Supplementary Notes for: A Model for Data-Driven Sonification using Soundscapes

The example input soundscape is included as Soundscape_Input.wav. A clip from the output soundscape that was rendered based on the mappings explained below is included as Soundscape_Output.wav.

1. Soundscape Feature Descriptions

Each sound used in the soundscape is from the freesound.org website. The full attribution of these sounds is listed in Table 4. By using pre-segmented sounds we avoid the difficult task of sound source separation. Here we present the features of the input soundscape, the ten different sound groups, and the many sound samples.

Table 1. Features of the input soundscape

Soundscape	# Interval Sound Groups	# Instant Sound Groups	# Both Sound Groups	Duration of Soundscape
$S^{in-forrest}$	3	5	2	122.3917

Table 2. Features of the sound groups

Sound Group	Group Description	Type	# Samples	Time in Soundscape (sec)	Avg Duration of Sound Group (sec)	% of Soundscape Duration
G_1^{stream}	stream	interval	1	122.3917	122.3917	100.00
$G_2^{nighingale}$	nightingale	instant	7	26.0773	3.7253	21.31
G_3^{frog}	frog	both	5	25.9734	5.1947	21.22
$G_4^{thunder}$	thunder	instant	2	22.9414	11.4707	18.74
G_5^{wolf}	wolf	instant	4	21.77476	5.4437	17.79
G_6^{owl}	owl	instant	6	11.7298	1.9550	9.58
G_7^{fly}	fly	instant	5	10.8616	2.1723	8.87
G_8^{rain}	rain	interval	1	46.5113	46.5113	38.00
$G_9^{crickets}$	crickets	both	1	122.3917	122.3917	100.00
G_{10}^{wind}	wind	interval	1	122.3917	122.3917	100.00

Table 3. Features of the sound samples

Sound Sample	Sample Name	Start Time (sec)	Stop Time (sec)	Duration (sec)
$g_{1,1}^{stream}$	stream1	0.0000	122.3917	122.3917
$g_{2,1}^{nightingale}$	nightingale1	3.0235	5.3386	2.3151
…	nightingale2	12.0939	15.3099	3.2160
…	nightingale3	24.5509	29.2534	4.7025
…	nightingale4	48.0133	50.9795	2.9662
…	nightingale5	63.7356	68.5104	4.7748
…	nightingale6	83.6907	86.8739	3.1832
$g_{2,7}^{nightingale}$	nightingale7	108.9673	113.8868	4.9195
$g_{3,1}^{frog}$	frog1	0.0000	9.2880	9.2880
…	frog2	33.7420	37.5298	3.7878
…	frog3	56.8419	60.3017	3.4598
…	frog4	74.8620	79.9240	5.0620
$g_{3,5}^{frog}$	frog5	103.0411	107.4169	4.3758
$g_{4,1}^{thunder}$	thunder1	80.7881	95.1729	14.3848
$g_{4,2}^{thunder}$	thunder2	103.0411	111.5977	8.5566
$g_{5,1}^{wolf}$	wolf1	62.4052	66.9207	4.5155
…	wolf2	71.0622	77.5870	6.5248
…	wolf3	83.6907	91.2768	7.5861
$g_{5,4}^{wolf}$	wolf4	95.5429	98.6913	3.1484
$g_{6,1}^{owl}$	owl1	31.5654	33.0747	1.5093
…	owl2	36.1612	38.8663	2.7051
…	owl3	44.0223	46.0067	1.9844
…	owl4	61.5587	63.9731	2.4144
…	owl5	79.9923	81.6460	1.6537
$g_{6,6}^{owl}$	owl6	99.7056	101.1685	1.4629
$g_{7,1}^{fly}$	fly1	14.2709	15.8409	1.5700
…	fly2	20.4389	22.2152	1.7763
…	fly3	28.4209	30.1624	1.7415
…	fly4	39.5474	43.1940	3.6466
$g_{7,5}^{fly}$	fly5	48.2552	50.3824	2.1272
$g_{8,1}^{rain}$	rain1	75.8803	122.3916	46.5113
$g_{9,1}^{crickets}$	crickets1	0.0000	122.3917	122.3917
$g_{10,1}^{wind}$	wind1	0.0000	122.3917	122.3917

Table 4. All of the sound samples are from freesound.org. The full attribution is listed in the table below.

