Crowdsourcing Audio Annotations: Findings and Next Steps

Mark Cartwright, Justin Salamon, Ayanna Seals, Ana Elisa Mendez Mendez, Graham Dove, Juan Bello, Oded Nov

Mark Cartwright
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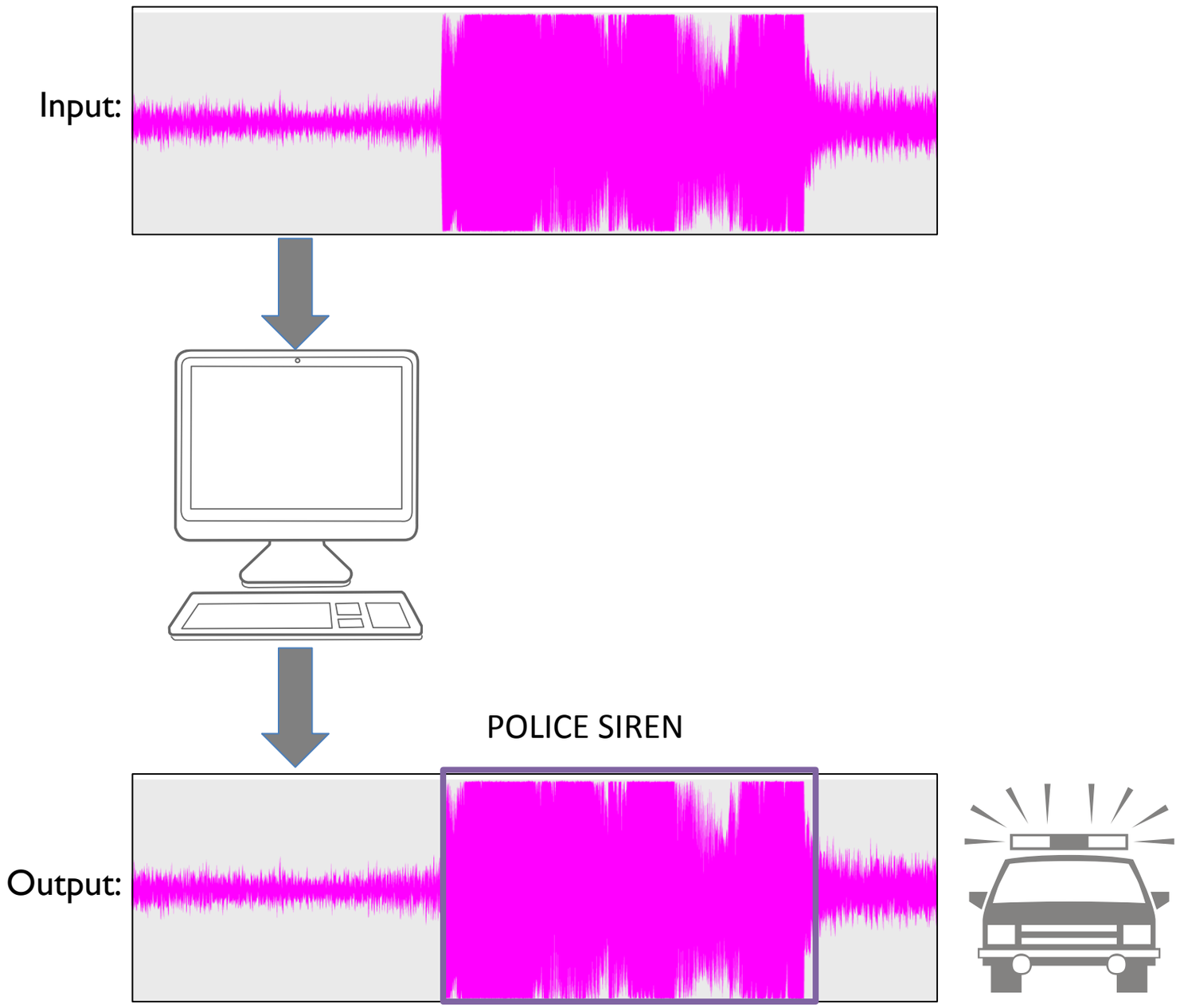
Music and Audio Research Laboratory

Audio Annotation of Sound-Event Detection



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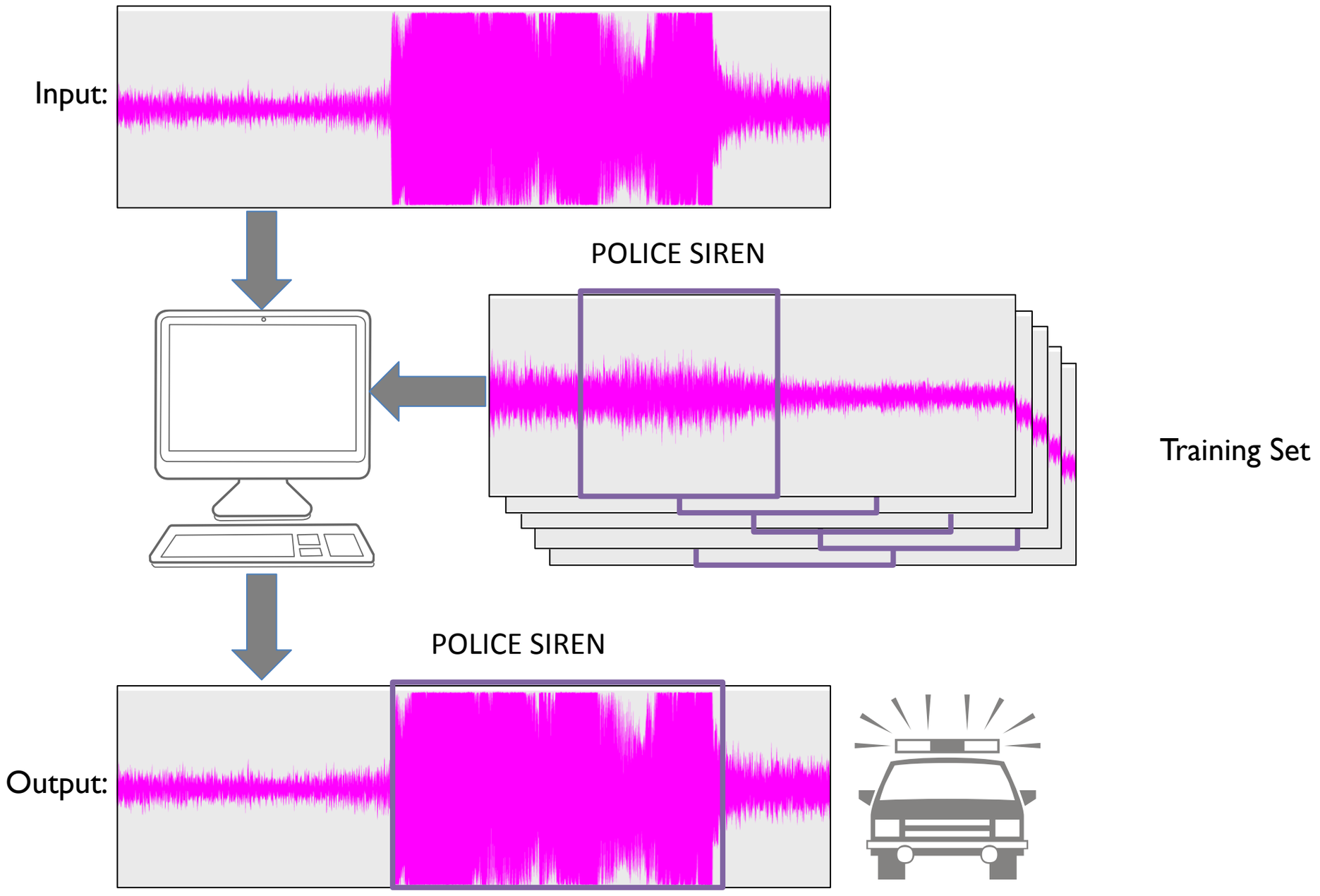

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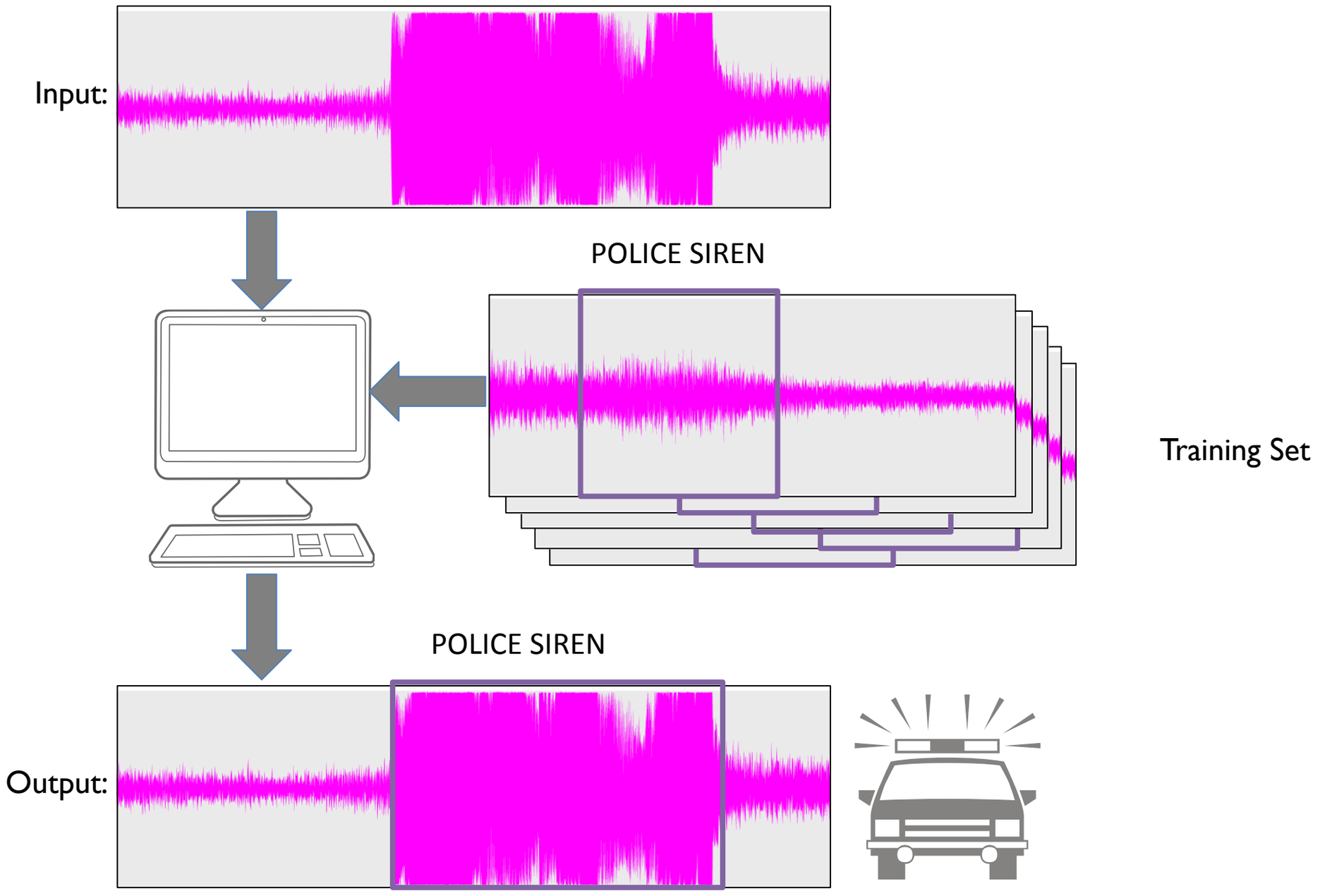
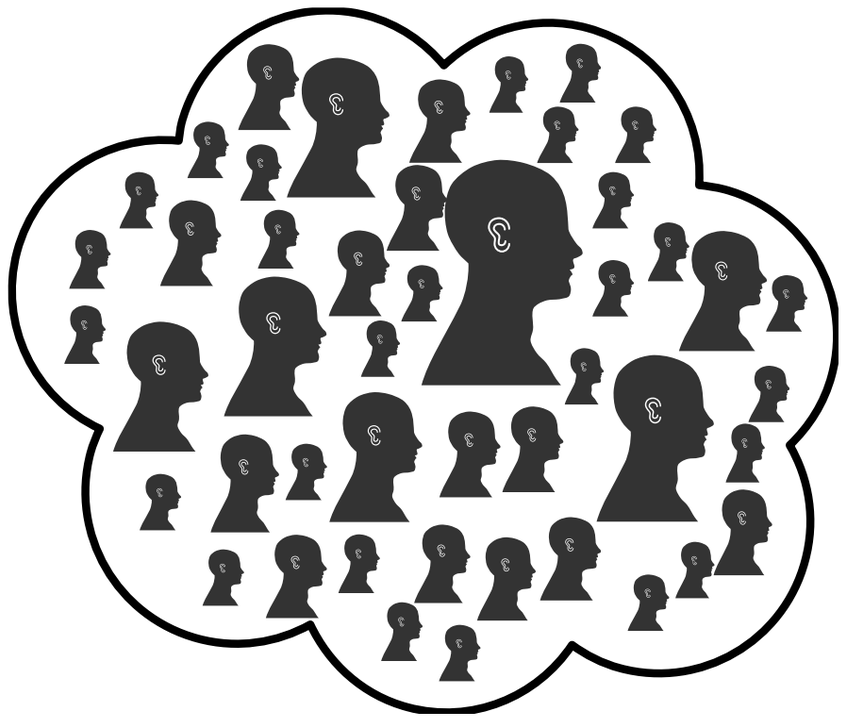


