Multi-class Spectral Clustering with Overlaps

for Speaker Diarization

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Motivation

What is speaker diarization?

Task of “who spoke when”

Input: ***recording containing multiple speakers***

Output: ***homogeneous speaker segments***

Xavier Anguera Miro et al., “Speaker diarization: A review of recent research,” IEEE Transactions on Audio, Speech, and Language Processing, 2012.

Motivation

What is speaker diarization?

Task of “who spoke when”

Input: ***recording containing multiple speakers***

Number of speakers may be unknown

Overlapping speech may be present

Output: ***homogeneous speaker segments***

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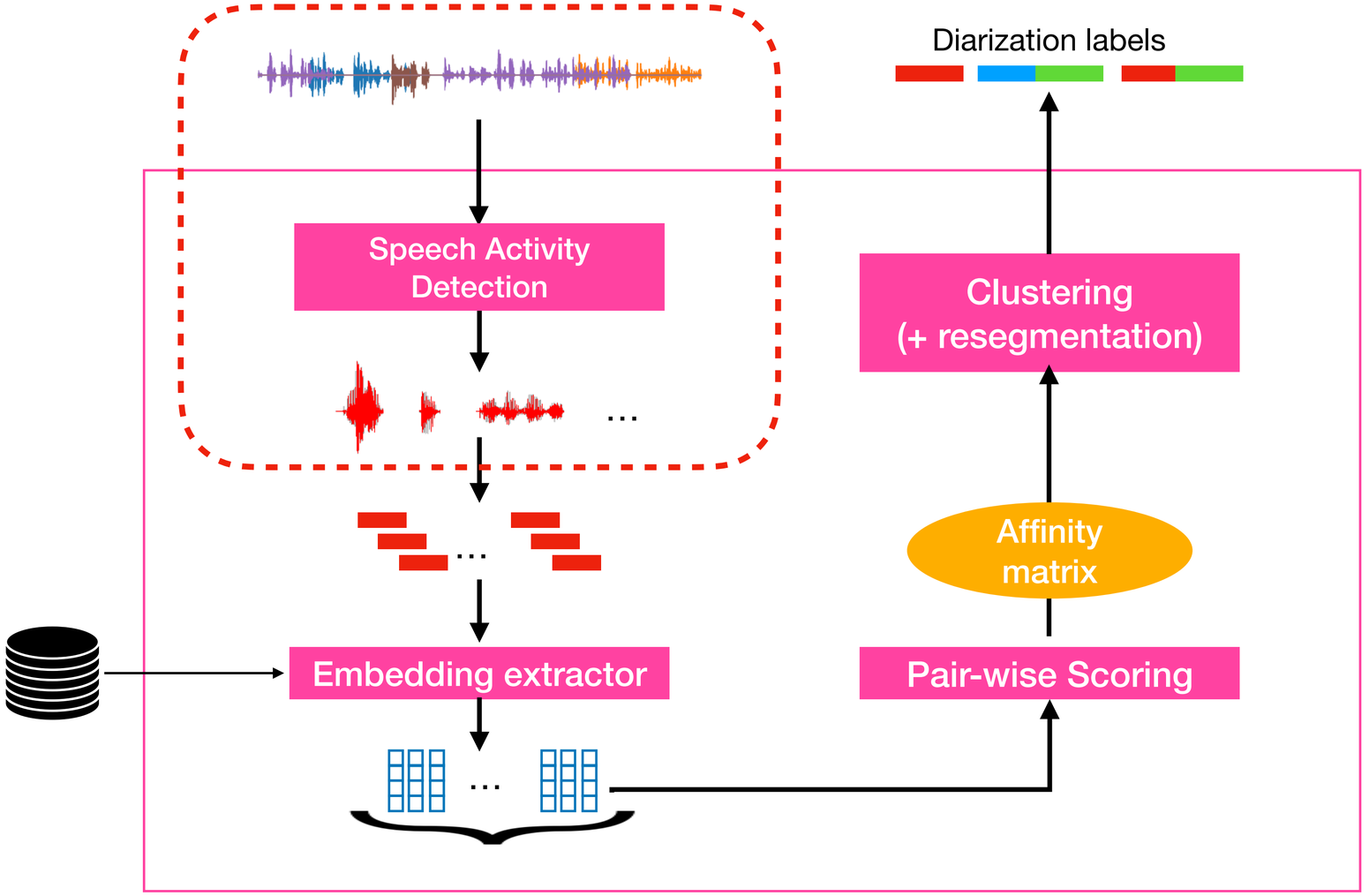
Traditional clustering-based diarization

SAD extracts speech segments from recordings



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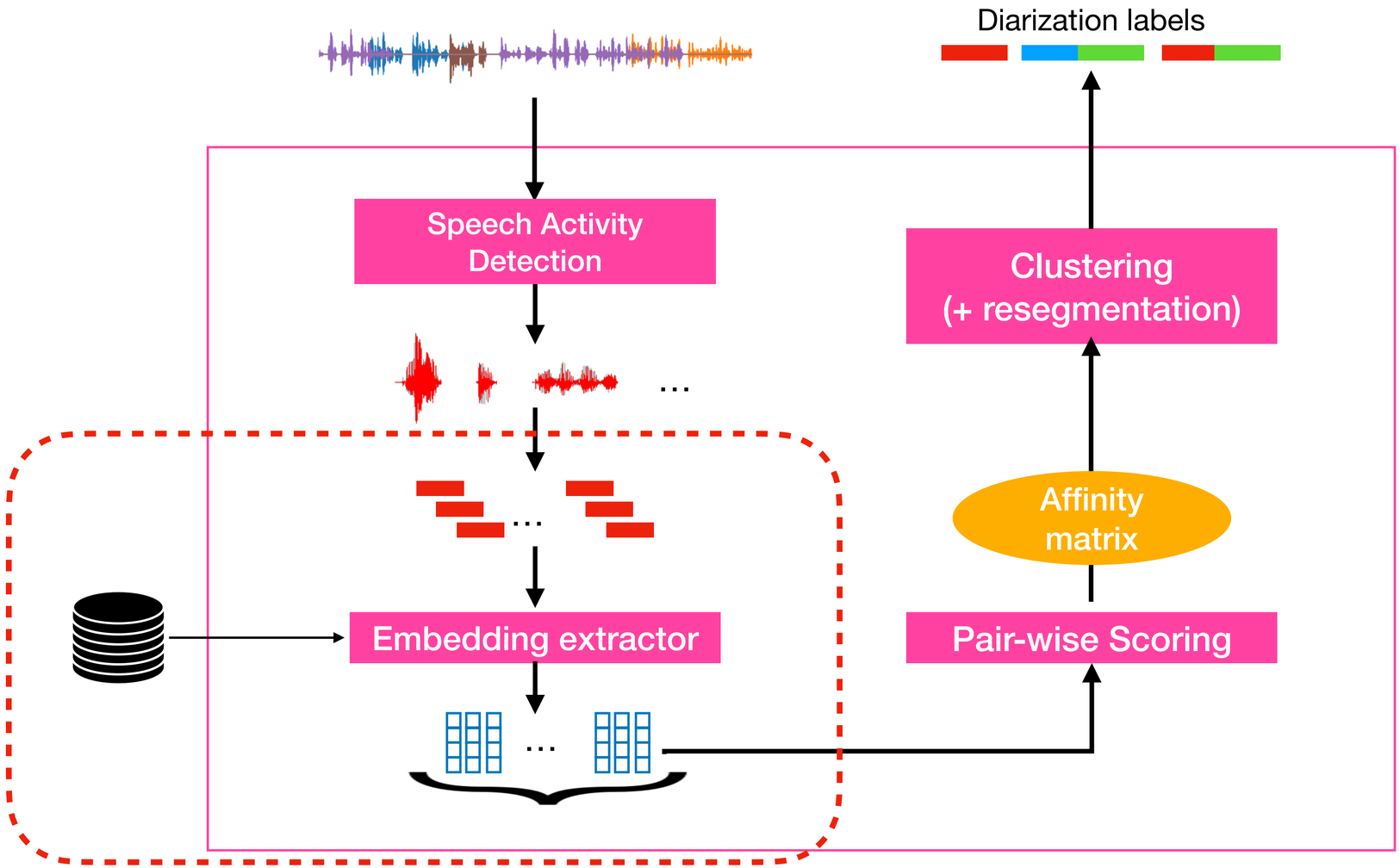
Traditional clustering-based diarization