Sound	Sound Title	User	URL
stream	Distant stream 1	Adam_N	https://www.freesound.org/people/Adam_N/
nightingale	nightingale	viaaico2013	https://www.freesound.org/people/viaaico2013/
frog	Frogs	juskiddink	https://www.freesound.org/people/juskiddink/
thunder	Distant Thunder	sean.townsend	https://www.freesound.org/people/sean.townsend/
wolf	Wolf Howl	Gorgoroth6669	https://www.freesound.org/people/Gorgoroth6669/
owl	Tawny Owls 2	Benboncan	https://www.freesound.org/people/Benboncan/
fly	flys-I	galeku	https://www.freesound.org/people/galeku/
rain	Rain light 1(rural)	jmbphilmes	https://www.freesound.org/people/jmbphilmes/
crickets	crickets	FreethinkerAnon	https://www.freesound.org/people/FreethinkerAnon/
wind	Wind in the Trees	willstepp	https://www.freesound.org/people/willstepp/

2. Twitter Data Feature Descriptions

The Twitter Data we use is a curated set taken from the first few minutes of the 2014 Super Bowl. In the tables below we explain the features of the data groups (Twitter groups) and data points (tweets). While we used this data to create the output soundscape, the output only plays for the first 7 minutes and 40 seconds (460 seconds) of the sonification.

Table 5. Features of the example Twitter groups: We chose seven groups that we thought would represent an exemplar set. The *group description* feature describes the connection between tweets in that group. For instance, $D_1^{\#superbowl}$ is the set of all tweets that contain #SuperBowl. As this data was taken while the Super Bowl was in progress, it is a very popular topic with 6,489 tweets over the course of ~15 minutes. Groups with notation like D_4^{u2} represent a group of tweets posted by User 2 (we removed usernames in order to anonymize the data). During the first few minutes of the game there was a safety (a scoring play in American football where the scoring team is awarded 2 points), so we chose to create a group for tweets that contain #saftey ($D_3^{\#saftey}$).

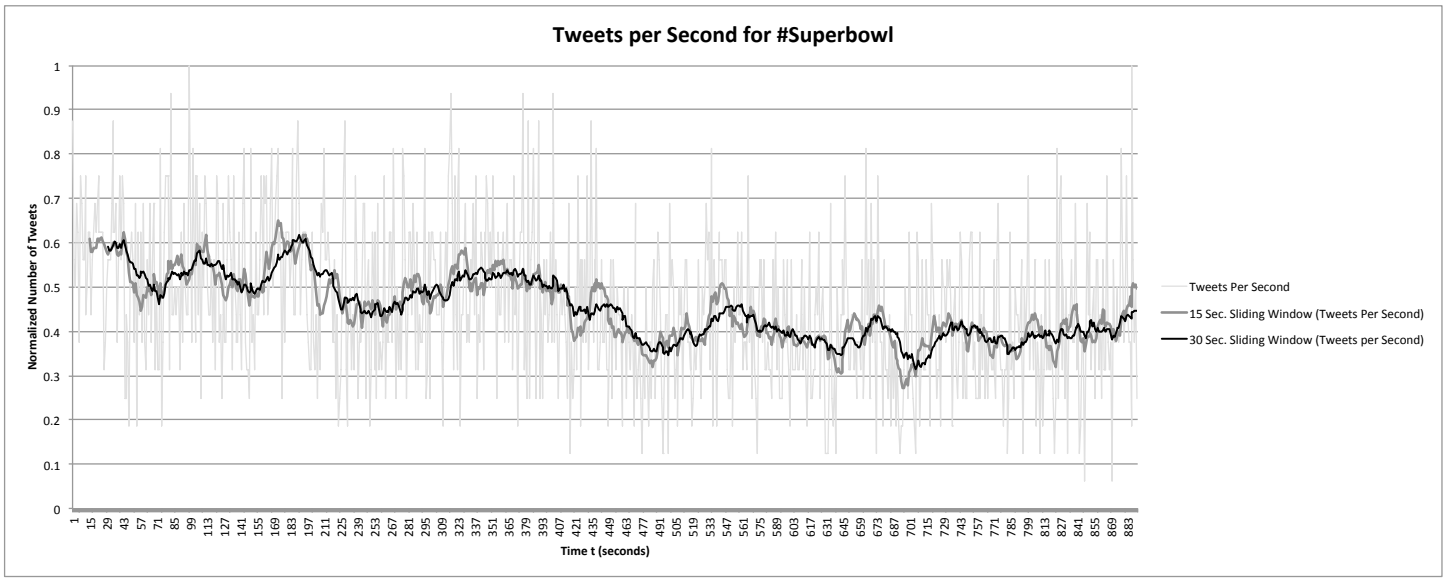
Data Group	Group Description	TPS * SD (SD = 1.4629)	Type	Total Number of Tweets	Average Length of Tweets	Max Length of Tweets	Tweets Per Second (TPS)	Number of Twitter Users
$\boldsymbol{D_1^{\#superbowl}}$	#SuperBowl	10.6404	Aggregated	6489	73.6304	144	7.2735	6396
$\boldsymbol{D_2^{\#GameTime}}$	#GameTime	0.0121	Single	6	60.5	93	0.0083	6
$\boldsymbol{D_3^{\#saftey}}$	#saftey	0.0368	Single	4	72.25	125	0.0252	4
$\boldsymbol{D_4^{u2}}$	u2	0.0247	Single	3	58.3333	80	0.0169	1
$\boldsymbol{D_5^{u3}}$	u3	0.0159	Single	3	67.6667	93	0.0109	1
$\boldsymbol{D_6^{u1}}$	u1	0.0061	Single	2	130.5	138	0.0042	1
$\boldsymbol{D_7^{u4}}$	u4	0.0131	Single	2	68.5	94	0.0090	1