Research Questions

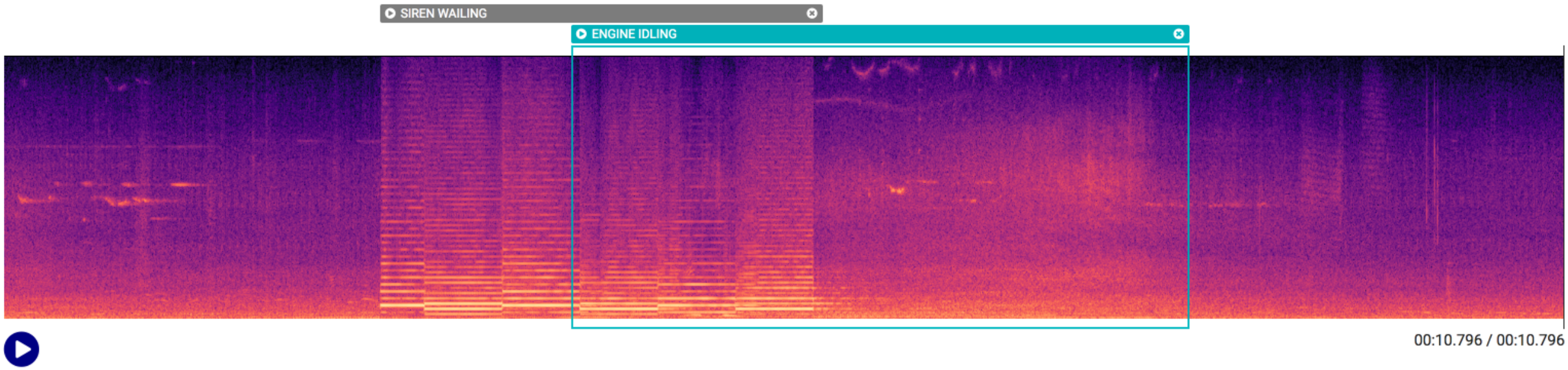
- Which sound visualization aid yields the highest quality crowdsourced audio annotations?

- What limitations can we expect from crowdsourced audio annotations as a function of soundscape complexity?



The Audio Annotator

Configured with the spectrogram visualization:

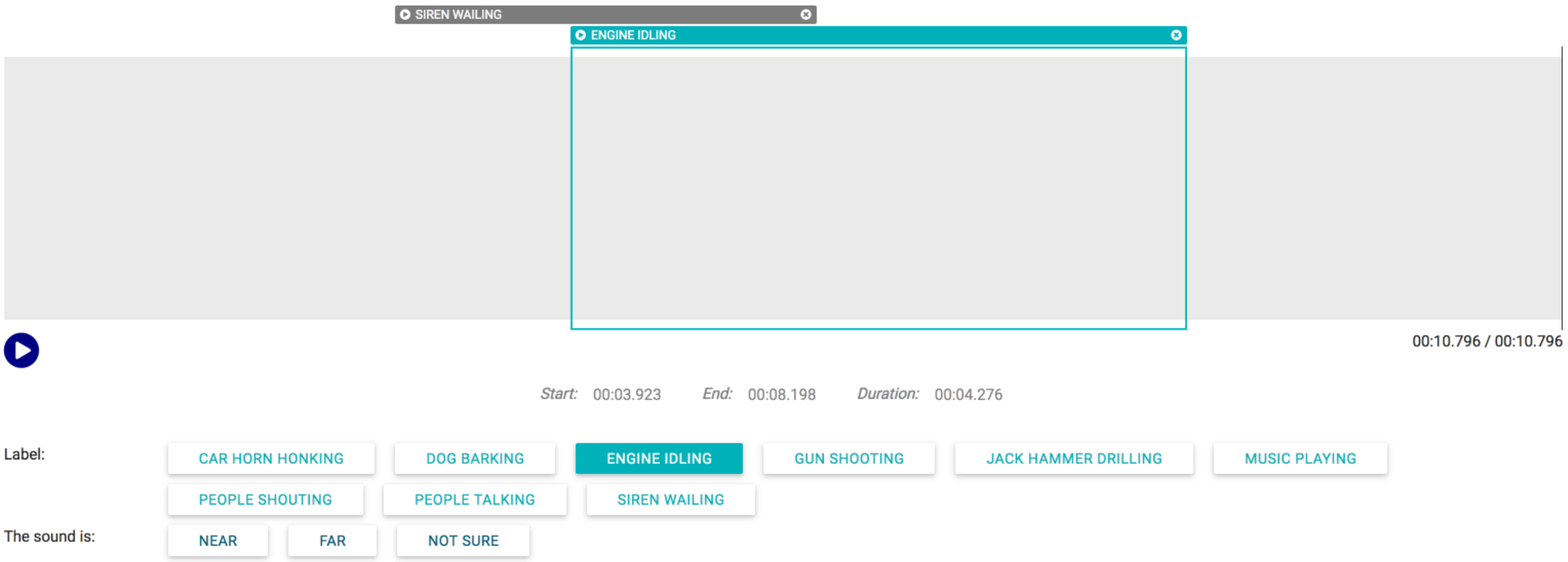


The Audio Annotator

Configured with the waveform visualization:

The Audio Annotator

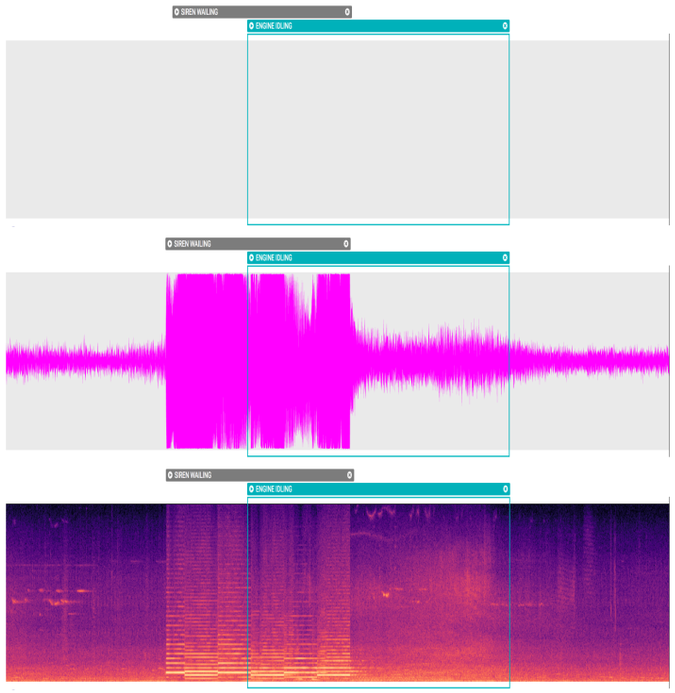
Configured without a visualization:



Experiment

- 3 x 3 x 2 between-subjects factorial design:

visualization	max-polyphony	gini-polyphony
NV	M0	G0
W	M1	G1
S	M2	



- Soundscape examples:
  M0G0 M0G1 M2G0 M2G1

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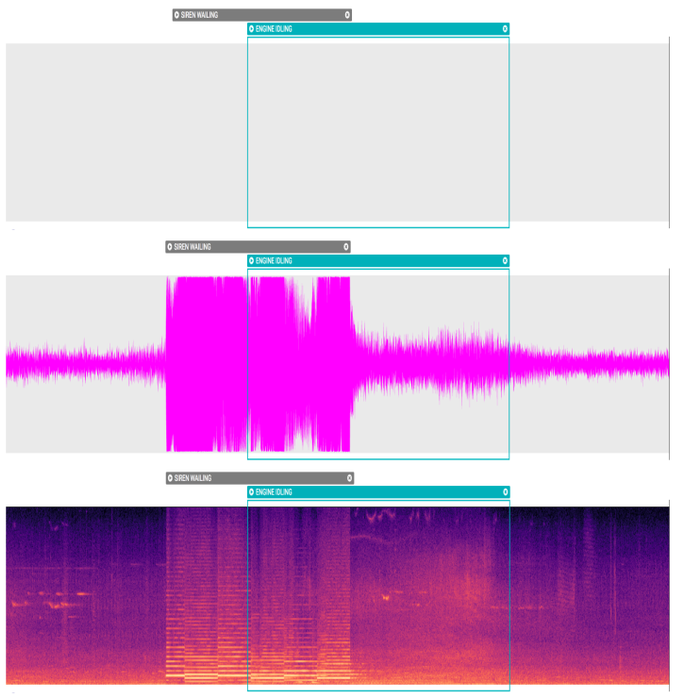
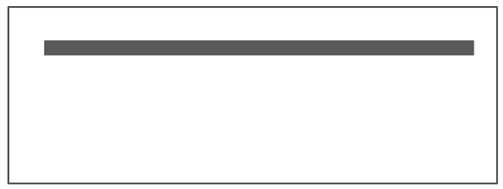
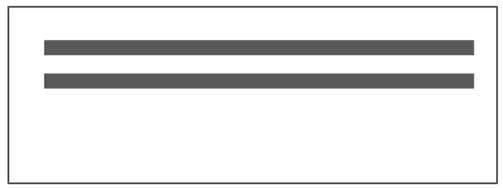
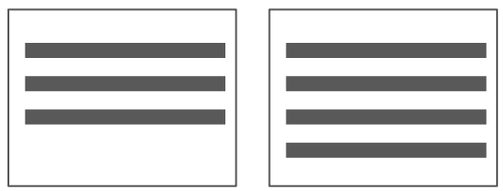
NV		M0 	G0 
W		M1 	G1 
S		M2 	

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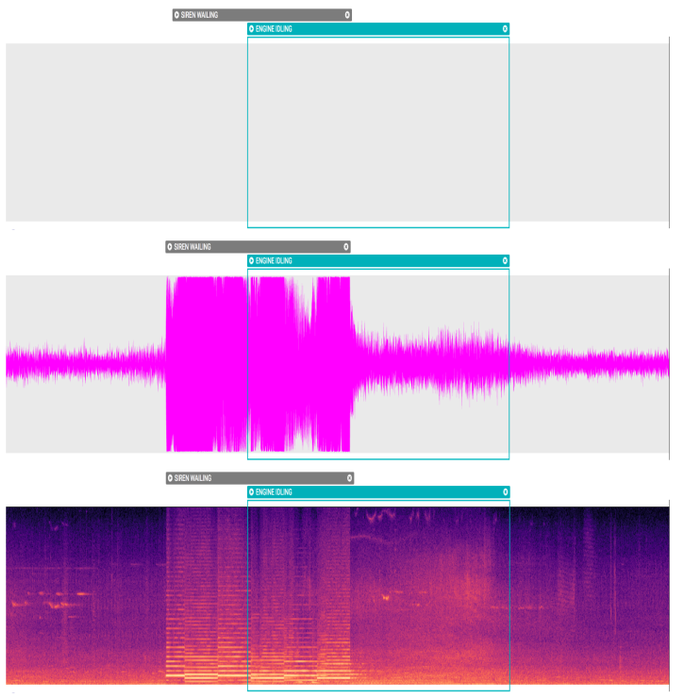
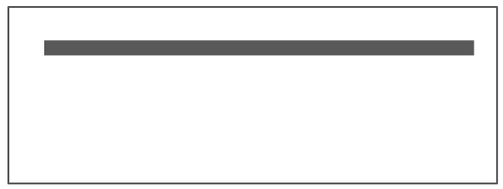
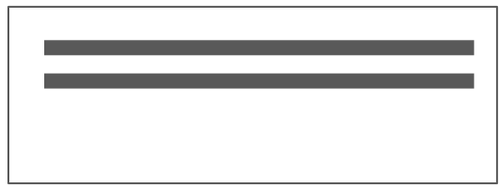
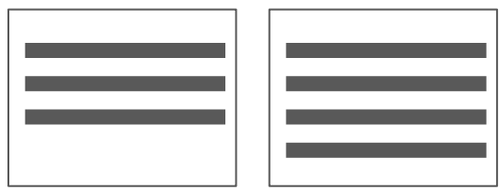
NV		M0 	G0 
W		M1 	G1 
S		M2 	