Embeddings extracted for small subsegments



i-vectors
x-vectors
d-vectors

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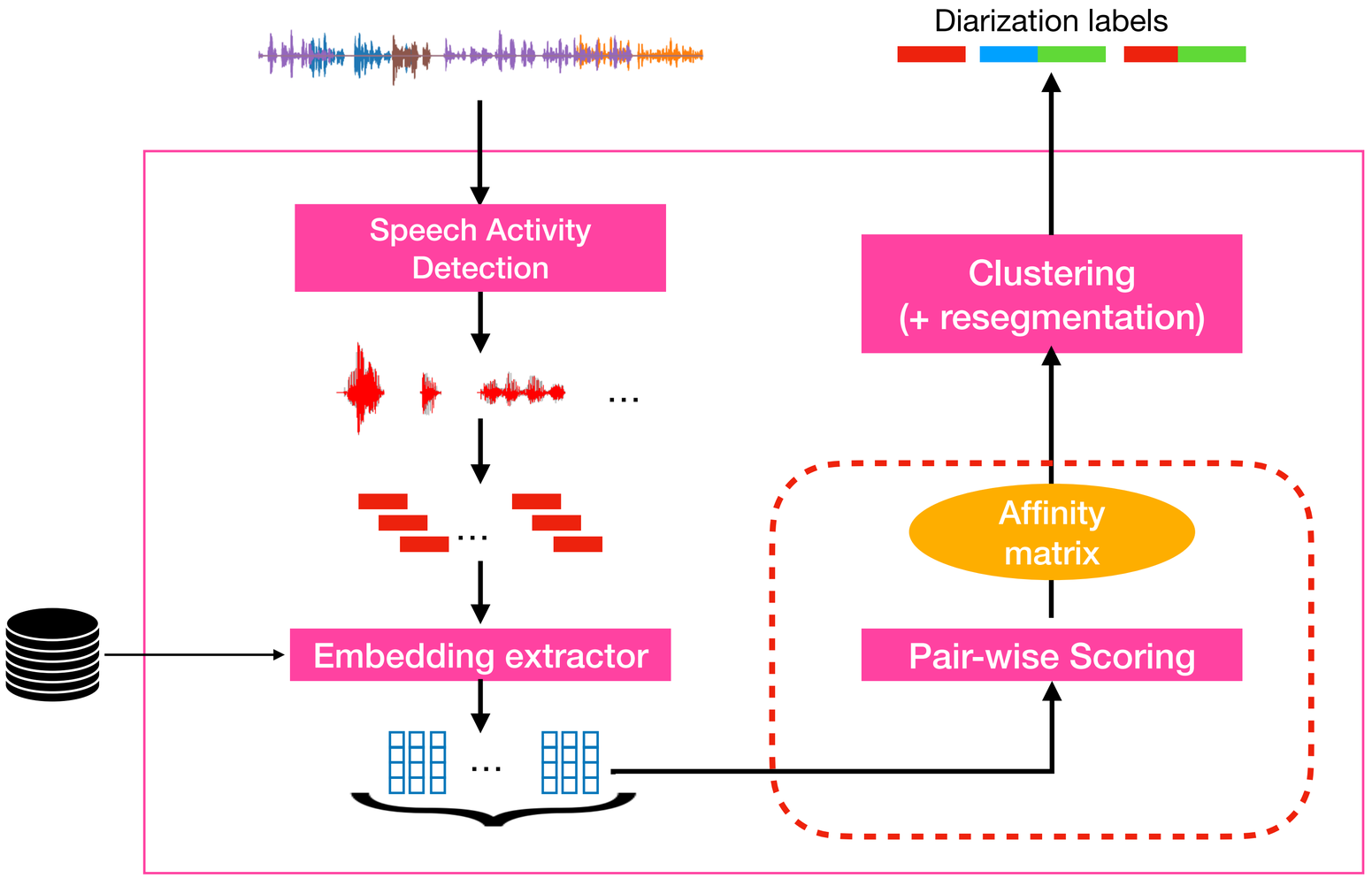
Traditional clustering-based diarization

Pair-wise scoring of subsegments



PLDA scoring
Cosine scoring

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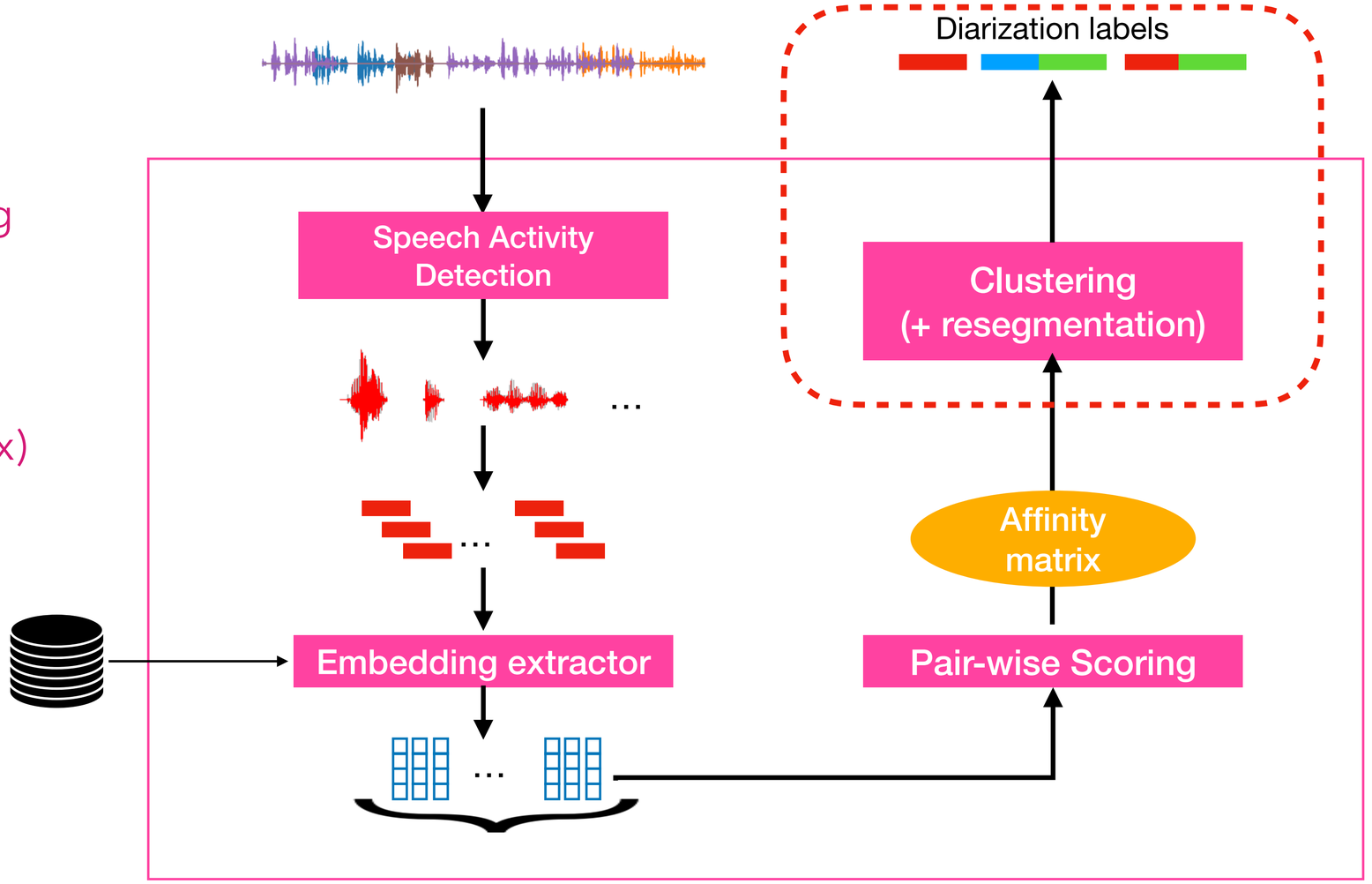
Traditional clustering-based diarization

