate contextual information in knowledge bases to provide better contextual prompts for LLMs
- Mitigating ASR output hallucinations

RAG-based Contextual Biasing for E2E ASR

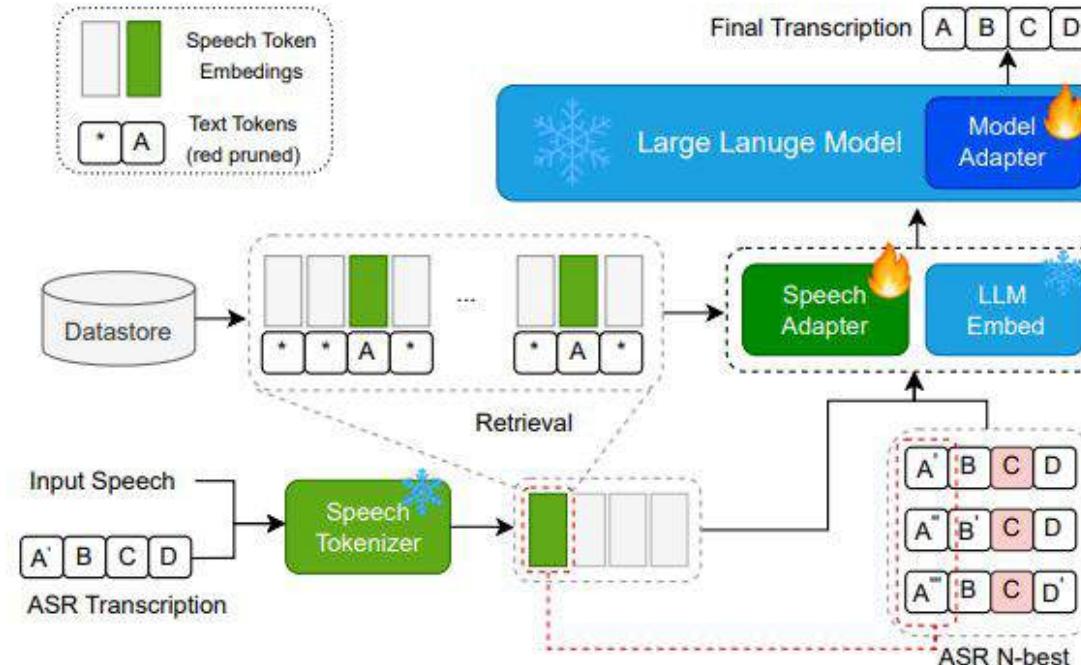
Text-based RAG + cross attention-based encoder biasing



From C. Xiao, "Contextual ASR with Retrieval Augmented Large Language Model", ICASSP 2025.

RAG-based Contextual Biasing for E2E ASR

RAG w/ multimodal embeddings for contextual biasing



From S. Li, "Enhancing LLM-based ASR Accuracy with Retrieval-Augmented Generation,
<https://arxiv.org/abs/2409.08597>.

Takeaways: Contextual Biasing w/ Longer Context

- Contextual biasing
 - Encoder biasing can be a little conservative than decoder biasing in terms of biasing ASR outputs, but decoder biasing could lead to more false positives, resulting in substitution errors.
 - Hybrid biasing has been popular, but is still challenged by large-scale biasing, e.g., 100k bias words.
- Large-scale biasing w/ retrieval
 - FAISS or something similar to enable efficient retrieval of contextual information from large-scale knowledge source has been recently explored with decent results.
- Retrieval augmented generation
 - Can be another biasing solution when it comes to LLMs being more utilized for ASR tasks.

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Recess (10 min) 16:50-17:00		
Huck (40 min) 17:00-17:40	Semantic Context and Speech-Language Modeling	
Kyu (30 min) 17:40-18:10	Contextual Biasing and Methods Leveraging Longer Semantic Context for Speech Systems	
Closing Remark (10 min) 18:10-18:20		
Q&A Session (10 min) 18:20-18:30		

Closing

Kyu J. Han

Long-Context Acoustic and Linguistic Insights



Acoustic Insights

- How **intrinsic variability** (Physiological traits, speaker characteristics) and **extrinsic variability** (mic, codecs) construct acoustic context for ASR
- How streaming ASR application and speaker attributed ASR takes advantage of acoustic context
- **Alternative architectures** for speech recognition
- Speech encoders and **ASR endpointing** in voice agents applications.