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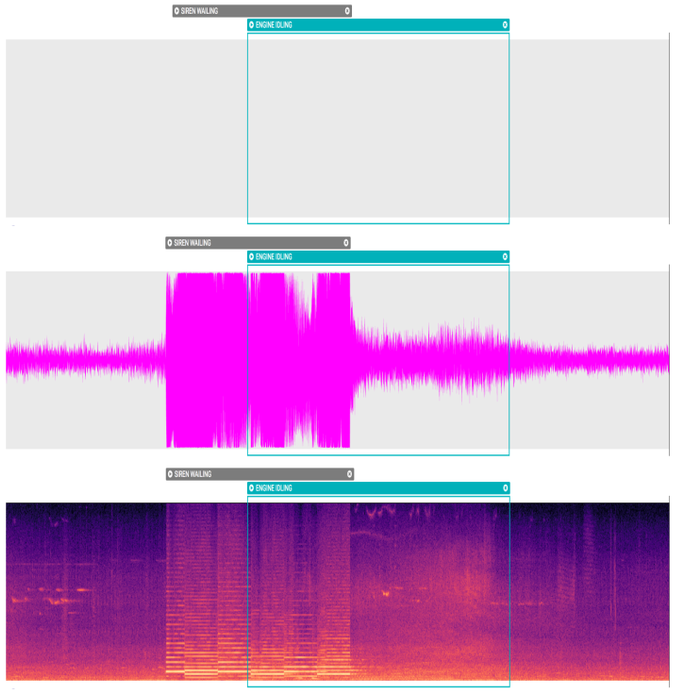

- Soundscape examples:
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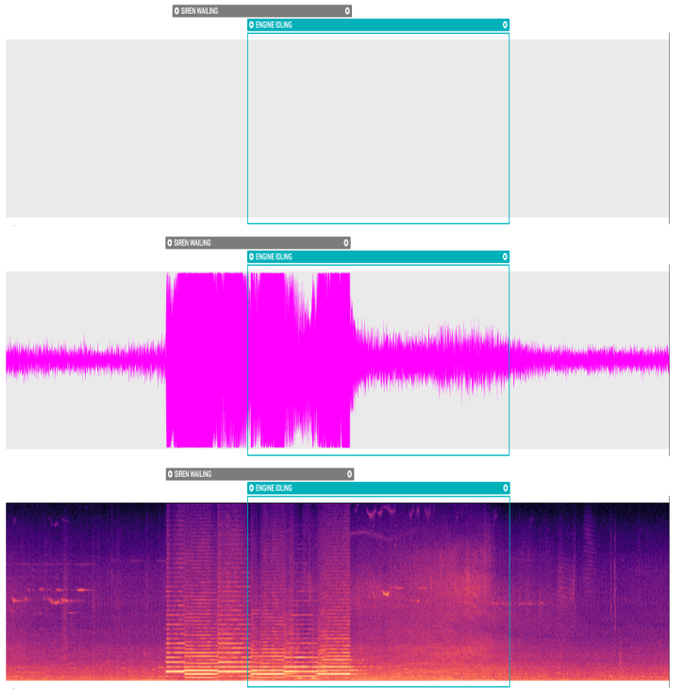

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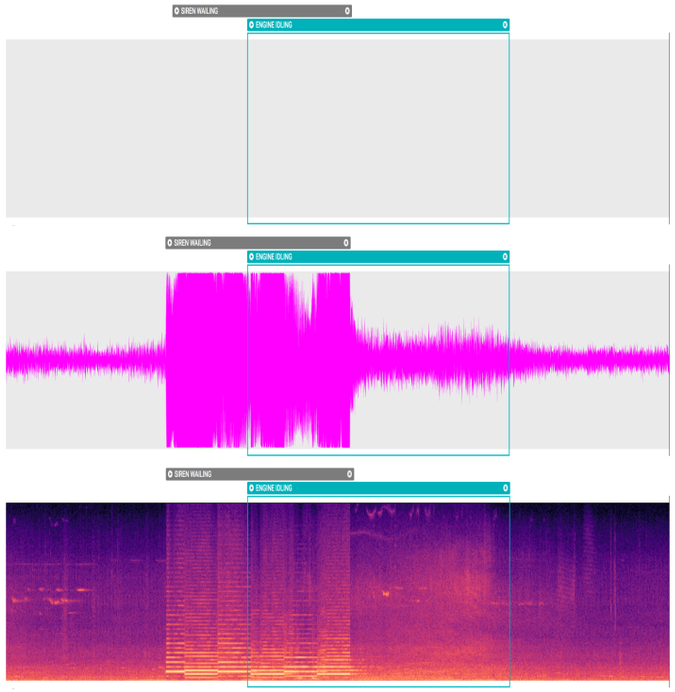

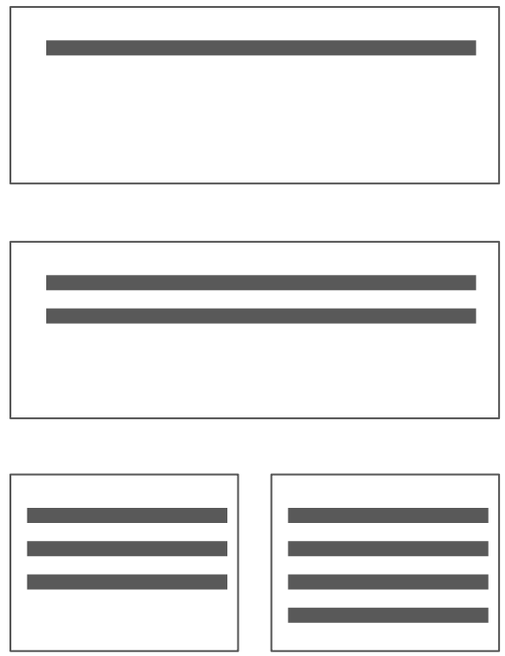

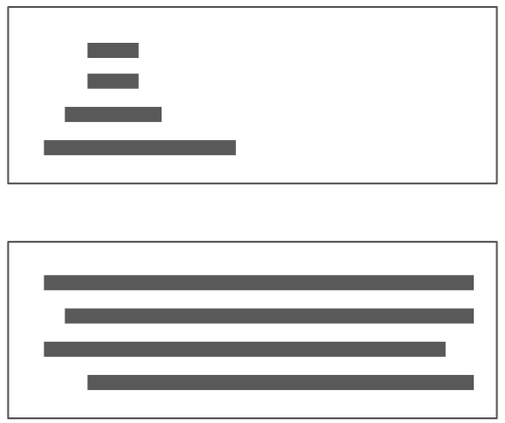

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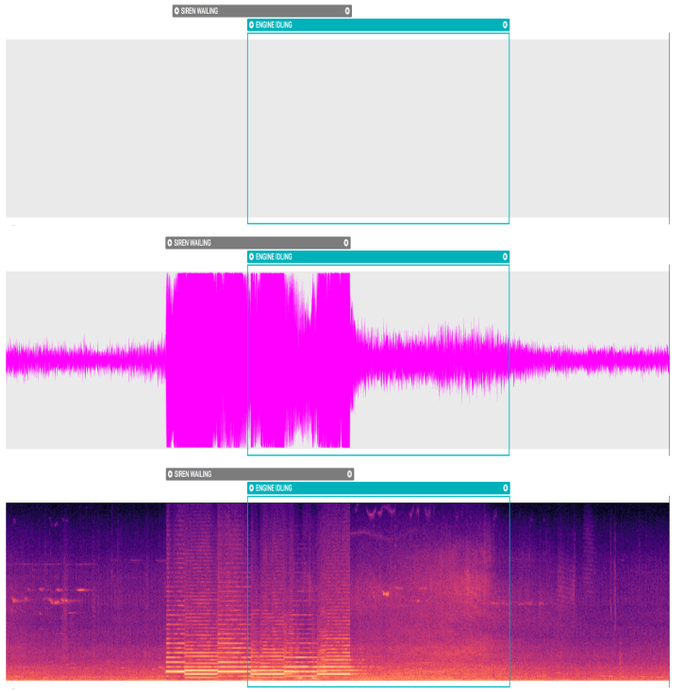

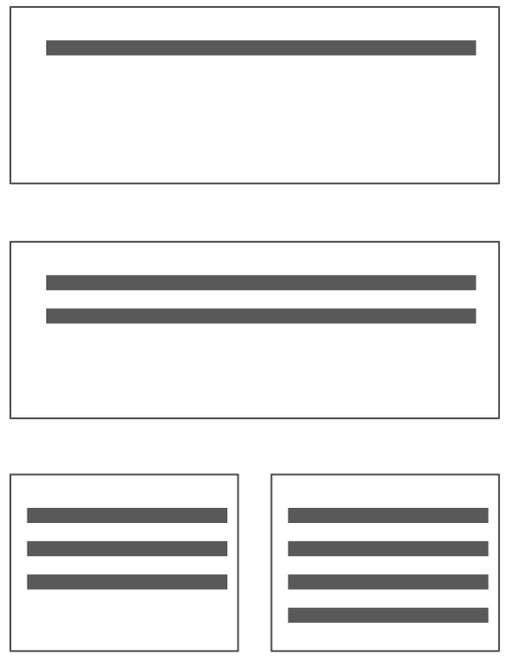

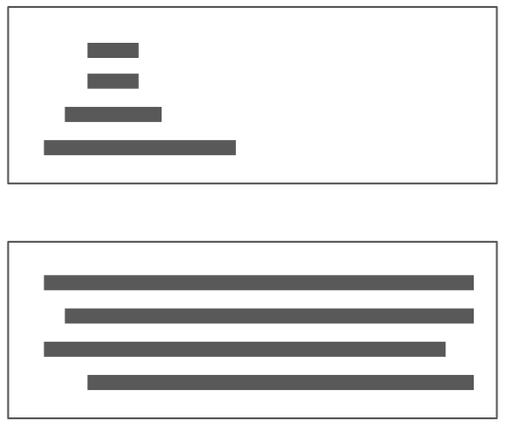

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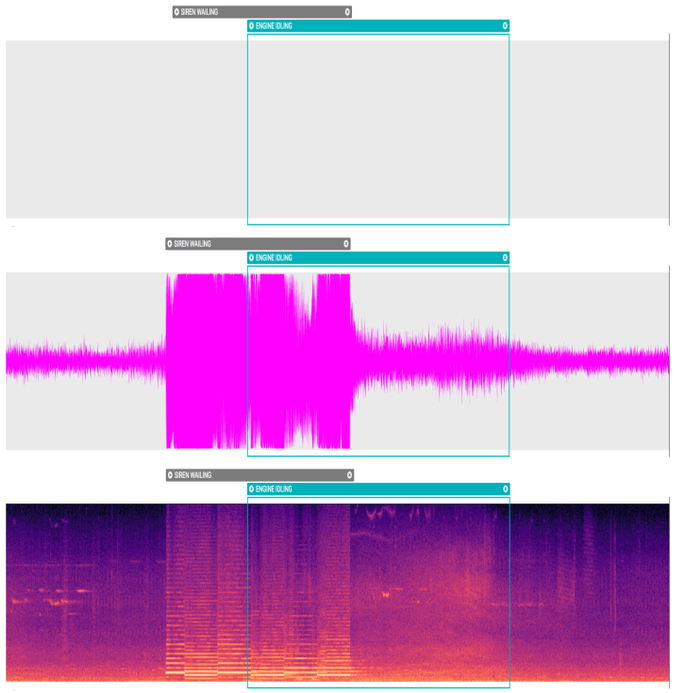