Clustering based on the affinity matrix, followed by optional resegmentation

Agglomerative hierarchical clustering

Spectral clustering

Variational Bayes (VBx)



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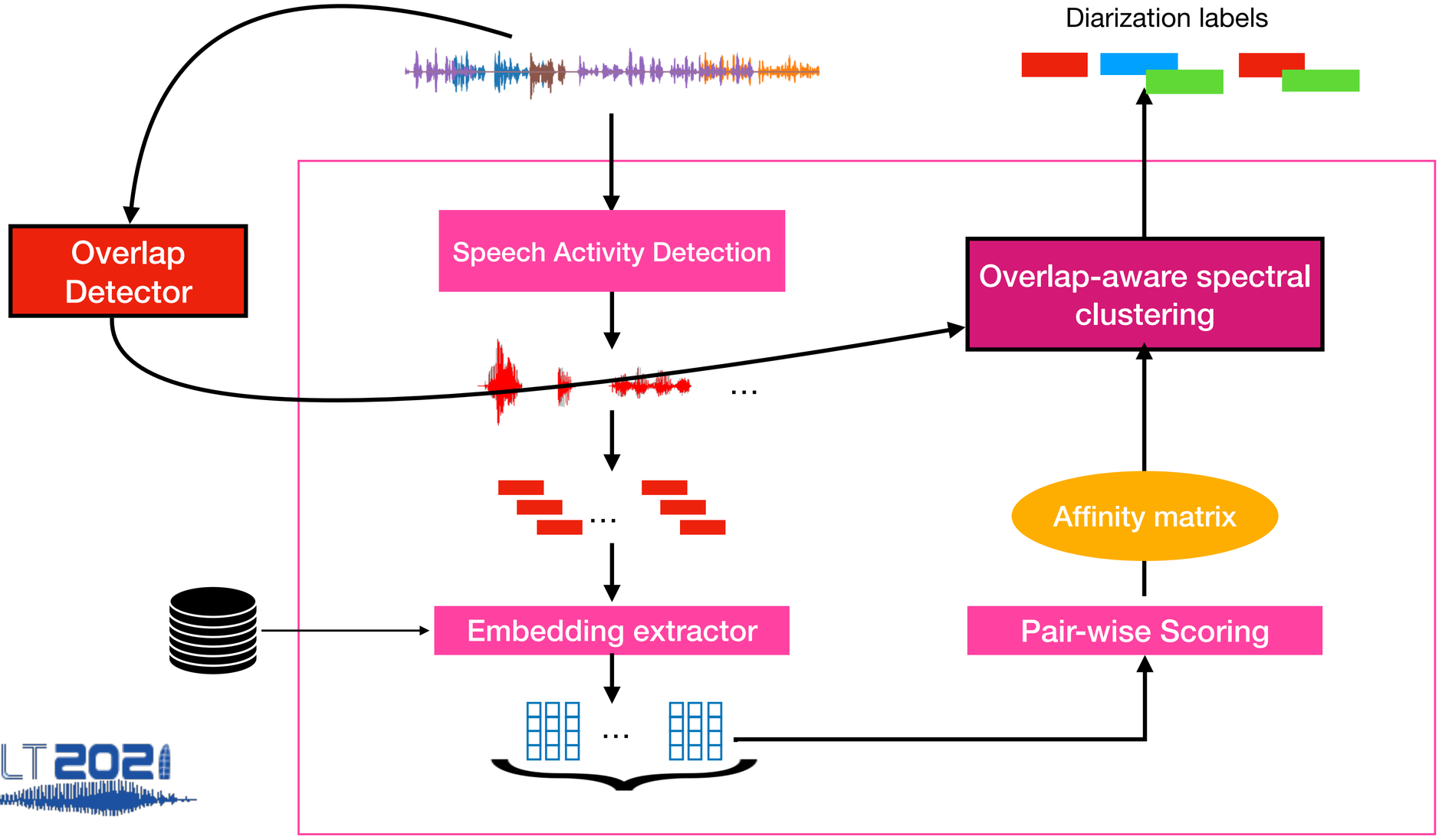
Clustering paradigm assumes single-speaker segments

So overlapping speakers are completely ignored!

Overlap-aware spectral clustering



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Results on AMI Mix-Headset eval

12.0% relative improvement over spectral clustering baseline

System	DER
Spectral clustering	26.9
AHC	28.3
VBx	26.2
Overlap-aware SC	**24.0**

Park et al., “Auto-tuning spectral clustering for speaker diarization using normalized maximum eigengap,” IEEE Signal Processing Letters, 2020.

Garcia-Romero et al., “Speaker diarization using deep neural network embeddings,” ICASSP 2017.

Dîez et al., “Speaker diarization based on Bayesian HMM with eigenvoice priors,” Odyssey 2018.

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Results on AMI Mix-Headset eval

Comparable with other overlap-aware diarization methods

System	DER
VB-based overlap assignment	23.8
Region proposal networks	25.5
Overlap-aware SC	**24.0**

Bullock, et al., “Overlap-aware diarization: resegmentation using neural end-toend overlapped speech detection,” ICASSP 2020.

Huang et al., “Speaker diarization with region proposal network,” ICASSP 2020.

Does not require **matching training data** or **initialization** with other diarization systems.