Linguistic Insights

- **Semantic Information Modeling** in End-to-End ASR: Classical ASR-LM, Post-processing ASR corrections
- Preference-based Semantic Modeling in Post-training
- **Semantic Understanding** from ASR to Audio Contexts
- Limitation and New Evaluation of Semantic Modeling: Data Leakage via Text, Pre-training Agentic & Instruction Evaluation



Context Biasing

- **Contextual Biasing** for E2E ASR Decoder, Encoder, Hybrid Biasing
- Retrieval Toward Large-Scale Biasing
- **Retrieval Augmented Generation (RAG)** and how RAG is used for contextual Biasing

Summary

Integrating long-context acoustic and linguistic insights

- Evaluation metrics
- Datasets
- Modeling frameworks leveraging acoustic and linguistic insights
- Trends in recent LLMs with long contextual information
- Semantic contextual biasing
- RAG-based contextual biasing for LLMs on ASR

Future Directions

- New tasks/datasets
 - Audio question answering, joint ASR/audio captioning, etc.
- More acoustic and semantic insights
 - Environmental, personal, regional, etc.
- Error correction and optimization with downstream tasks
 - For example, WER improvement vs. more useful clinical note generation, does the former guarantee the latter all the time?
- RAG vs. long-context LLMs
 - Whether to use RAG or use long-context LLMs as is.
- Multimodal biasing for multimodal LLMs
 - How to incorporate multimodal context biasing.

Future Directions

CARE
Conference on
Animal Rights in Europe
14th - 16th AUGUST 2020
Online

**STIEN VAN
DER PLOEG**

You Don't Need to
Be a Manager to Lead



Slide

GT	okay so let me introduce our 1st speaker who is stien van der ploeg	without it we are less effective without it we will not have justice we are all animals
AV	okay so let me introduce our 1st speaker who is stein van der ploeg	without it we are less effective without it we will not have justice we are all animals
A	okay so let me introduce our 1st speaker who is steam funder plu	without it we are less effective without it we will not have guests we are all animals

DIVERSITY, EQUITY, INCLUSION

- **Diversity:** people with different identities and ways of thinking are represented
- **Equity:** people have what they need to thrive
- **Inclusion:** people are heard and feel they belong

Without it we are less effective. Without it we won't have **justice**. We are all animals.



Thank you for your Attention!