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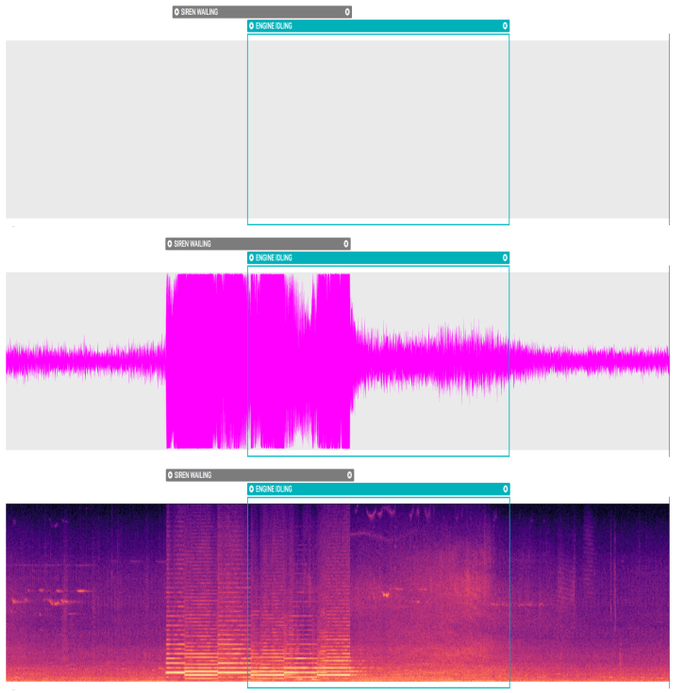


- Soundscape examples:
  M0G0 M0G1 M2G0 **M2G1**

Experiment

- 10s synthesized urban soundscapes (i.e. audio stimuli)

- Classes: car horn honking, dog barking, engine idling, gun shooting, jack hammer drilling, music playing, people shouting, people talking, siren wailing

- 30 replications / 540 participants from Mechanical Turk

- 10 soundscapes per complexity condition
  (i.e. max- x gini-polyphony pair)

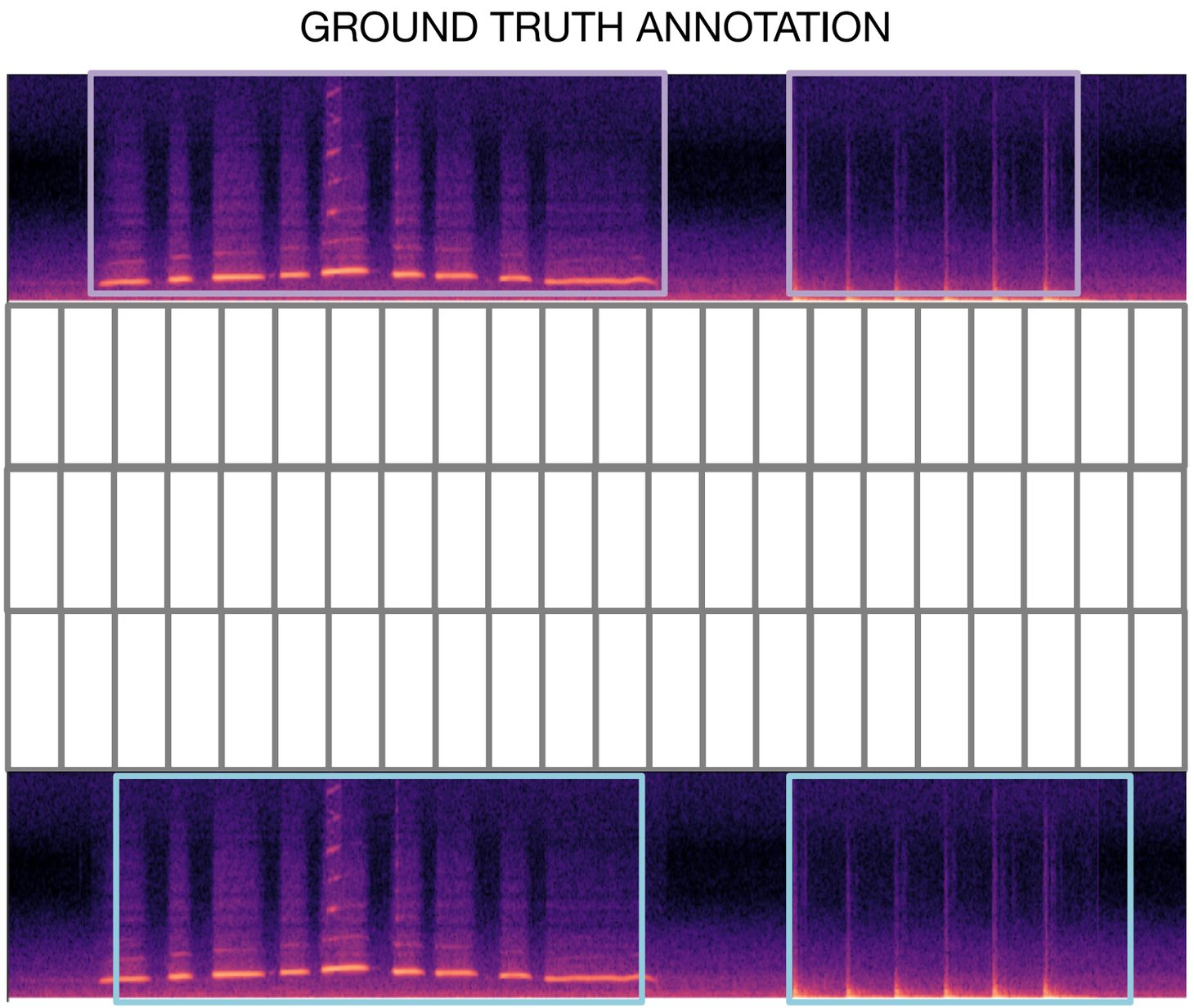
- Counterbalanced ordering of soundscapes

Participant Tasks

- Hearing screening
- Pre-task questionnaire
- Tutorial video
- Practice annotation task
- Series of 10 annotation tasks
- Post-task questionnaire

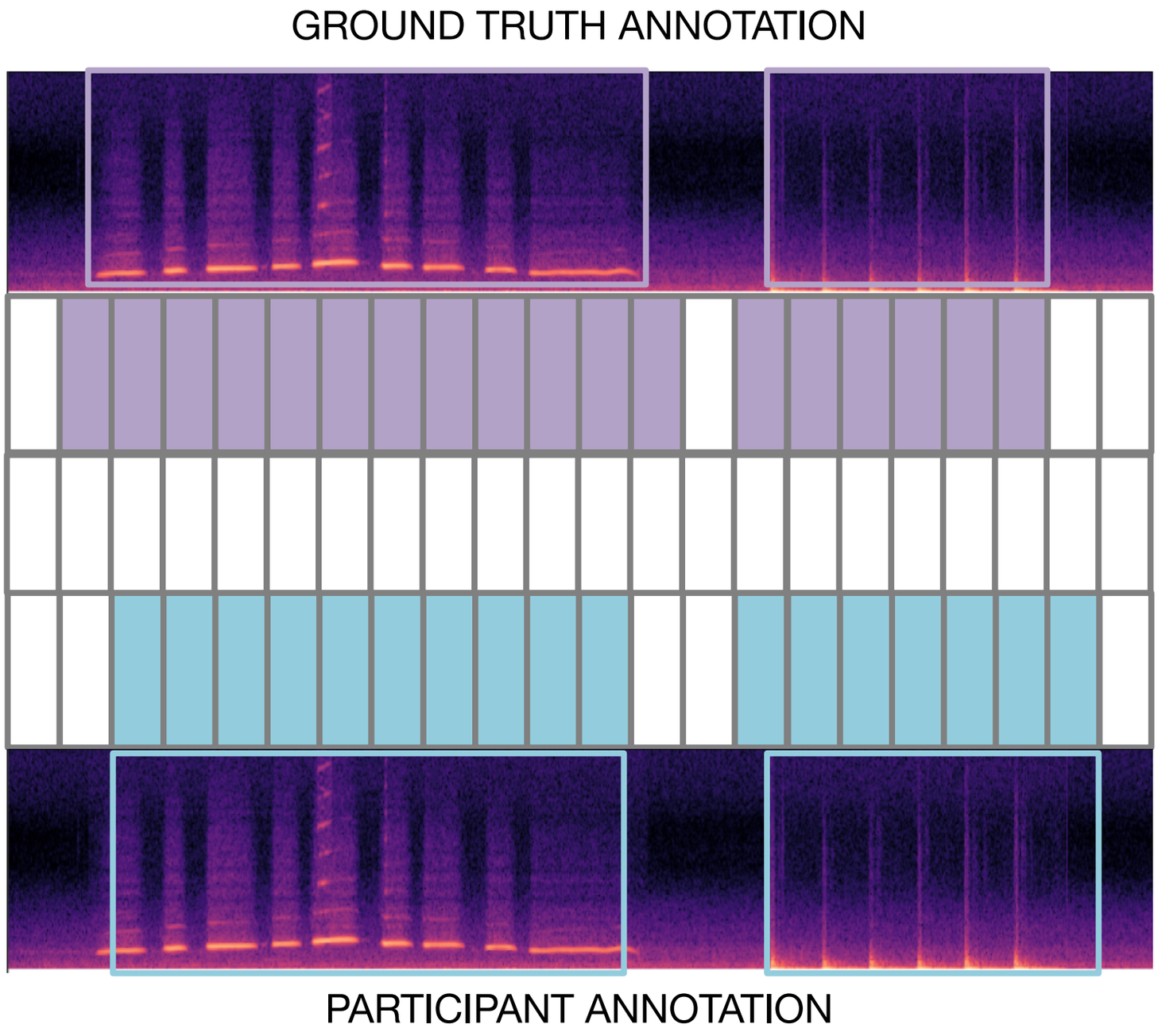
Frame-based Evaluation

- Segment signal into 100ms frames.



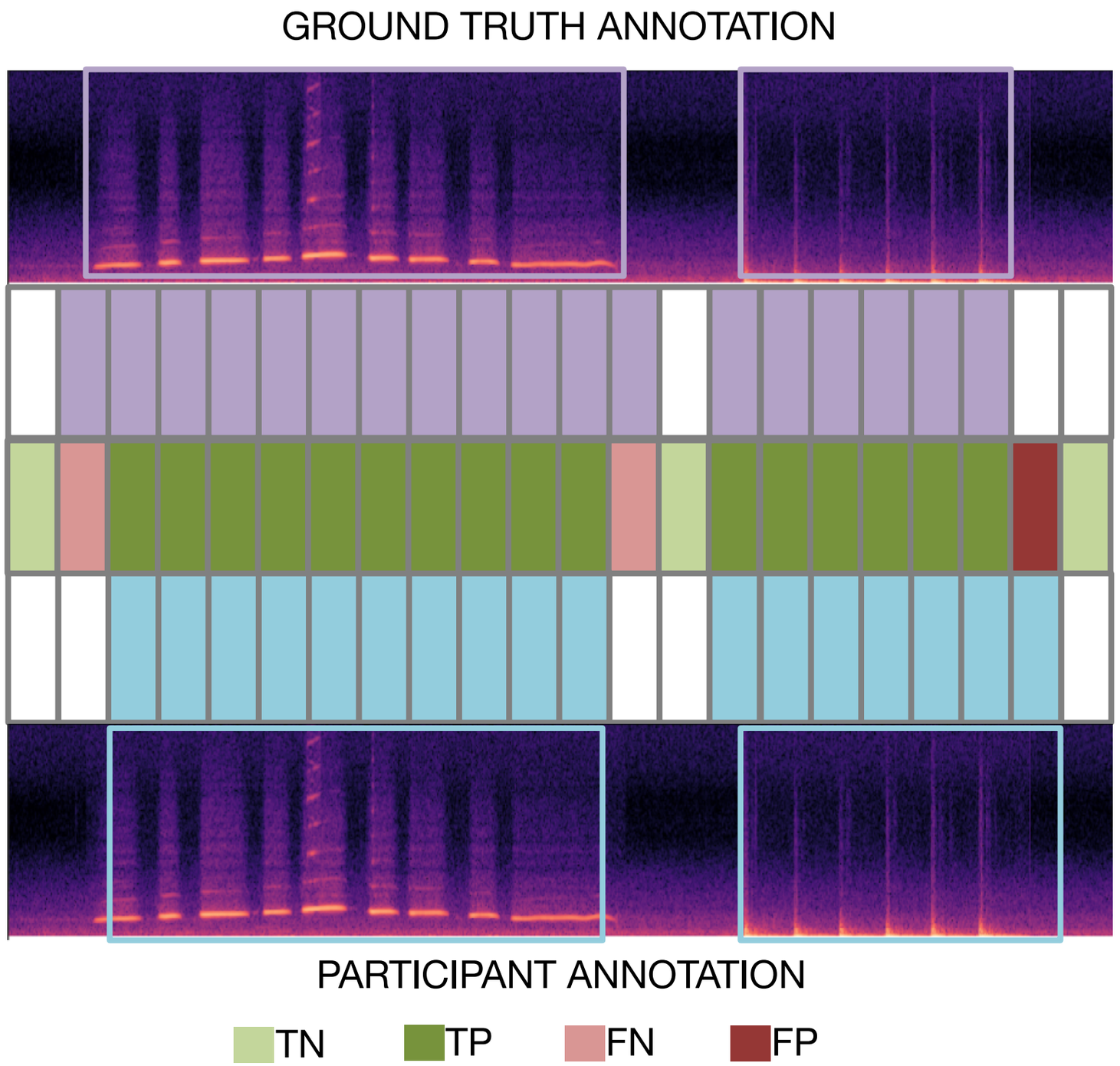
Frame-based Evaluation

- Segment signal into 100ms frames.
- Round the annotations to the outer frame boundaries