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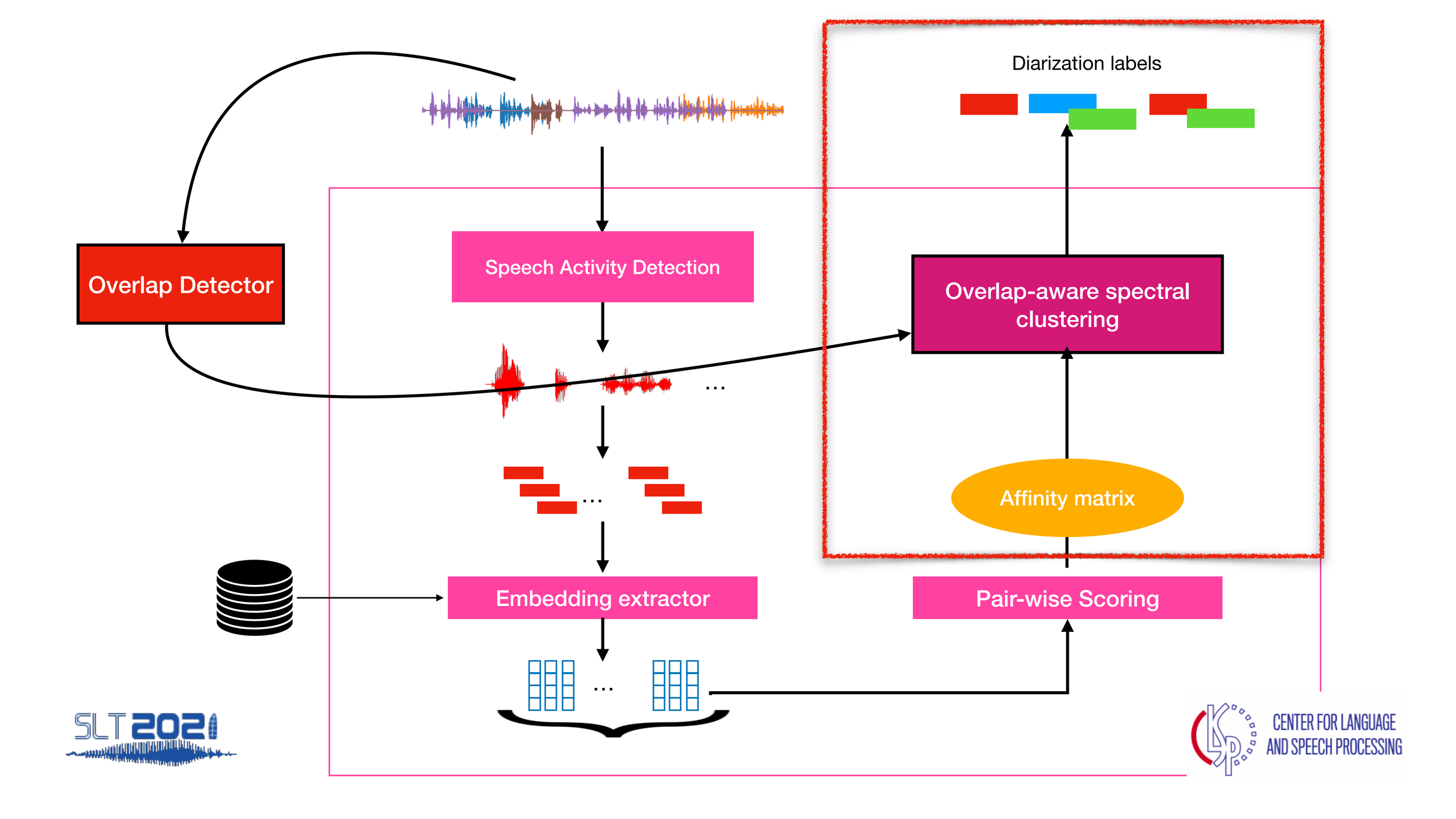
End of Highlight

Overview

- Overlap-aware spectral clustering
  - Estimating number of speakers
  - Reformulation of the clustering problem
  - Incorporating overlap detector output
- HMM-DNN overlap detector: Overview
- More Results
  - Error analysis on AMI


Diarization labels
Overlap Detector
Speech Activity Detection
Overlap-aware spectral clustering
Affinity matrix
Embedding extractor
Pair-wise Scoring
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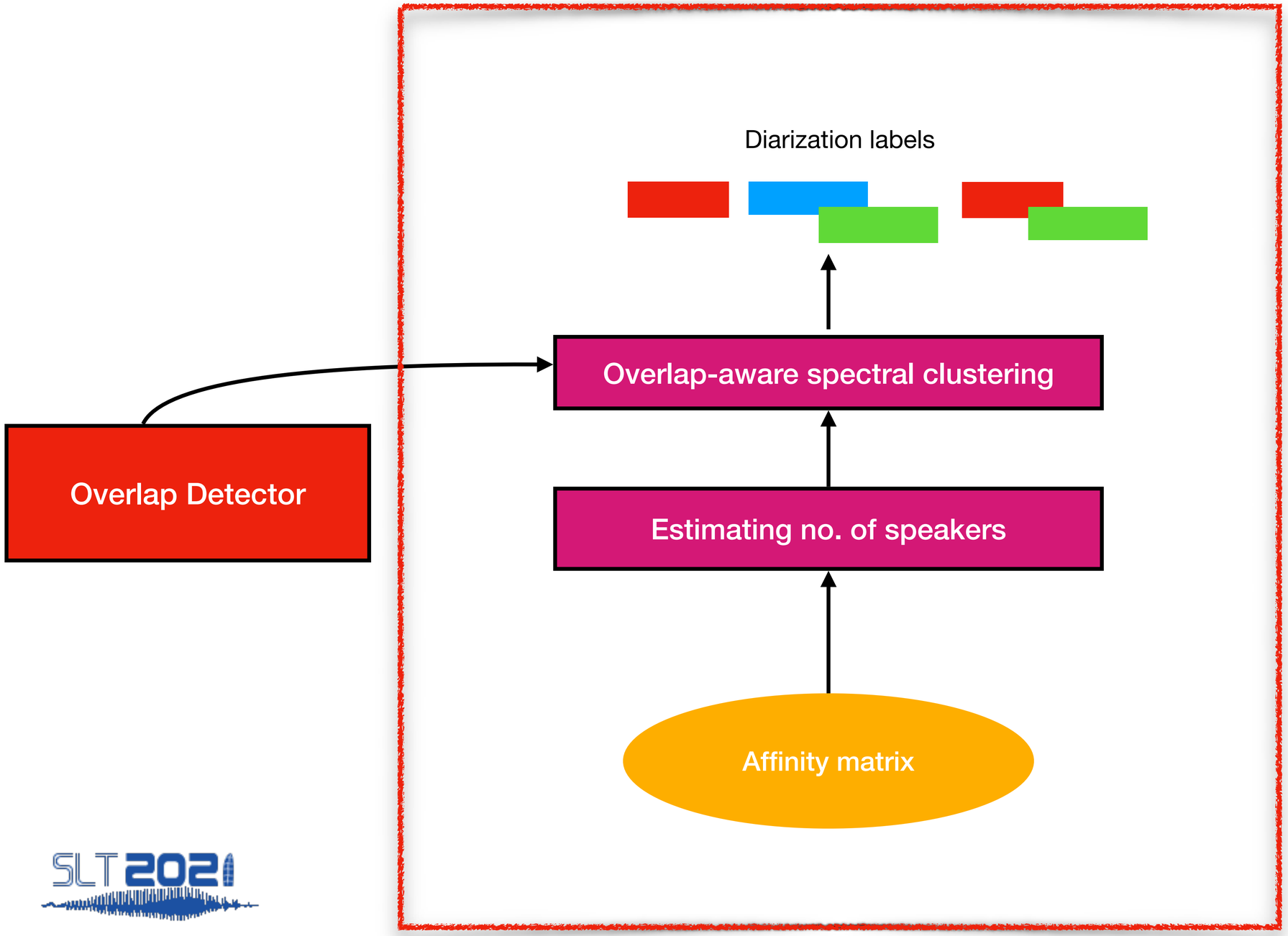