Questions And Answers



Backup Appendix

Appendix: Privacy and LLM Data Leakage

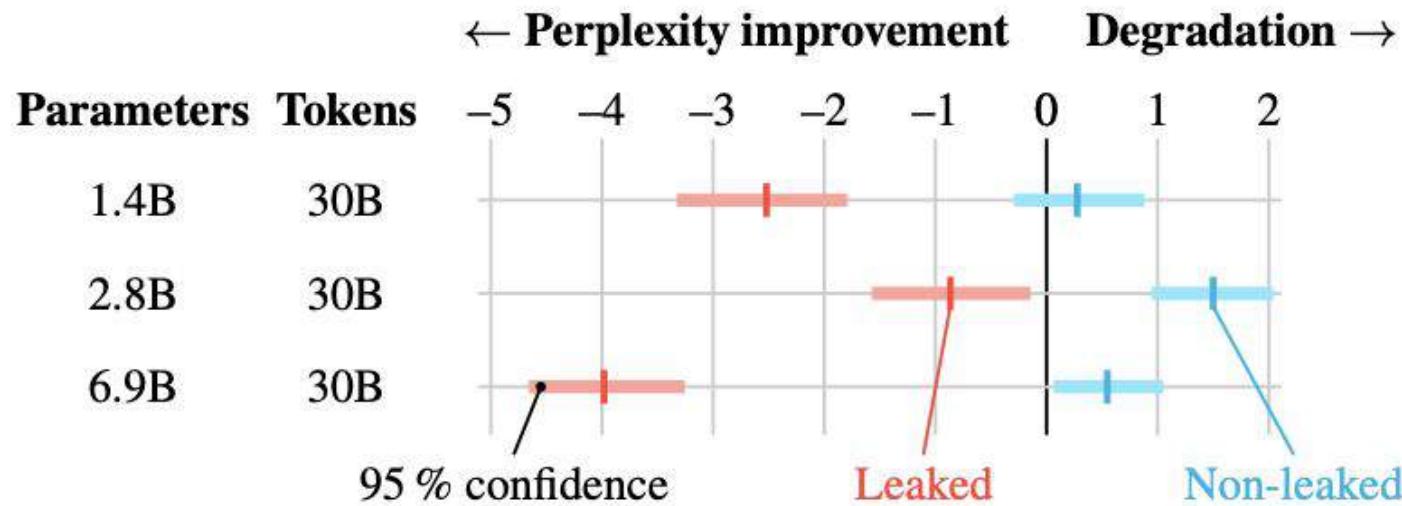
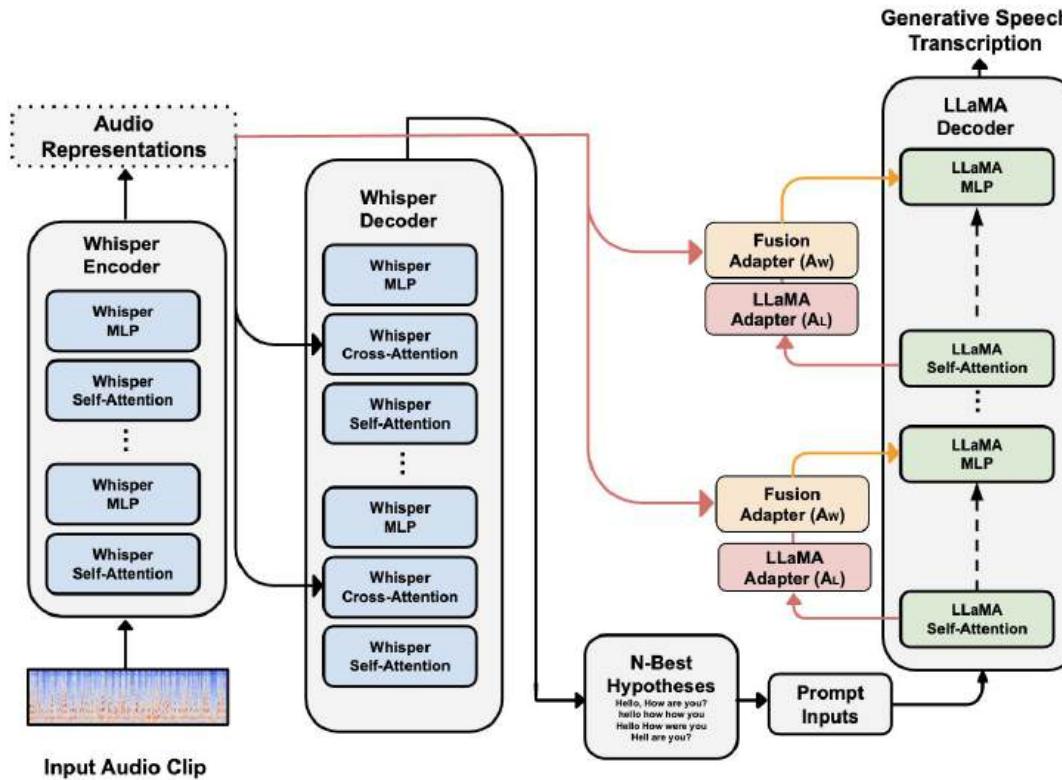


Image Source: Evaluation of LLMs in Speech is Often Flawed:
Test Set Contamination in Large Language Models for Speech
Recognition, Yuan Tseng et al. 2025

Appendix: Whispering-LLaMA on the attention merging



Pipeline