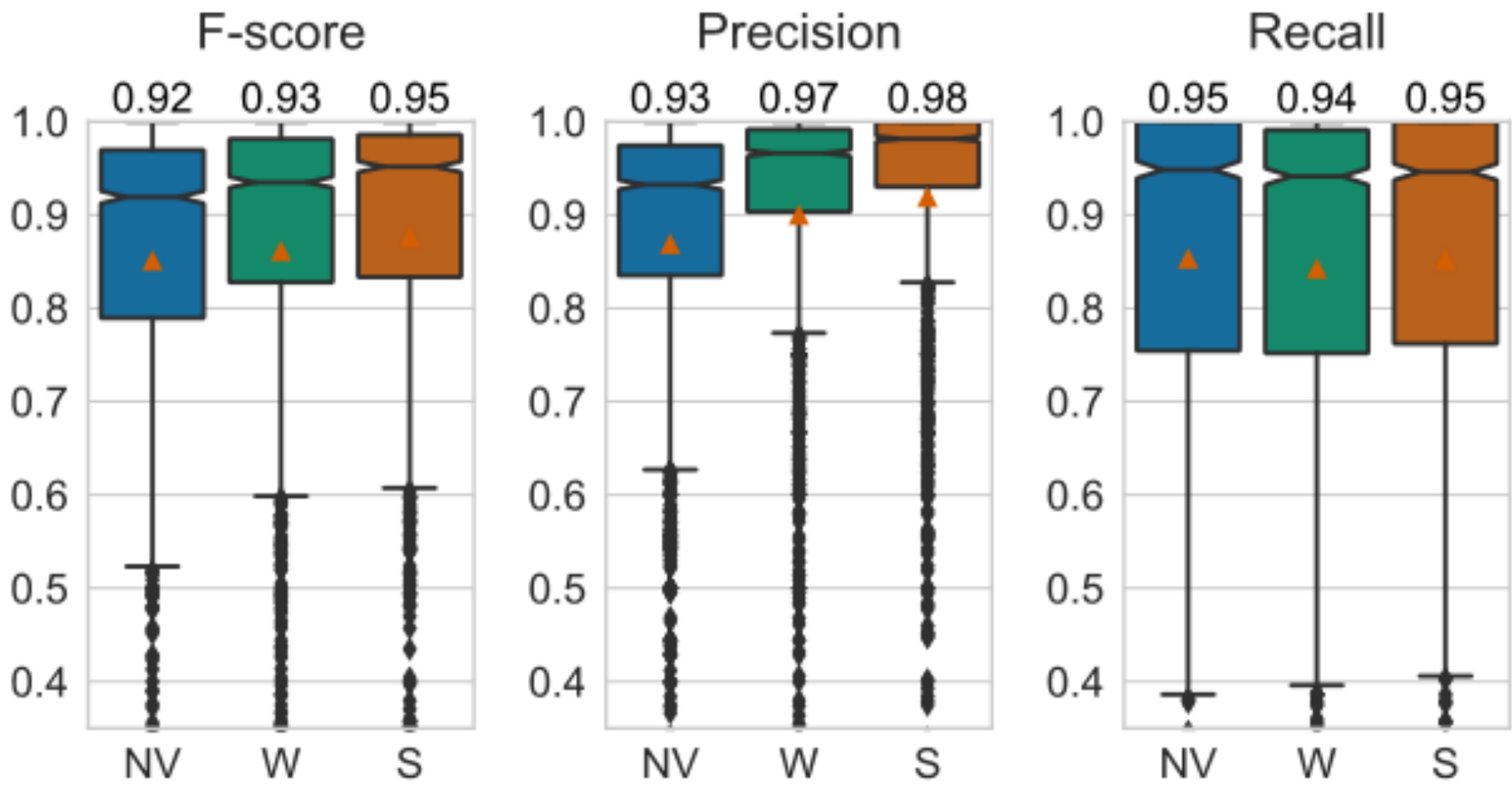
Frame-based Evaluation

- Segment signal into 100ms frames.
- Round the annotations to the outer frame boundaries
- Count TP, FP, FN for each class and calculate precision, recall, F-score



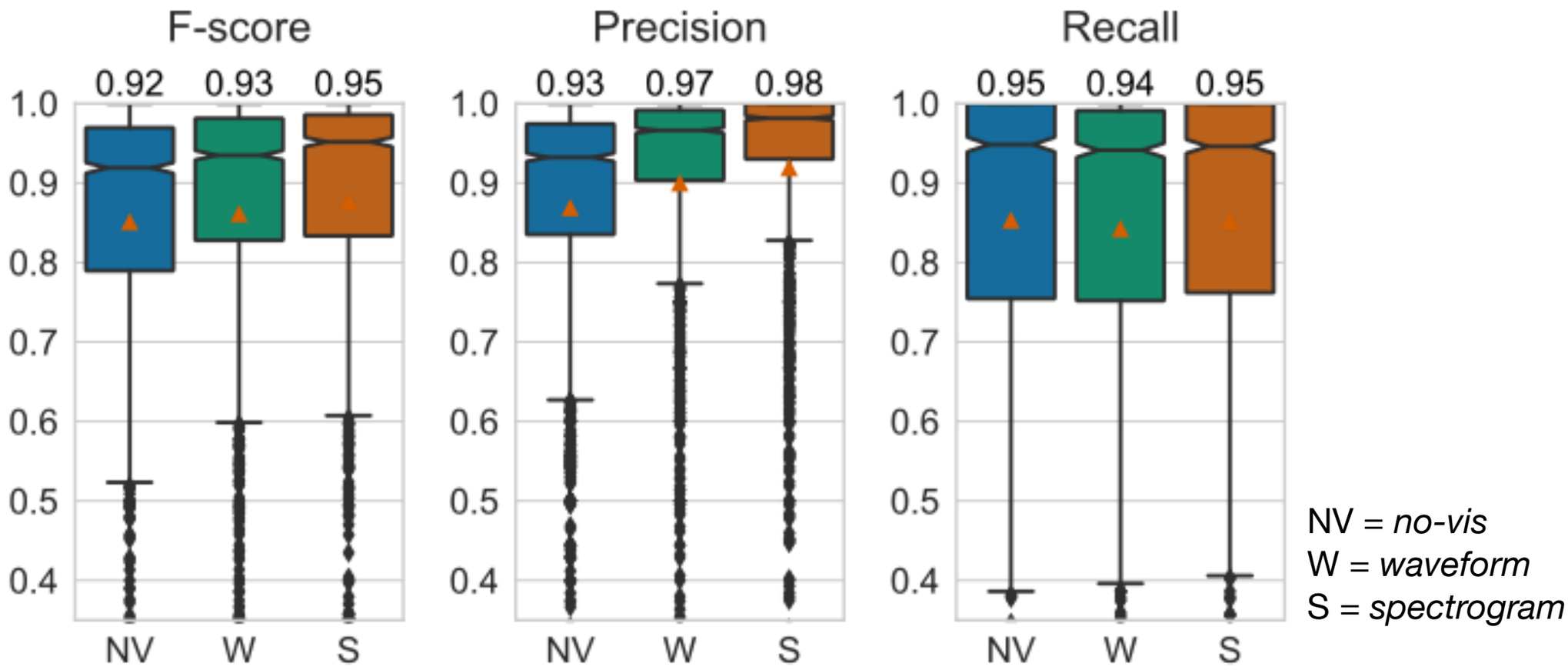
Results

Effect of Visualization on Quality of Annotations



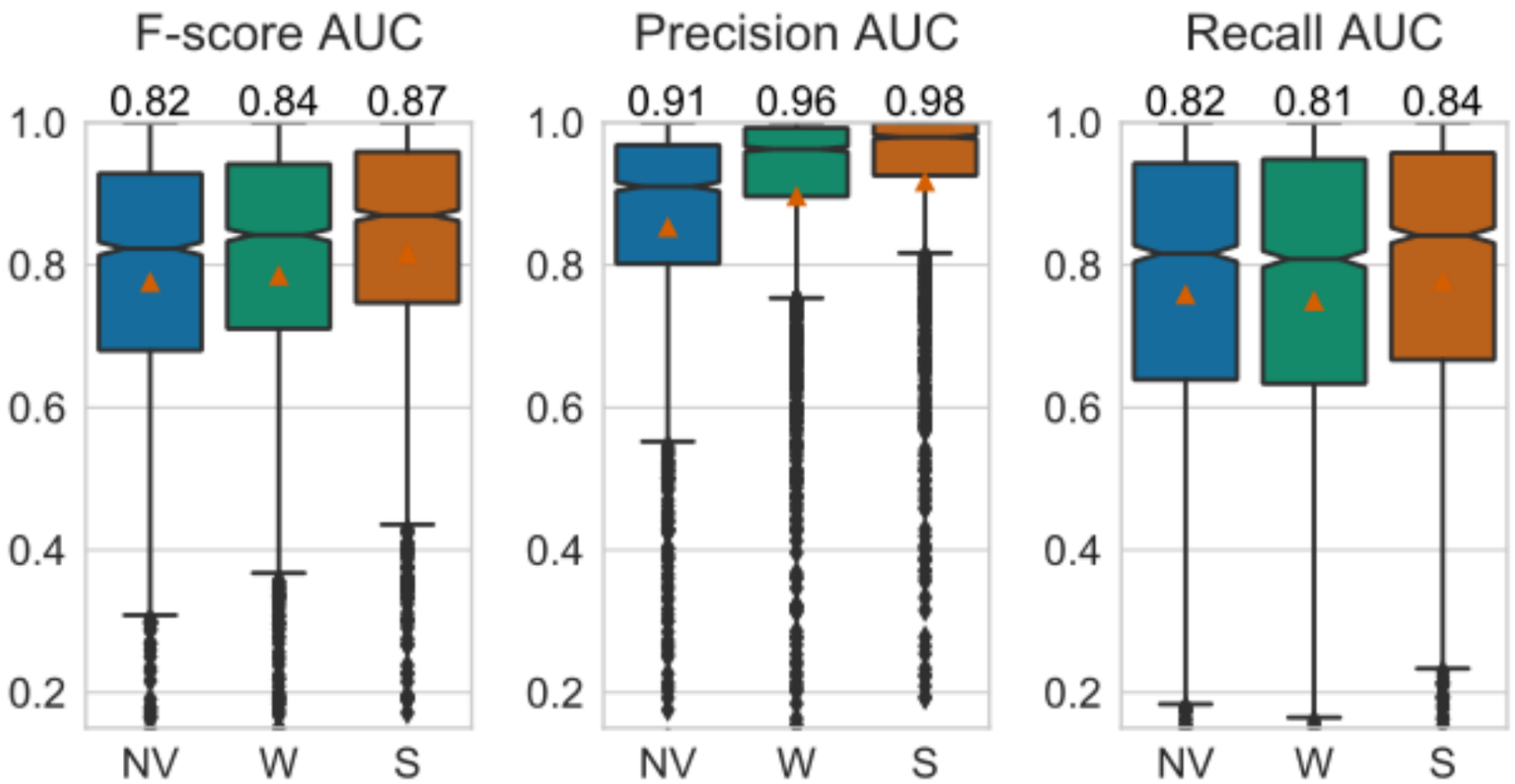
NV = *no-vis*
W = *waveform*
S = *spectrogram*