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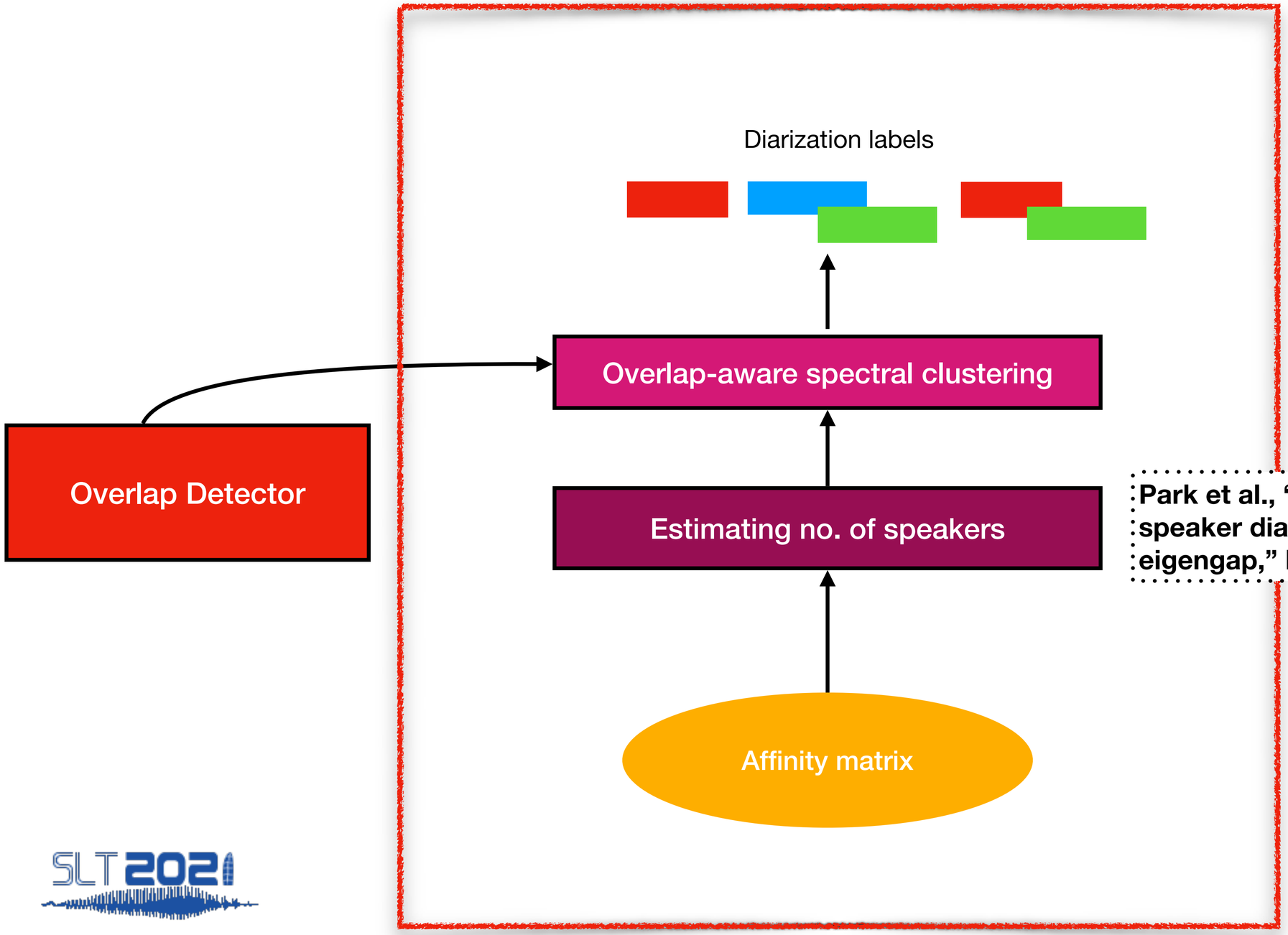

Park et al., “Auto-tuning spectral clustering for speaker diarization using normalized maximum eigengap,” IEEE Signal Processing Letters, 2020.

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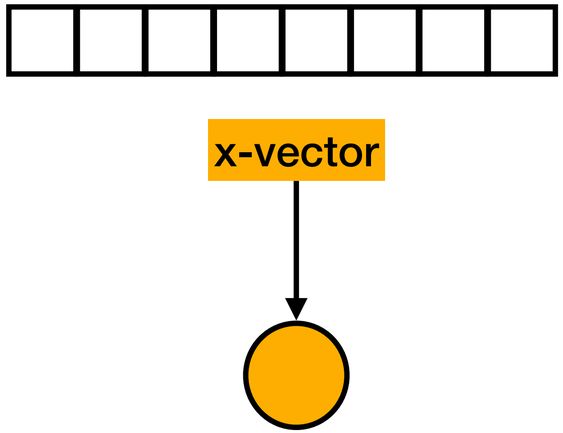
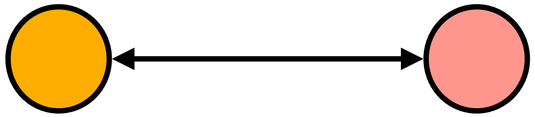
New formulation for spectral clustering

The basic clustering problem: a graph view

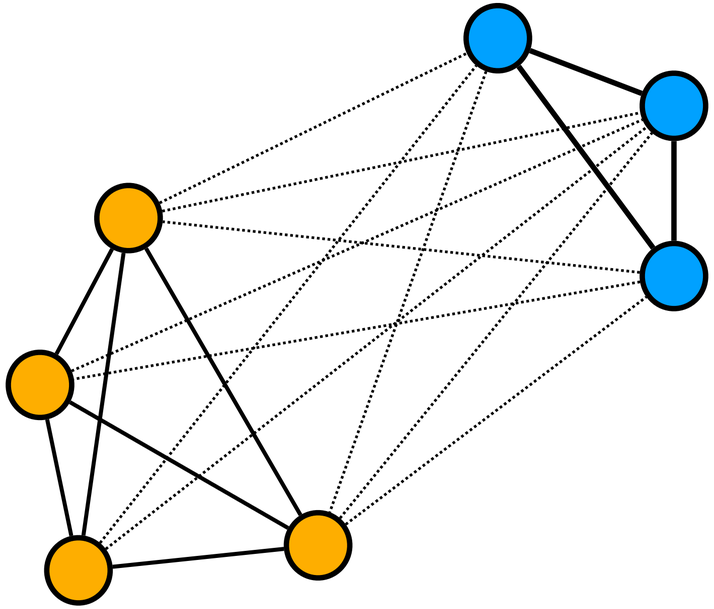




Cosine similarity

New formulation for spectral clustering

The basic clustering problem: a graph view

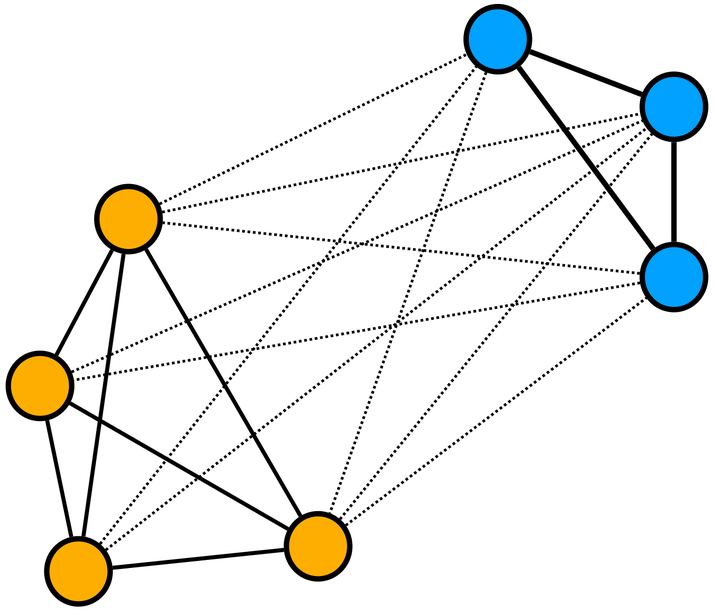


Edge weights within a group

Edge weights across groups

New formulation for spectral clustering

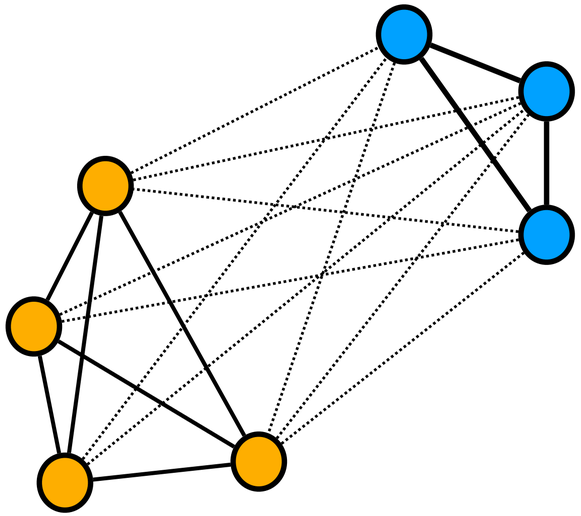
The basic clustering problem: a graph view



$$\textit{maximize} \quad \frac{\text{Edge weights within a group}}{\text{Edge weights across groups}}$$