Table 6. Features of the Tweets: There are many tweets we use in our data, so I will only specify the features for a few example tweets. Since we have an aggregated Twitter group that aggregates information about the tweets in that group over time, we depict the normalized number of tweets per second over time in Figure 1.

Twitter Data Point	Data Group	User Name	Length of Tweet	Tweet	Time t of Tweet (sec)
$\boldsymbol{d_{2,25}^{\#gametime}}$	#GameTime	u9	66	Let's Go #SB48 #Broncos #Seahawks #GameTime http://t.co/A1AcP2mRxd	25
$\boldsymbol{d_{2,157}^{\#gametime}}$	#GameTime	u10	93	#BOOMAnd we're off...It's #GameTime... #SuperBowlXLVIII #SuperBowl #SuperBowlSunday #Seahawks	157
$\boldsymbol{d_{6,160}^{u1}}$	u1	u1	138	Seattle Seagulls going for a shot on goal straight	160

				from kick off! Very brave #GoSeahawks #SuperBowlXLVIII #SuperBowl #DenverBroncos @C4NFL	
$d_{2,216}^{\#gametime}$	#GameTime	u11	20	#SuperBowl #GameTime	216
$d_{2,264}^{\#gametime}$	#GameTime	u12	84	#GameTime #SuperBowl #NFL w/ @FlorentDroy & a sleepy @lnacody http://t.co/CvckxEHXIV	264
$d_{3,281}^{\#saftey}$	#saftey	u5	30	Great start #saftey #SuperBowl	281
$d_{5,361}^{u3}$	u3	u3	61	RT @peoplemag: RT if you're rooting for the Seattle Seahawks.	361
$d_{5,391}^{u3}$	u3	u3	93	RT @Seahawks: Fastest score in @SuperBowl history: 12 seconds by the Seahawks. Yes. 12. #SB48	391
$d_{2,415}^{\#gametime}$	#GameTime	u14	44	RT @nwinesickle: Lets go broncos.. #GameTime	415
$d_{3,424}^{\#saftey}$	#saftey	u6	106	Looks like the Broncos are gonna play it safe for this game #broncos #seahawks #superbowl #saftey #yousuck	424
$d_{3,434}^{\#saftey}$	#saftey	u7	125	Wow!!! ALL #SuperBowl pools have just been big time adjusted! Eveyone who thought they had good numbers now... don't! #saftey	434
$d_{3,440}^{\#saftey}$	#saftey	u8	28	Broncos! Yea! Whoop! #saftey	440
$d_{4,508}^{u2}$	u2	u2	80	RT @DailyDeadNews: Super Bowl Trailer for Captain America: The Winter Soldier http://t.co/rcTos1IEHr	508
$d_{4,619}^{u2}$	u2	u2	51	#Superbowl and #lawandorder flipping back and forth cause my state ain't in it..	619
$d_{7,631}^{u4}$	u4	u4	43	Broncos better lose .. Just because they cheated ..	631
$d_{5,635}^{u3}$	u3	u3	49	RT @Seahawks: Seahawks are in the #RedZone. #SB48	635
$d_{6,640}^{u1}$	u1	u1	123	Seahawks running gamevsBroncos passing game	640
$d_{4,686}^{u2}$	u2	u2	44	Nice 12 yard pass there but the defenders closed him down quickly so he couldn't get through on goal #GoSeahawks #SuperBowl	686
$d_{2,748}^{\#gametime}$	#GameTime	u15	56	This is only the Beginning Seahawks vs Broncos #GameTime	748
$d_{7,853}^{u4}$	u4	u4	94	The Seahawks will lead but then the Broncos will make an epic comeback and win #gameprediction	853

Figure 1. Aggregated Twitter Group #Superbowl: The number of tweets per second is depicted below, with 15 second and 30 second sliding window averages.