Effect of Visualization on Quality of Annotations



Spectrogram → higher-quality annotations

Effect of Visualization on Quality and Speed of Annotations



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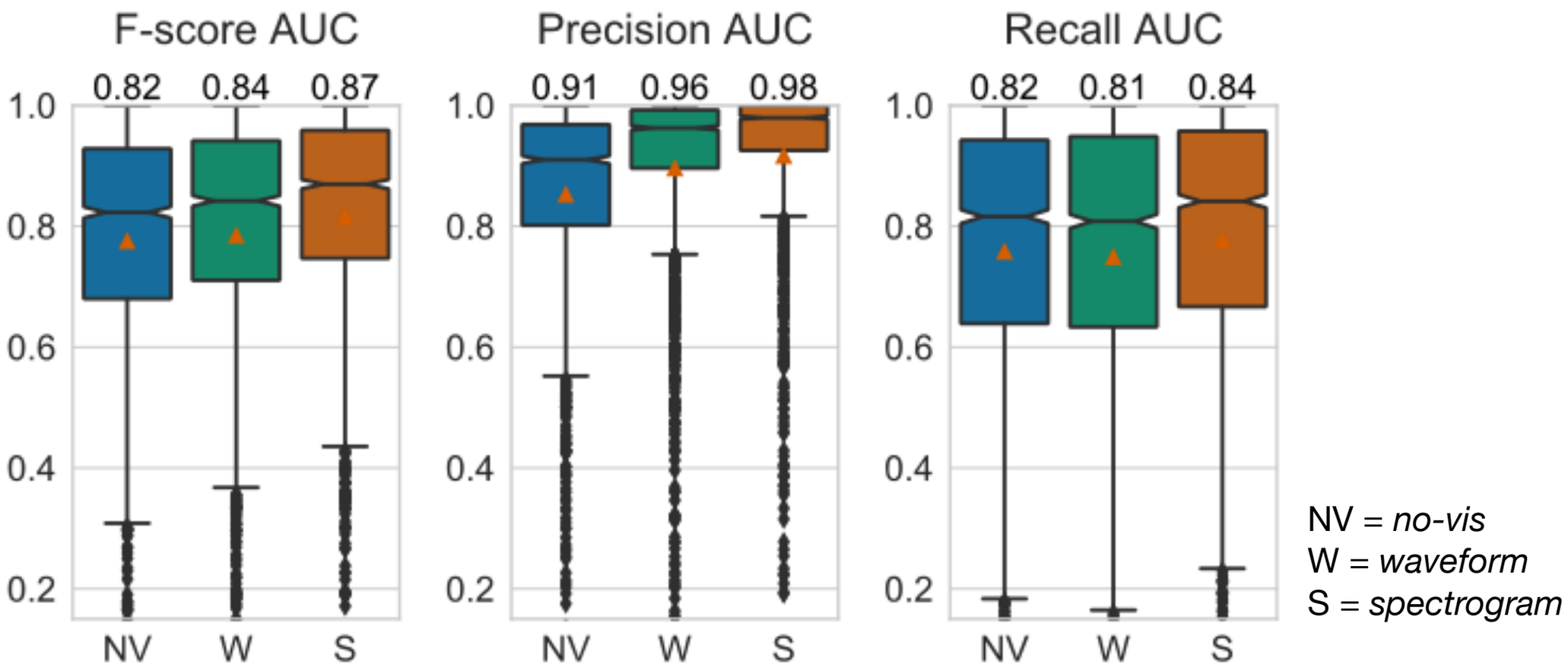
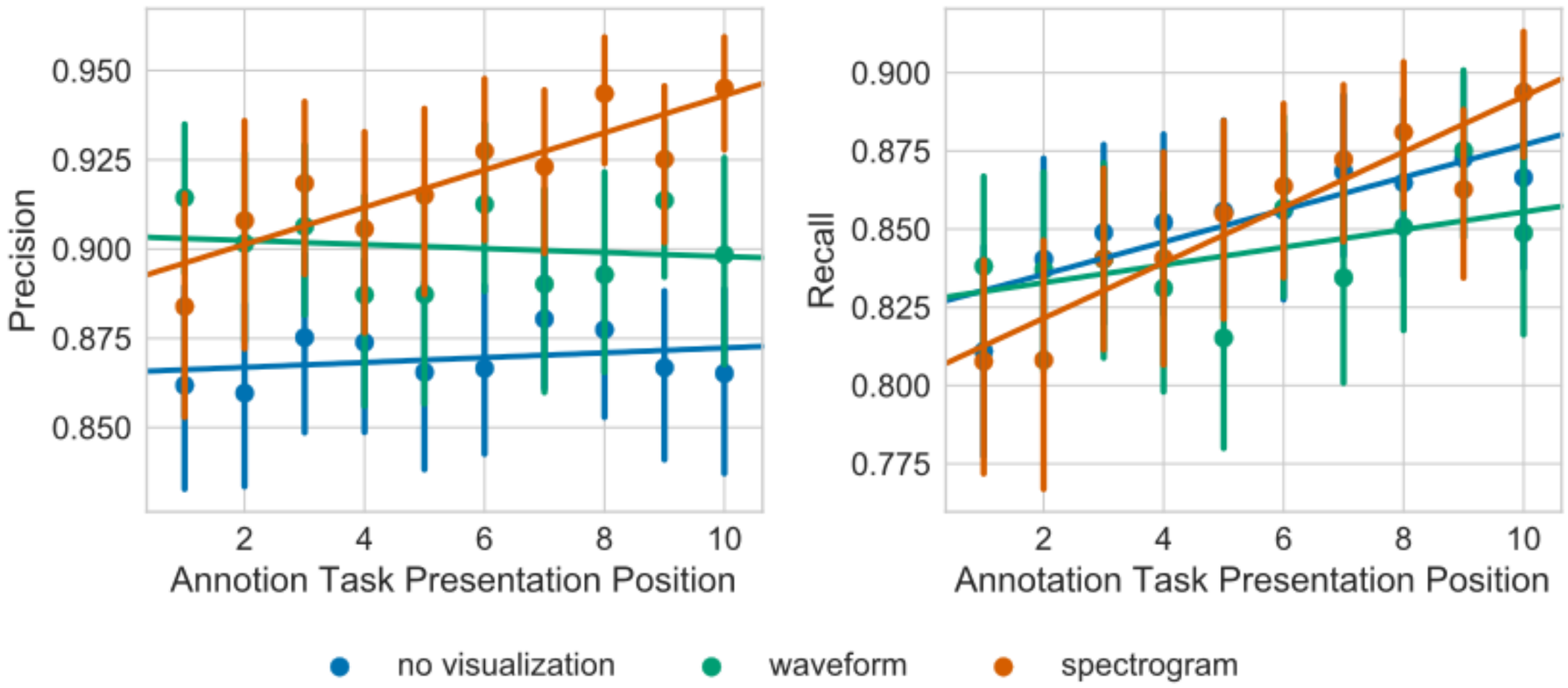
Effect of Visualization on Quality and Speed of Annotations



Spectrogram → higher-quality and faster annotations

Effect of Visualization on Task Learning



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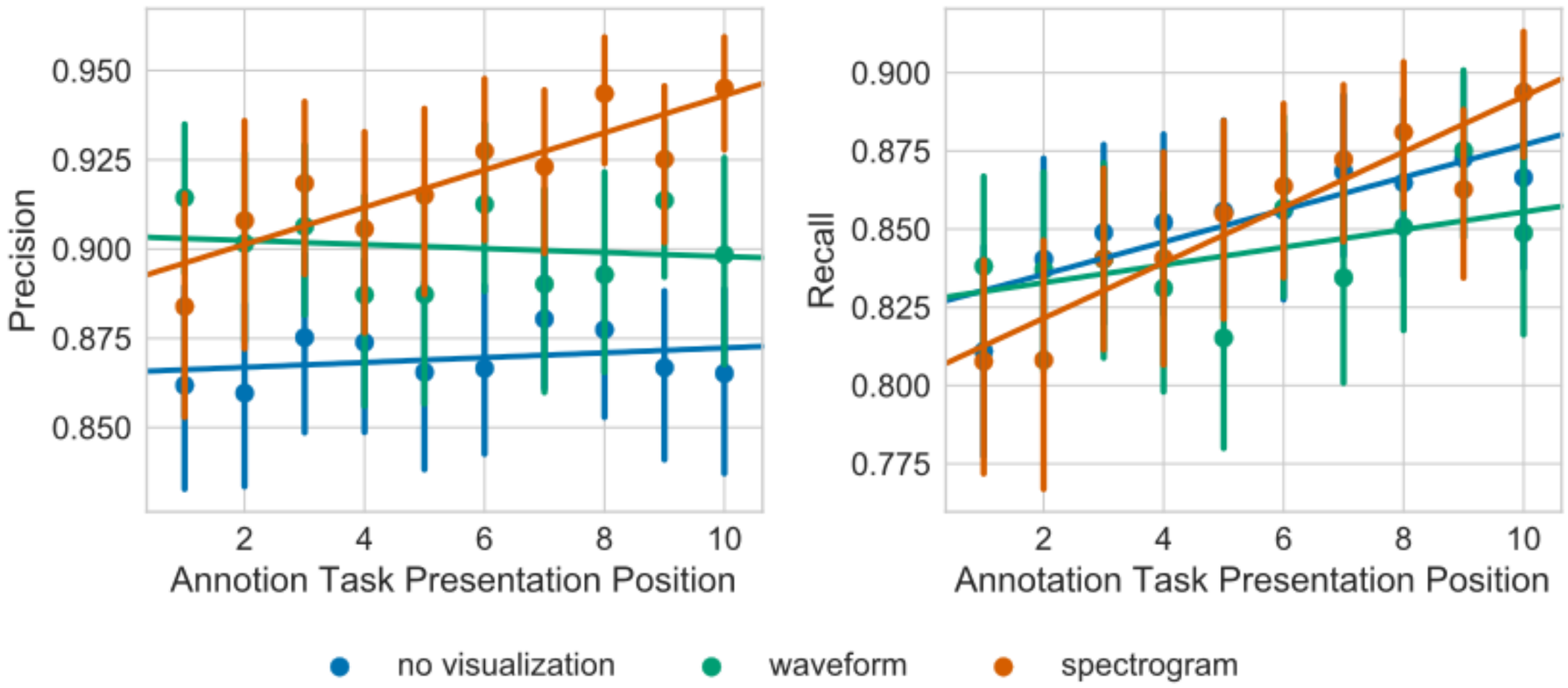
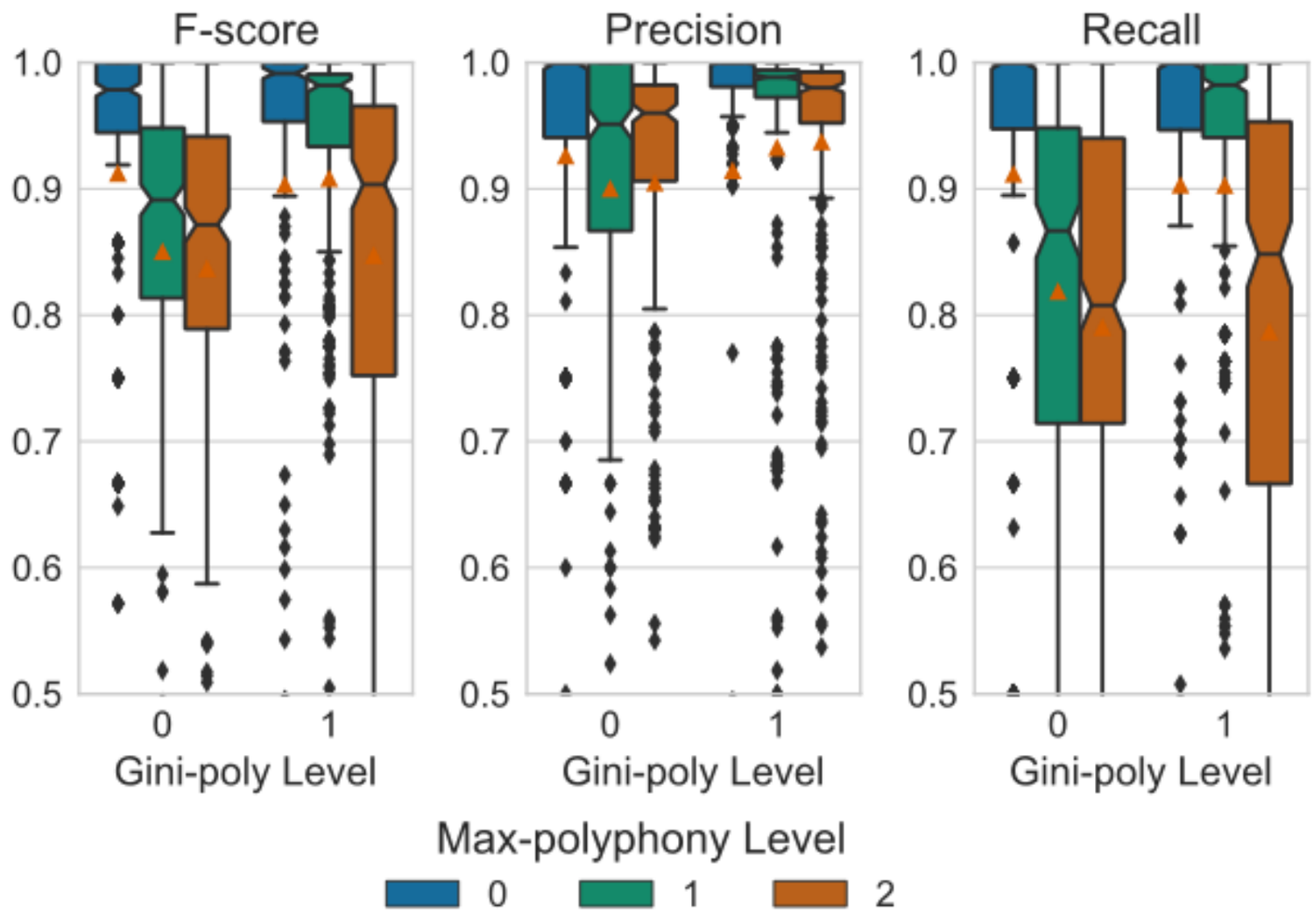