New formulation for spectral clustering

The basic clustering problem: a graph view



maximize $\dfrac{\text{Edge weights within a group}}{\text{Edge weights across groups}}$

$$\text{maximize} \quad \epsilon(X) = \frac{1}{K}\sum_{k=1}^{K}\frac{X_k^T\mathbf{A}X_k}{X_k^T\mathbf{D}X_k}$$

$$\text{subject to} \quad X \in \{0,1\}^{N\times K},$$

$$X\mathbf{1}_K = \mathbf{1}_N\,.$$

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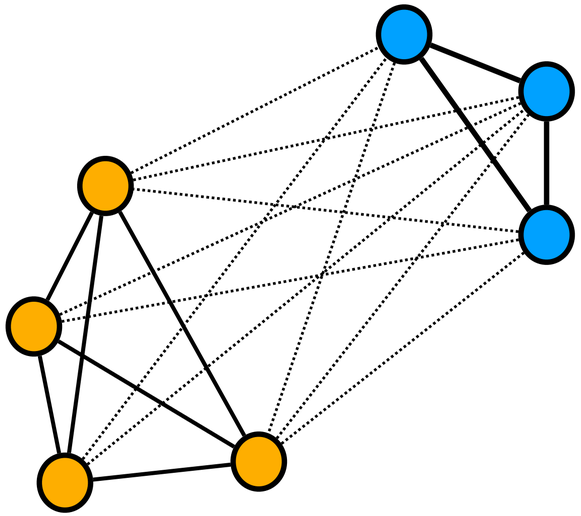
New formulation for spectral clustering

The basic clustering problem: a graph view



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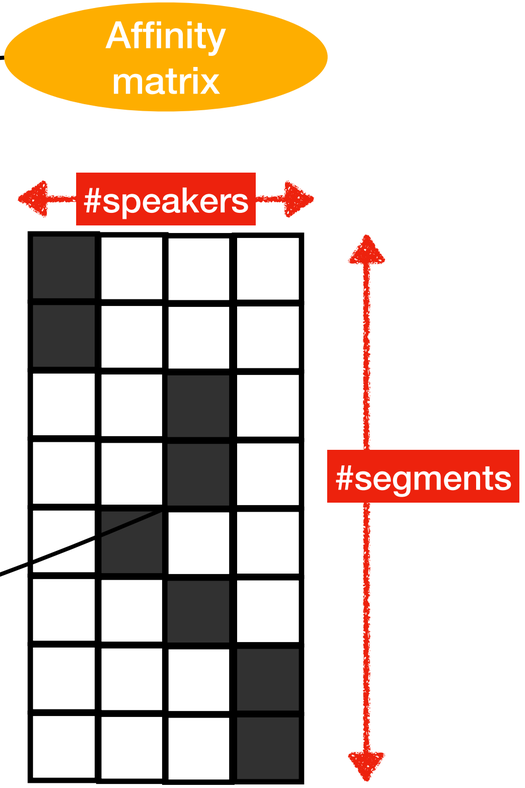


New formulation for spectral clustering

This problem is NP-hard!

$$\text{maximize} \quad \epsilon(X) = \frac{1}{K} \sum_{k=1}^{K} \frac{X_k^T \mathbf{A} X_k}{X_k^T \mathbf{D} X_k}$$

$$\text{subject to} \quad X \in \{0,1\}^{N \times K},$$

$$X\mathbf{1}_K = \mathbf{1}_N.$$

Remove the discrete constraints to make the problem solvable

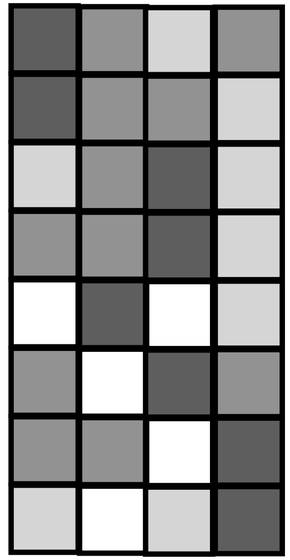
New formulation for spectral clustering

Relaxed problem has a set of solutions

$$\text{maximize} \quad \epsilon(X) = \frac{1}{K} \sum_{k=1}^{K} \frac{X_k^T \mathbf{A} X_k}{X_k^T \mathbf{D} X_k}$$