3. Policy for (Data Group $\longmapsto$ Sound Group) Mapping

Limitations on Data

Note that when a user selects the data they wish to sonify, there are initial constraints that the data must satisfy:

$$\text{Total \# Aggregated Tweet Groups} <= \text{Total \# of Interval Sound Groups} + \left\lfloor \frac{\text{Total \# of Both Groups}}{2} \right\rfloor$$

$$\text{Total \# Single Tweet Groups} <= \text{Total \# of Instant Sound Groups} + \left\lfloor \frac{\text{Total \# of Both Groups}}{2} \right\rfloor$$

In the case of our example data:

1 Aggregated Tweet Group <= 3 Interval Sound Groups + 1 Both Sound Group

6 Single Tweet Groups <= 5 Interval Sound Groups + 1 Both Sound Group

Table 7. Example (Data Group $\longmapsto$ Sound Group) Mapping: The data group to sound group mapping is selected by the user. However, creating a mapping from Aggregated data groups, the options for the sound groups are limited to those of type Interval or Both. Similarly, a mapping from Single data groups are limited to the sound groups of type instant or both. We hope automate this mapping in the future.

$\boldsymbol{D_1^{\#SuperBowl} \longmapsto G_1^{stream}}$ (Aggregated-Interval)
$\boldsymbol{D_2^{\#GameTime} \longmapsto G_2^{nighingale}}$ (Single-Instant)
$\boldsymbol{D_3^{\#saftey} \longmapsto G_4^{frog}}$ (Single-Instant)
$\boldsymbol{D_4^{u2} \longmapsto G_4^{thunder}}$ (Single-Instant)
$\boldsymbol{D_5^{u3} \longmapsto G_5^{wolf}}$ (Single-Instant)
$\boldsymbol{D_6^{u1} \longmapsto G_6^{owl}}$ (Single-Instant)
$\boldsymbol{D_7^{u4} \longmapsto G_7^{fly}}$ (Single-Instant)

4. Policy for (Tweet Data Point ⟼ Sound Sample) Mapping

Table 8. Aggregated-Interval Mapping: We use a ranking to decide which sample features to use for the mapping. Each Mapping should only be used once starting from the top of the list (if there are more than 3 groups, start again from the beginning). The twitter data point feature we map the data to in all cases is the tweets per second. We then map that to a random sample in that sound group, which we loop and change sound feature at each time point t.

(1) Gain range: 0 - 1	$\frac{\#\ of\ tweets\ d_{i,t}\ at\ time\ t}{max\ \#\ of\ tweets\ at\ once\ in\ D_i} \longmapsto$ $gain(looped\ g_{j,random(1,\#samples)})\ updated\ at\ each\ t$
(2) Density number of layers , range: 0 - 6	$\left\lceil \frac{\#\ of\ tweets\ d_{i,t}\ at\ time\ t}{max\ \#\ of\ tweets\ at\ once\ in\ D_i} * 6 \right\rceil \longmapsto$ $layers(looped\ g_{j,random(1,\#samples)})\ updated\ at\ each\ t$
(3) Pitch playback rate, range: 0.5 - 1.5	$\frac{\#\ of\ tweets\ d_{i,t}\ at\ time\ t}{max\ \#\ of\ tweets\ at\ once\ in\ D_i} + 0.5 \longmapsto$ $rate(looped\ g_{j,random(1,\#samples)})\ updated\ at\ each\ t$

Table 9. Aggregated-Interval Mapping: We use the playback of a sample to indicate that a tweet in a single group has occurred. We differentiate the mappings on whether there is a single user in the tweet group, or if there are many.