Expect even higher quality annotations after learning period

Effect of Soundscape Complexity on Annotation Quality



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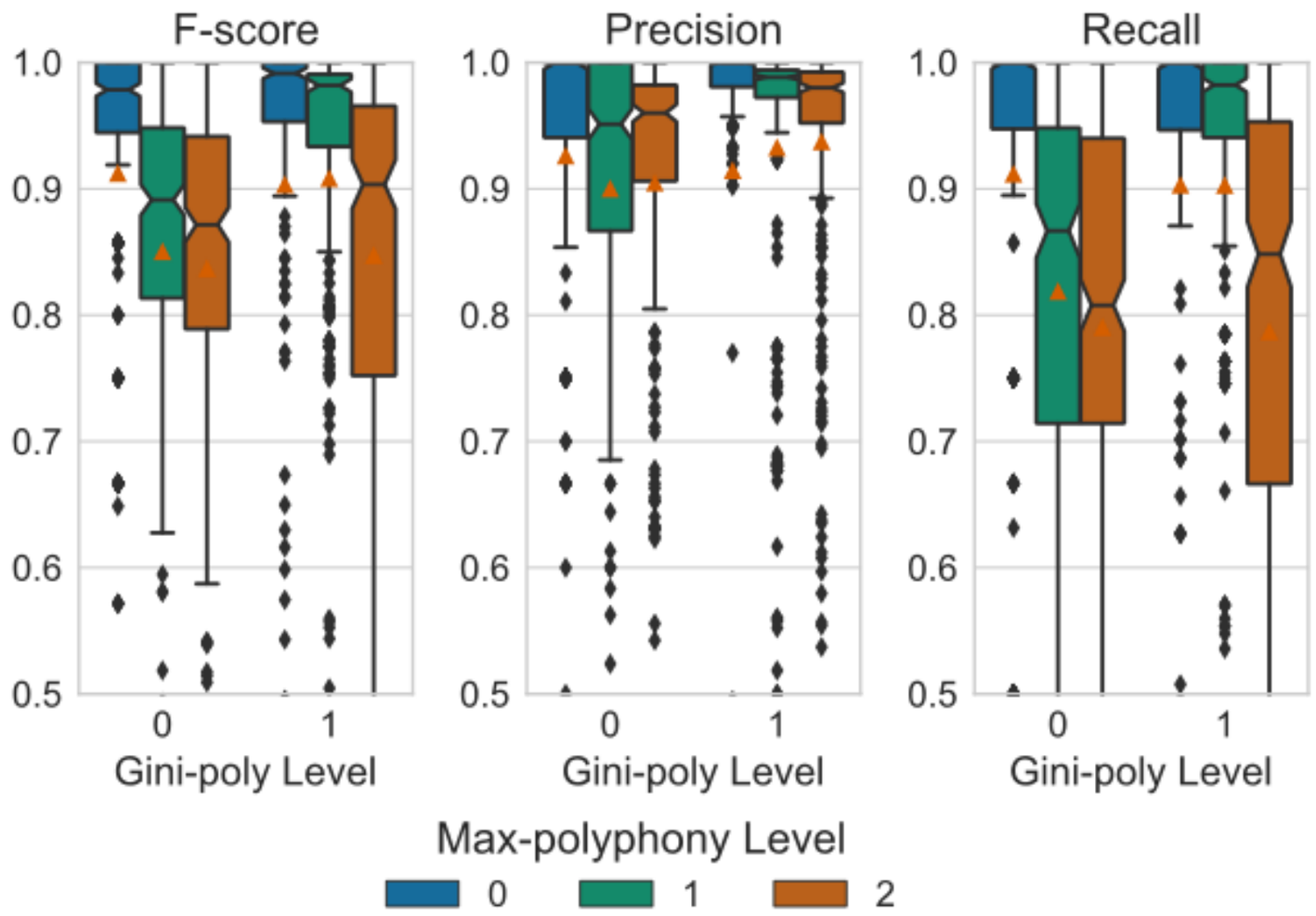
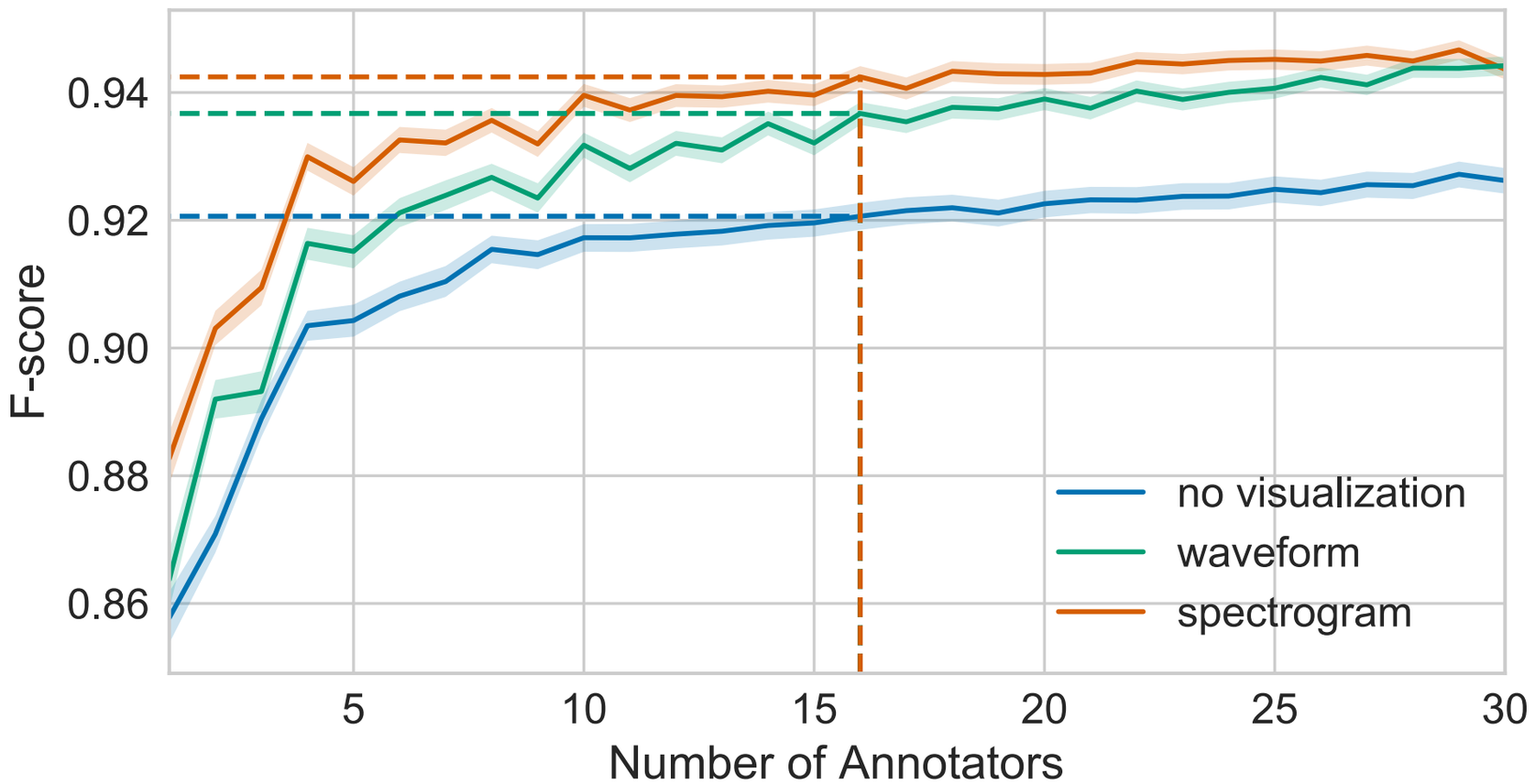


Complex soundscapes → expect precise but incomplete annotations

Effect of Number of Annotators on Aggregate Annotation Quality



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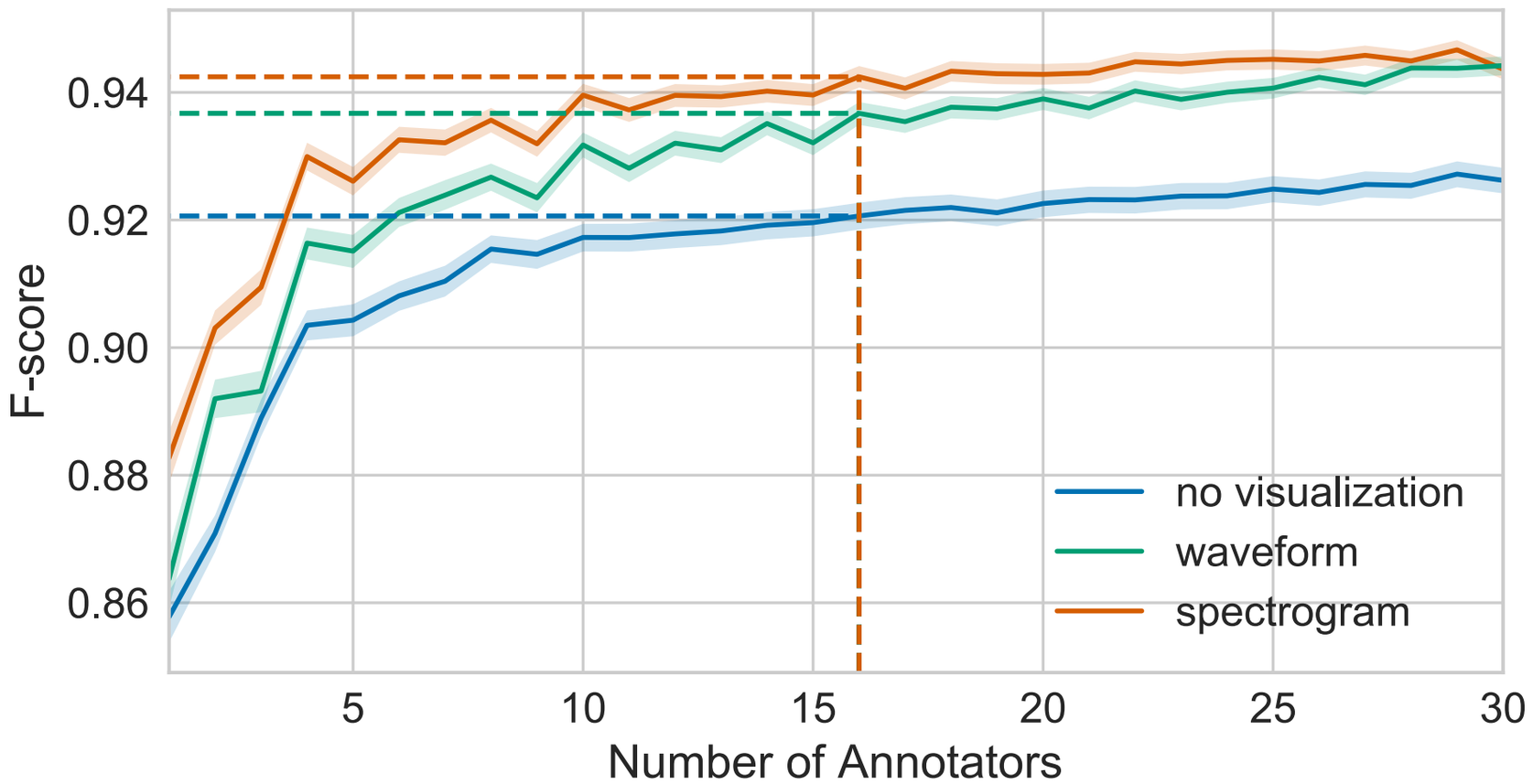


16 annotators captured 90% of gain in annotation quality, but
5 annotators is reasonable choice with respect to cost/quality trade-off

Practical Implications

- Spectrogram → higher-quality and faster annotations
- Expect even higher quality annotations after learning period
- Complex soundscapes → expect precise but incomplete annotations
- 5 annotators is reasonable choice with respect to cost/quality trade-off

Publications

- Cartwright, M., Seals, A., Salamon, J., Williams, A., Mikloska, S., MacConnell, D., Law, E., Bello, J.P., Nov, O. **Seeing Sound: Investigating the Effects of Visualizations and Complexity on Crowdsourced Audio Annotations**. In *Proceedings of the ACM on Human-Computer Interaction*, vol. 1(2), 2017.