$$\text{subject to} \quad X \in \{0,1\}^{N \times K},$$

$$X\mathbf{1}_K = \mathbf{1}_N.$$

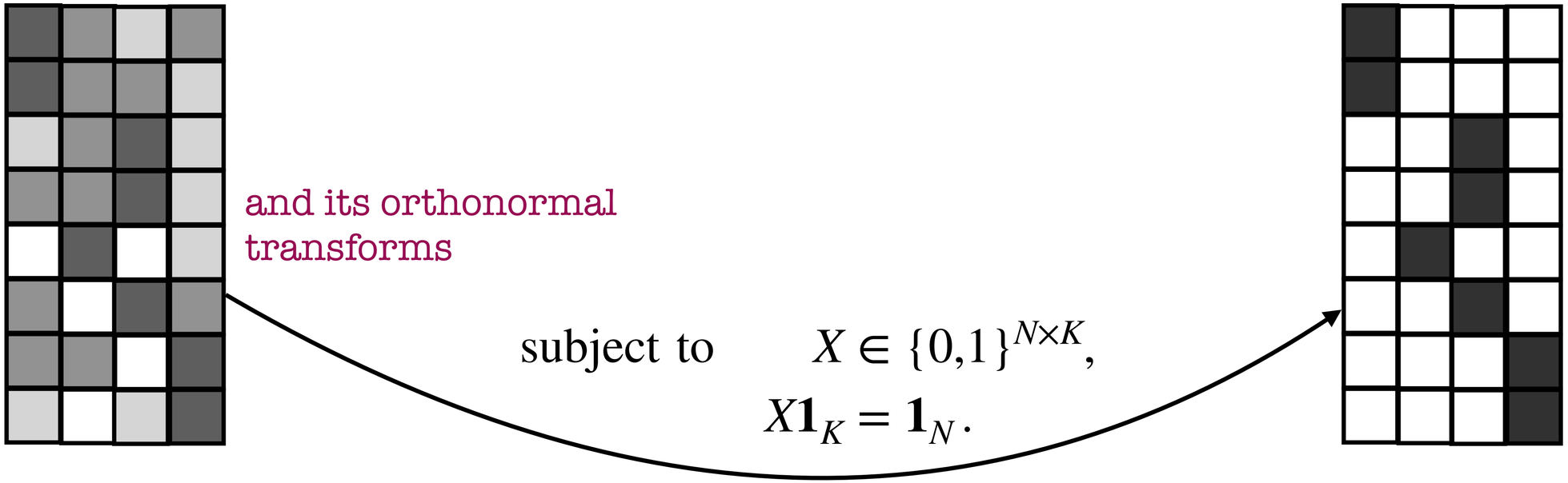


and its orthonormal transforms

Solution to the **relaxed** problem

New formulation for spectral clustering

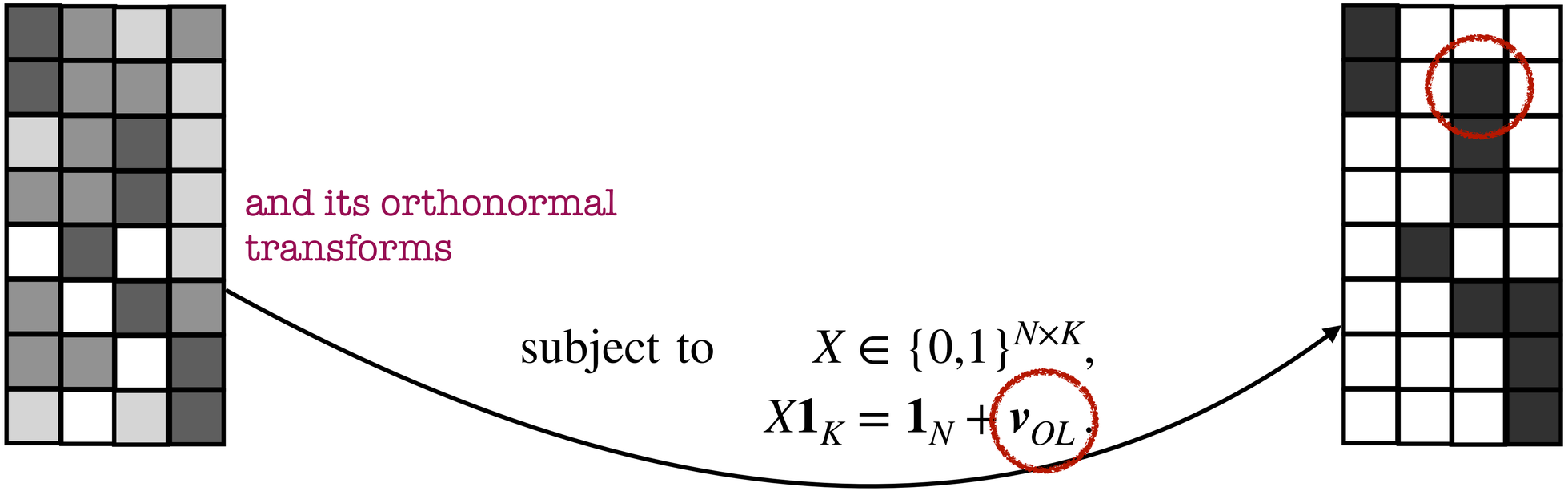
Now we need to discretize this solution!



Find a matrix which is **discrete** and also close to any one of the **orthonormal transformations** of the relaxed solution

Here we use the overlap detector output

Suppose we have $\mathbf{v}_{OL}$



Non-maximal suppression: for overlapping segments, select top 2 speakers

How does it compare with …

… VB-based overlap assignment

Bullock, et al., "Overlap-aware diarization: resegmentation using neural end-toend overlapped speech detection," ICASSP 2020.

	Overlap-aware SC	VB based overlap assignment	
✓	No initialization required	Needs initialization, e.g. from AHC system	✗
✗	Does segment-level assignment (coarse)	Does frame-level assignment (fine-grained)	✓

How does it compare with …

… EEND, RPN, TS-VAD

	Overlap-aware SC	RPN, EEND, TS-VAD	
✗	Uses external overlap detector	Includes overlap detection/assignment	✓
✓	Matched training data not required	Requires matched (simulated) training data	✗

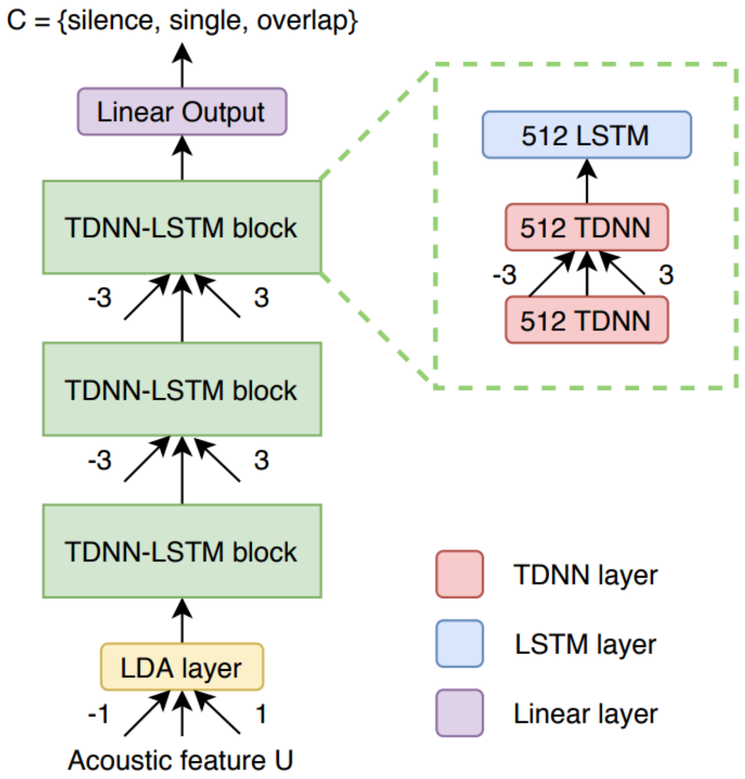
Huang et al., “Speaker diarization with region proposal network,” ICASSP 2020.

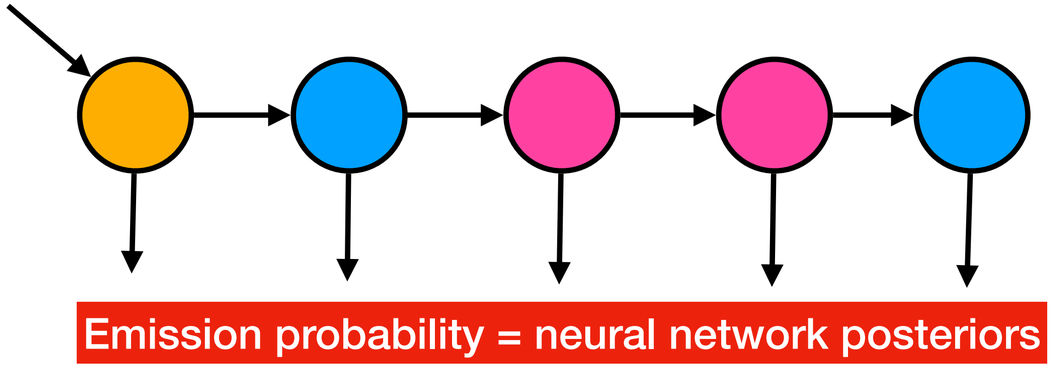
Fujita et al., “End-to-end neural diarization: Reformulating speaker diarization as simple multi-label classification,” ArXiv.

Medennikov, et al., “Target speaker voice activity detection: a novel approach for multispeaker diarization in a dinner party scenario,” Interspeech 2020.