$If\ \binom{\#Users}{in\ Group} == 1$	Map each tweet to a random sample in that group: $d_{i,t}\ at\ time\ t \longmapsto sample\ g_{j,random(1,\#samples)}$ **at time** t
$If\ \binom{\#\ Users}{in\ Group} > 1$	Each user will have a "voice" in the soundscape by using different samples. When (# Users in Tweet Group) > (# Samples in Sound Group), we utilize panning. $\left\lceil \frac{\#\ Users\ in\ Tweet\ Group}{\#\ Samples\ in\ Sound\ Group} \right\rceil = \#\ Source\ Locations$ $If\ \#\ Source\ Locations == 1$ $Username\ of\ tweet\ (d_{i,t})\ at\ time\ t$ $\longmapsto sample\ g_{j,t}$ **at time** t **with panning 0** $If\ \#\ Source\ Locations > 1$ $Username\ of\ tweet\ d_{i,t}\ (U_k)\ at\ time\ t$ $\longmapsto sample\ g_{j,(k\ mod\ \#samples)+1}$ **at time t with panning** p: $p = \frac{2 * \left\lceil \frac{k}{\#\ samples} - 1 \right\rceil}{\#SL - 1} - 1$

5. Example (Twitter Data Point ⟼ Sound Sample) Mappings

Table 10: Example Mappings for Soundscape_Output.wav: Using the example data and policy described above, and the selection of data-sound group mappings shown in Table 7, we generate the following data point ⟼ sound sample mapping.

Data Group ⟼ Sound Group Mapping	Data Point ⟼ Sound Sample Mapping
$\boldsymbol{D_1^{\#SuperBowl} \longmapsto G_1^{stream}}$ (Aggregated-Interval)	$\dfrac{\textbf{\# of tweets } \left(\mathbf{d_{1,t}^{\#SuperBowl}}\right) \textbf{ at time t}}{\textbf{max \# of tweets at once in } (\mathbf{D_1^{\#SuperBowl}})} \longmapsto \mathbf{gain}\left(\mathbf{g_{1,1}^{stream}}\right) \textbf{ at time t}$
$\boldsymbol{D_2^{\#GameTime} \longmapsto G_2^{nighingale}}$ (Single-Instant)	6 Users in $D_2^{\#GameTime}$ < 7 Samples in $G_2^{night.}$, $\#\ Source\ Loc. = \left\lceil \frac{6}{7} \right\rceil = 1$ **Username k of** $\boldsymbol{d_{2,t}^{\#gametime}}$ ***at time t*** $\boldsymbol{\longmapsto}$ **sample** $\boldsymbol{g_{2,k}^{nightingale}}$ **played at time t**
$\boldsymbol{D_3^{\#saftey} \longmapsto\ G_3^{frog}}$ (Single-Instant)	4 Users in $D_3^{\#saftey}$ < 5 Samples in G_3^{frog}, $\#\ Source\ Loc = \left\lceil \frac{4}{5} \right\rceil = 1$ **Username k of** $\boldsymbol{d_{3,t}^{\#saftey}}$ ***at time t*** $\boldsymbol{\longmapsto}$ **sample** $\boldsymbol{g_{3,k}^{frog}}$ **played at time t**
$\boldsymbol{D_4^{u2} \longmapsto\ G_3^{thunder}}$ (Single-Instant)	1 user in data group D_4^{u2}: map each tweet to a random sound sample $\boldsymbol{d_{4,t}^{u2}}$ ***at time t*** $\boldsymbol{\longmapsto}$ ***sample*** $\boldsymbol{g_{4,random(1,2)}^{thunder}}$ **played at time** $\boldsymbol{t}$
$\boldsymbol{D_5^{u3} \longmapsto\ G_5^{wolf}}$ (Single-Instant)	1 user in data group D_5^{u3}: map each tweet to a random sound sample $\boldsymbol{d_{5,t}^{u3}}$ ***at time t*** $\boldsymbol{\longmapsto}$ ***sample*** $\boldsymbol{g_{5,random(1,4)}^{wolf}}$ **played at time** $\boldsymbol{t}$
$\boldsymbol{D_6^{u1} \longmapsto\ G_6^{owl}}$ (Single-Instant)	1 user in data group D_6^{u1}: map each tweet to a random sound sample $\boldsymbol{d_{6,t}^{u1}}$ ***at time t*** $\boldsymbol{\longmapsto}$ ***sample*** $\boldsymbol{g_{6,random(1,6)}^{owl}}$ **played at time** $\boldsymbol{t}$
$\boldsymbol{D_7^{u4} \longmapsto\ G_7^{fly}}$ (Single-Instant)	1 user in data group D_7^{u4}: map each tweet to a random sound sample $\boldsymbol{d_{7,t}^{u4}}$ ***at time t*** $\boldsymbol{\longmapsto}$ ***sample*** $\boldsymbol{g_{7,random(1,5)}^{fly}}$ **played at time** $\boldsymbol{t}$