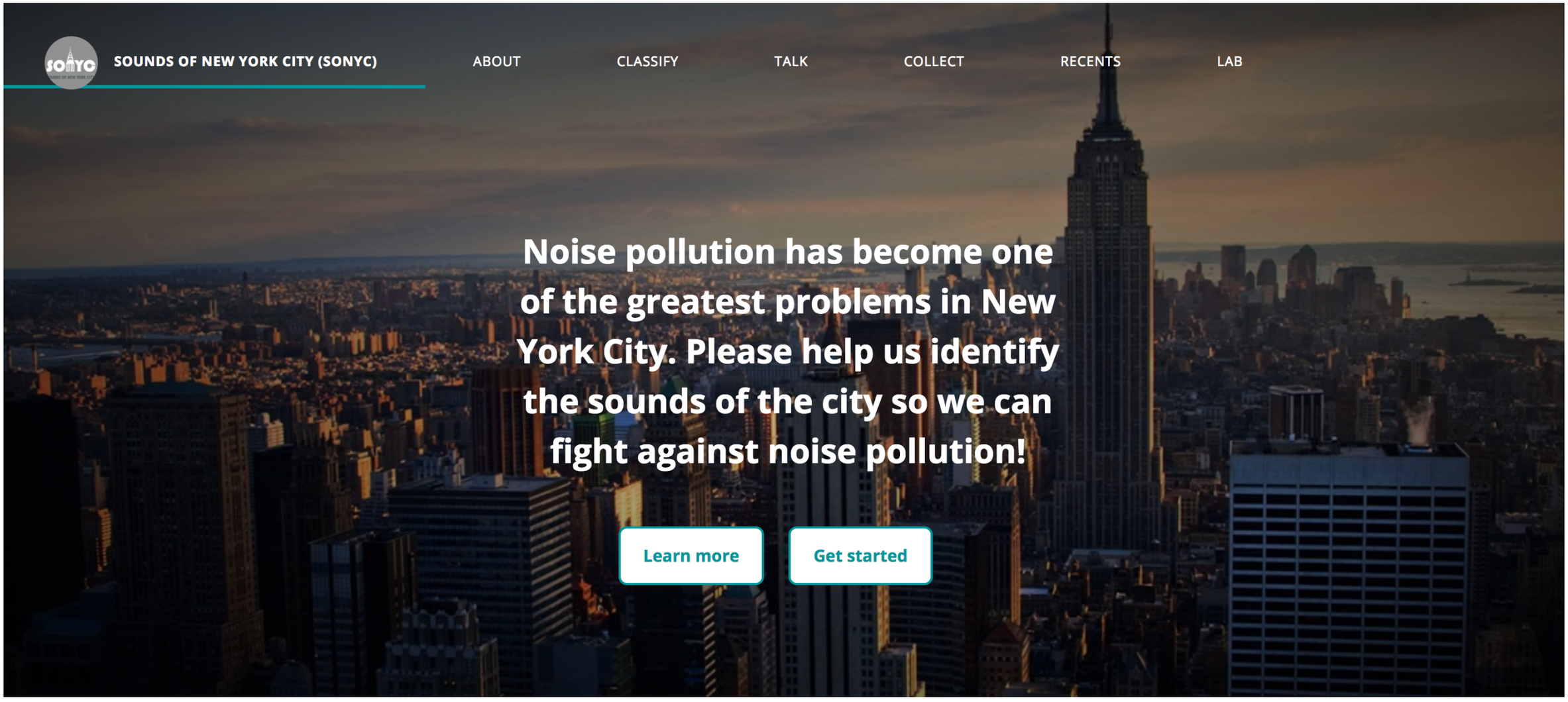
- Cartwright, M., Salamon, J., Seals, A., Nov, O., Bello, J.P. **Investigating the Effect of Sound-Event Loudness on Crowdsourced Audio Annotations**. In *Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2018

Next Steps

Annotation Goals for Machine Listening

- Annotate SONYC sensor recordings on 22 urban sound classes
- Identify at least 1000 positive examples for each sound class
- “Positive example” -> “weak label” (binary) on 10s sensor recordings
- All recordings assessed for all sound classes

Citizen Science Annotation Campaign



Deciding Which Recordings to Annotate

- Uniform sampling -> skew towards everyday street sound (would need much more annotation to reach targets)

- Bias sampling probabilities by similarity to known sound class examples from YouTube

- Compute similarity by distance in VGGish features (a deep audio embedding), extracted for 1/10th of data, ~5 million audio recording

- Release to Zooniverse in groups that are spaced in location and time to protect privacy

- Eventually move to an active sampling approach…

Urban Sound Classes

- **Engines:**
  - Small-sounding engine
  - Medium-sounding engine
  - Large-sounding engine
  - Other/unknown engine
- **Powered sawing tools:**
  - Chain saw
  - Small->medium rotating saw
  - Large rotating saw
  - Other/unknown saw
- **Music:**
  - Stationary music
  - Mobile music
  - Ice-cream truck
  - Other/unknown music
- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound
- **Alert signals:**
  - Car horn
  - Car alarm
  - Siren
  - Reverse beeper
  - Other/unknown alert signal
- **Human and animal vocalization sounds:**
  - Person or small group talking
  - Person shouting
  - Crowd
  - Amplified speech
  - Dog barking/whining
  - Other/unknown human or animal vocalization sound
- **Other/unknown sound:**
  - Other/unknown sound
  - Other/unknown construction sound

Experiment on Weak Multi-Label Audio Annotations

How do **label set specificity** and **task assignment strategy** affect

- annotation quality?
- annotation speed/throughput?
- annotator satisfaction?
- annotator retention?

Label set specificity:

- General (1-pass annotation)
- 2-stage
- Specific (multi-pass annotation)

Task assignment strategy:

- Random
- Annotator-choice

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small->medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
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- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small > medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
- Person or small group talking
- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small > medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
- Person or small group talking
- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small > medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
- Person or small group talking
- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small->medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
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- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Powered sawing tools**
  - Chain saw
  - Small->medium rotating saw
  - Large rotating saw
  - Other/unknown saw

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small->medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
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- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Powered sawing tools**
  - Chain saw
  - Small->medium rotating saw
  - Large rotating saw
  - Other/unknown saw

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small > medium rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
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- Other/unknown alert signal
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- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small- or medium-rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
- Person or small group talking
- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small- or medium-rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
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- Other/unknown impact sound
- Car horn
- Car alarm
- Siren
- Reverse beeper
- Other/unknown alert signal
- Person or small group talking
- Person shouting
- Crowd
- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
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- Other/unknown music
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- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Specific (Multi-pass) Annotation Task

- Car horn

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small- or medium-rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
- Pile driver
- Other/unknown impact sound
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- Amplified speech
- Dog barking/whining
- Other/unknown human or animal vocalization sound
- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Specific (Multi-pass) Annotation Task

- Jackhammer

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small- or medium-rotating saw
- Large rotating saw
- Other/unknown saw
- Stationary music
- Mobile music
- Ice-cream truck
- Other/unknown music
- Rock drill
- Jackhammer
- Hoe ram
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- Crowd
- Amplified speech
- Dog barking/whining
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- Other/unknown sound
- Other/unknown construction sound

Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Specific (Multi-pass) Annotation Task

- Jackhammer

Varying Label Set Specificity

General (Single-pass) Annotation Task

- Small-sounding engine
- Medium-sounding engine
- Large-sounding engine
- Other/unknown engine
- Chain saw
- Small- or medium-rotating saw
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Hybrid (2-stage) Annotation Task

Stage 1

- Engines
- Powered sawing tools
- Music
- Impact sounds
- Alert signals
- Human and animal vocalization sounds
- Other/unknown sound
- Other/unknown construction sound

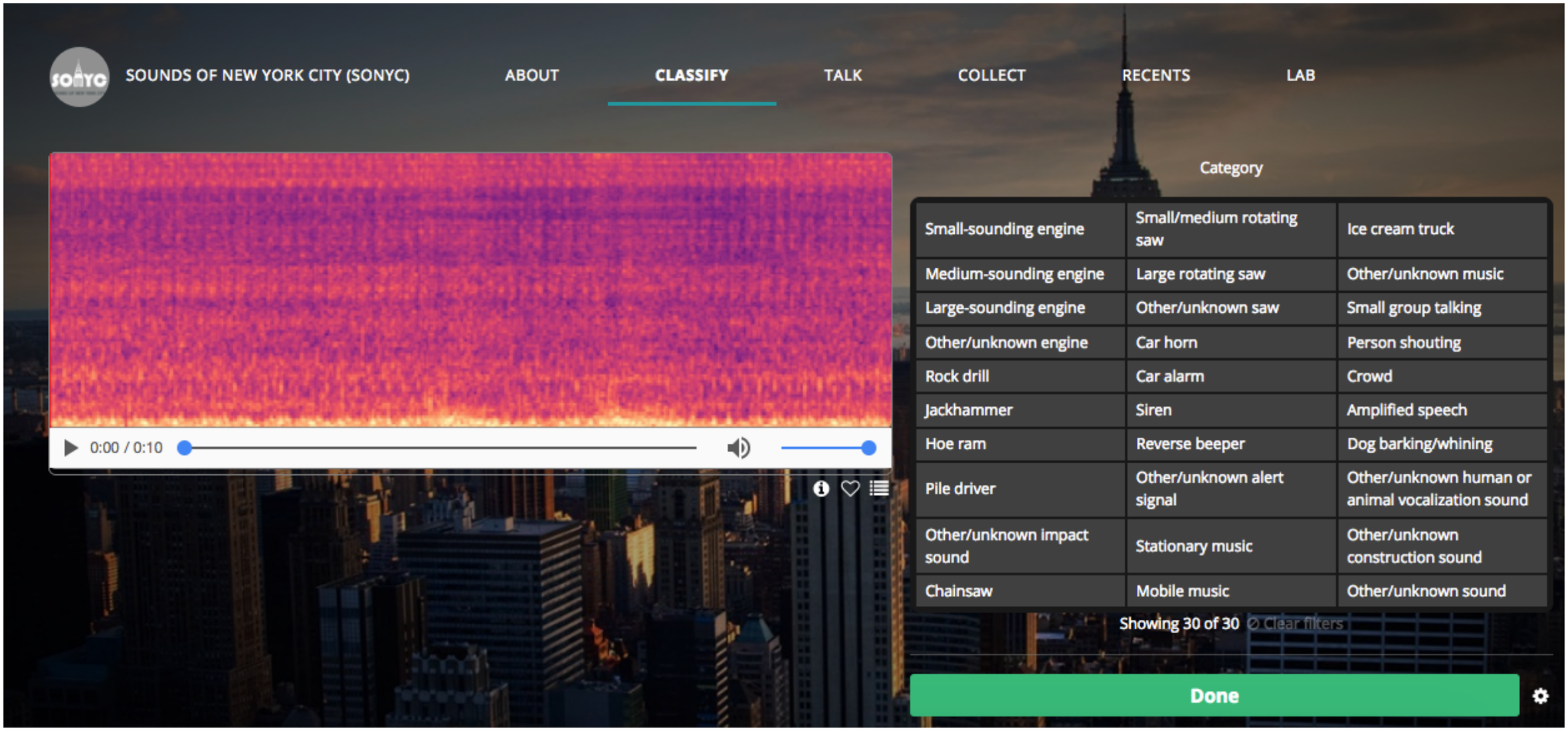
Stage 2

- **Impact sounds:**
  - Rock drill
  - Jackhammer
  - Hoe ram
  - Pile driver
  - Other/unknown impact sound

Specific (Multi-pass) Annotation Task

- etc….

Example of “General” Task on Zooniverse



Summary of Next Steps

- Begin Zooniverse Annotation Campaign in the next couple of weeks
- Initially experiment with variations in task design
- Continue with best task design
- Eventually transition to an active sampling scheme to potentially reduce the number of overall annotations (collecting at least 1000 example per class in total)

Questions?

- Come see Ana Elisa's poster later to learn more details about the Zooniverse project and its associated upcoming experiment!

- Thanks to help from Ana Elisa Mendez, Ayanna Seals, Justin Salamon, Graham Dove, Juan Pablo Bello, and Oded Nov