Hybrid HMM-DNN overlap detector

(Now merged as a KALDI recipe)





Viterbi decoding used for inference

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Results: DER breakdown on AMI eval

System	Missed speech	False alarm	Speaker conf.	DER
AHC/PLDA	19.9	0.0	8.4	26.9
Spectral/cosine	19.9	0.0	7.0	28.3
VBx	19.9	0.0	6.3	26.2
VB-based overlap assignment	13.0	3.6	7.2	23.8
RPN	9.5	7.7	8.3	25.5
Overlap-aware SC	11.3	2.2	10.5	24.0

Results: DER breakdown on AMI eval

Missed speech decreases significantly

System	Missed speech	False alarm	Speaker conf.	DER
AHC/PLDA	19.9	0.0	8.4	26.9
Spectral/cosine	19.9	0.0	7.0	28.3
VBx	19.9	0.0	6.3	26.2
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Results: DER breakdown on AMI eval

Speaker confusion increases

System	Missed speech	False alarm	Speaker conf.	DER
AHC/PLDA	19.9	0.0	8.4	26.9
Spectral/cosine	19.9	0.0	7.0	28.3
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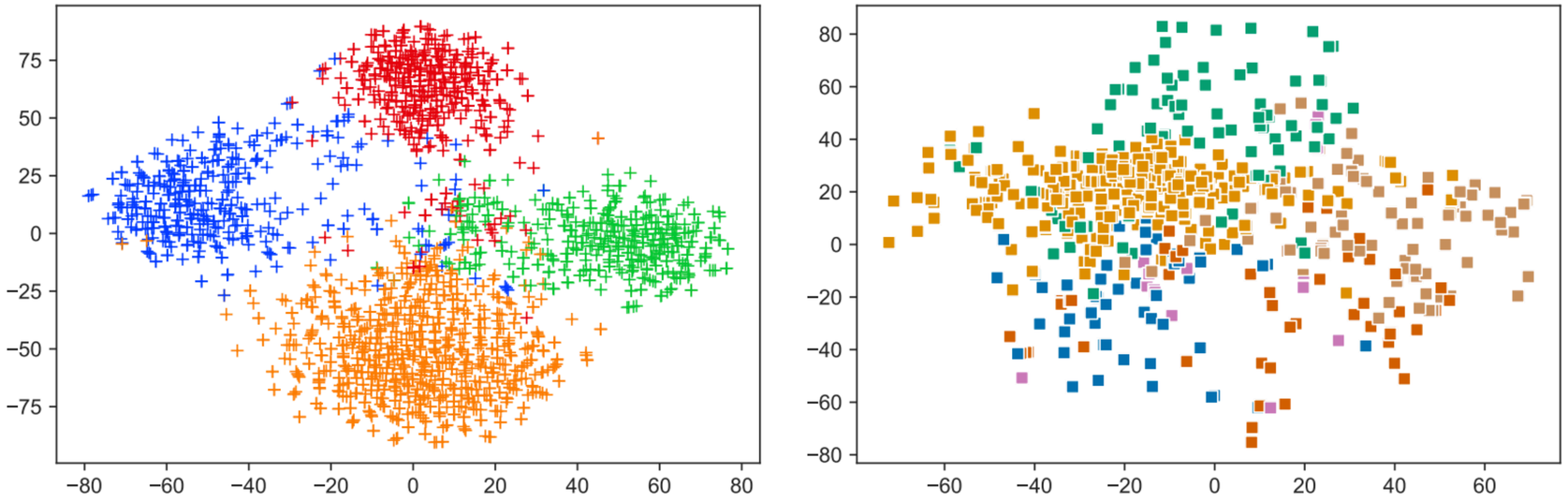
Future work: train a more robust x-vector extractor



Non-overlapping segments

Overlapping segments

T-SNE plot of x-vector embeddings

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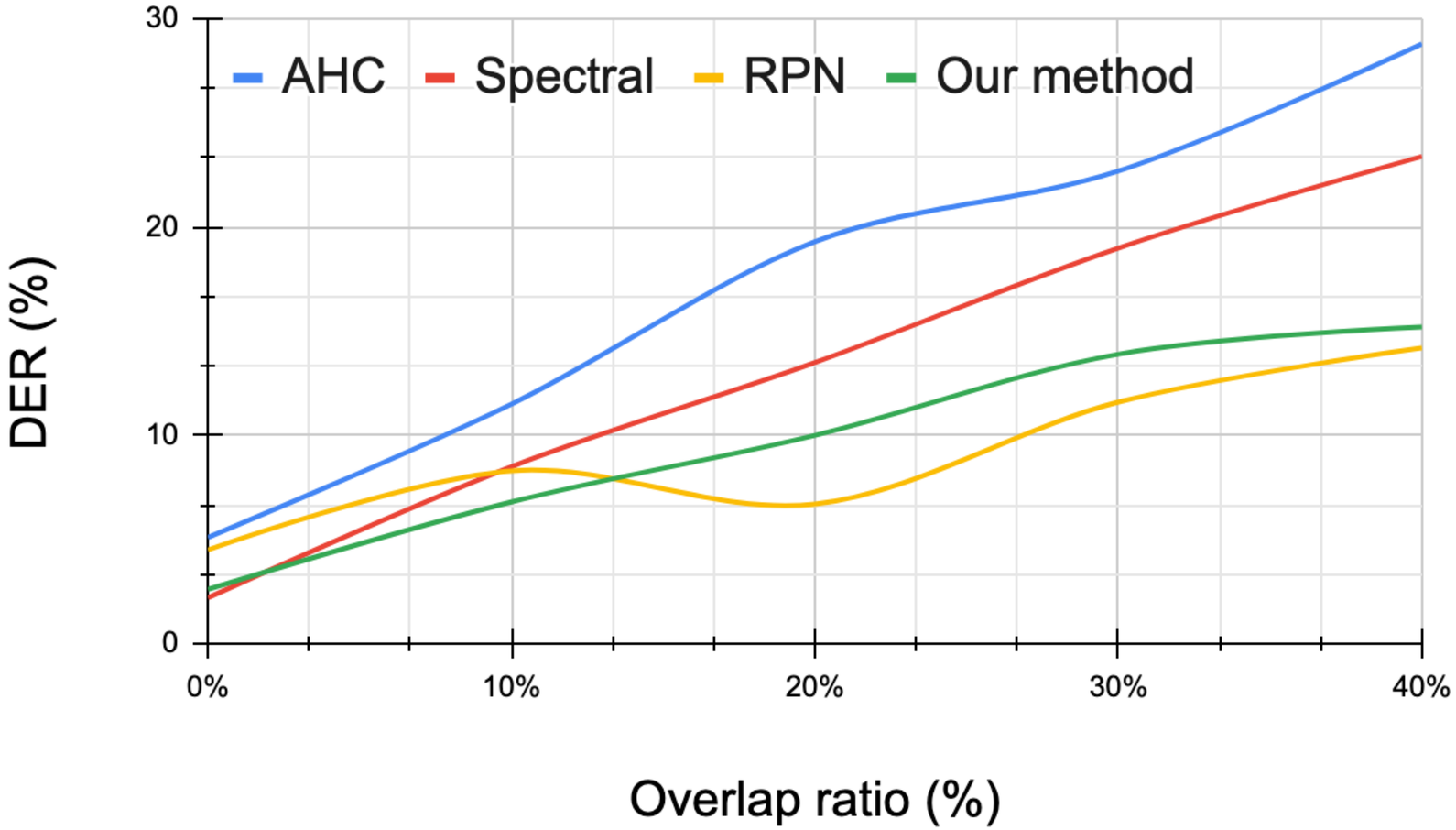
More results: DER on LibriCSS



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Try out the code!

Acknowledgments:

Paola Garcia, for helpful discussions and insights.

Takuya Yoshioka, for simulation script for generating LibriCSS training data.

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