

Year, Month, Monthly\_MSL, Linear\_Trend, High\_Conf., Low\_Conf.

1935,5,-0.263,-0.228,-0.215,-0.242  
1935,6,-0.237,-0.228,-0.215,-0.242  
1935,7,-0.26,-0.228,-0.214,-0.241  
1935,8,-0.205,-0.228,-0.214,-0.241  
1935,9,-0.226,-0.227,-0.214,-0.241  
1935,10,-0.289,-0.227,-0.214,-0.24  
1935,11,-0.046,-0.227,-0.213,-0.24  
1935,12,-0.194,-0.226,-0.213,-0.239  
1936,1,-0.255,-0.226,-0.213,-0.239  
1936,2,-0.18,-0.226,-0.213,-0.239  
1936,3,-0.203,-0.225,-0.212,-0.238  
1936,4,-0.269,-0.225,-0.212,-0.238  
1936,5,-0.291,-0.225,-0.212,-0.238  
1936,6,-0.234,-0.224,-0.211,-0.237  
1936,7,-0.181,-0.224,-0.211,-0.237  
1936,8,-0.281,-0.224,-0.211,-0.237  
1936,9,-0.232,-0.223,-0.211,-0.236  
1936,10,-0.246,-0.223,-0.21,-0.236  
1936,11,-0.339,-0.223,-0.21,-0.236  
1936,12,-0.191,-0.223,-0.21,-0.235  
1937,1,-0.103,-0.222,-0.209,-0.235  
1937,2,-0.076,-0.222,-0.209,-0.235  
1937,3,-0.27,-0.222,-0.209,-0.234  
1937,4,-0.15,-0.221,-0.209,-0.234  
1937,5,-0.224,-0.221,-0.208,-0.234  
1937,6,-0.237,-0.221,-0.208,-0.233  
1937,7,-0.151,-0.22,-0.208,-0.233  
1937,8,-0.309,-0.22,-0.207,-0.233  
1937,9,-0.196,-0.22,-0.207,-0.232  
1937,10,-0.243,-0.219,-0.207,-0.232  
1937,11,-0.238,-0.219,-0.207,-0.232  
1937,12,-0.185,-0.219,-0.206,-0.231  
1938,1,-0.17,-0.218,-0.206,-0.231  
1938,2,-0.168,-0.218,-0.206,-0.231  
1938,3,-0.224,-0.218,-0.205,-0.23  
1938,4,-0.211,-0.218,-0.205,-0.23  
1938,5,-0.184,-0.217,-0.205,-0.229  
1938,6,-0.225,-0.217,-0.205,-0.229  
1938,7,-0.285,-0.217,-0.204,-0.229  
1938,8,-0.266,-0.216,-0.204,-0.228  
1938,9,-0.266,-0.216,-0.204,-0.228  
1938,10,-0.14,-0.216,-0.203,-0.228  
1938,11,-0.226,-0.215,-0.203,-0.227  
1938,12,-0.206,-0.215,-0.203,-0.227

# Data Sonification

Sara Bouchard

FLUXNET artist-in-residence

Adjunct Professor, VCUarts Kinetic Imaging



With special guest and collaborator

# Chris Gough

FLUXNET scientist  
Professor of Biology at VCU

# What is sonification?

1937,5,-0.224,-0.221,-0.208,-0.234  
1937,6,-0.237,-0.221,-0.208,-0.233  
1937,7,-0.151,-0.22,-0.208,-0.233  
1937,8,-0.309,-0.22,-0.207,-0.233  
1937,9,-0.196,-0.22,-0.207,-0.232  
1937,10,-0.243,-0.219,-0.207,-0.232  
1937,11,-0.238,-0.219,-0.207,-0.232  
1937,12,-0.185,-0.219,-0.206,-0.231  
1938,1,-0.17,-0.218,-0.206,-0.231  
1938,2,-0.168,-0.218,-0.206,-0.231  
1938,3,-0.224,-0.218,-0.205,-0.23  
1938,4,-0.211,-0.218,-0.205,-0.23  
1938,5,-0.184,-0.217,-0.205,-0.229  
1938,6,-0.225,-0.217,-0.205,-0.229  
1938,7,-0.285,-0.217,-0.204,-0.229  
1938,8,-0.266,-0.216,-0.204,-0.228  
1938,9,-0.266,-0.216,-0.204,-0.228  
1938,10,-0.14,-0.216,-0.203,-0.228  
1938,11,-0.226,-0.215,-0.203,-0.227  
1938,12,-0.206,-0.215,-0.203,-0.227  
1939,1,-0.249,-0.215,-0.203,-0.227  
1939,2,-0.238,-0.214,-0.202,-0.226

# Can you name these sonification tools?

[Listen](#)



# Johannes Kepler, *Harmonices Mundi* (1619)

EBook

206 DE MOTIBUS PLANETARUM

CAP. V. helij verò Jovis, Veneris, & ferè Saturni ; quadamtenus verò etiam Telluris ; & proculdubio etiam Mercurij. Nam si loj non aphelius Veneris, sed perihelius 3 pr. 3 sec. locum e capite ei proxime accedit etiam perihelius Mercurij 3 pr. 0 sec. per Diffidiaspon, per finem capitis IV. Huius verò perihelij 3 pr. 3 sec. pars decima, 1 g. sec. ablata, relinquit 2 pr. 45 sec. perihelium Jovis, obtinentem locum d. & pars quindecima 12 pr. addita, cumulat 5 pr. 15 sec. aphelium Martis ferè, obtinentem locum f. & sic in h. sequentur eandem ferè tensiones etiam perihelius Saturni & aphelius Jovis. At pars octava 22 sec. sumptu quinque, dat 1 pr. 55 sec. qui est perihelius Telluris ; qui etiā in eandem cum premis- sis non quadratur quia non ordinat intervallum 5. g. infra e, nec 24. 25. supra G. tamen si jam perihelius Veneris, & fieretiam aphelius Mercurii, extra ordinem pro e, capiant locum d., tunc hic perihelius Telluris caput locum G. & confiniet etiam aphelius Mercurij, qui pars tertia i pr. 1 sec. de 3 pr. 3 sec. sumptu quinque, fit 5 pr. 5 sec. cuius dimidium 2 pr. 32 sec. & proximè accedit ad aphelium Mercurij, qui in hac extraordinaria accommodacione obtinet locum c. Sunt igitur hi omnes inter se quidem tensiones ejusdem : aliter tamen Scalam dividit Veneris perihelius cum tribus (vel quinque) prioribus, eodem sc. genere Harmonico, q. apheli ejusdem, in tensione sua, puta genere Duro: aliter etiam ejusdem Veneris perihelius cum duobus posterioribus, diversa dividit: puta, non in Concinna alia, sed faltem in diversum Concinnum ordinem, qui feliciter proprius est generis Mollis.

Sufficit autem, hoc capite, quid in causa veretur, ob osculos posuisse: quare vero unumquodque sic fuerit factum, & quæ causæ non tantum configurationem, sed etiam difficultatem per minima id lucu- lentiissimis demonstrationibus patefecit Cap: IX.

C A P. VI

In Extremitatibus motuum Plane-  
tiorum expressos else quodammodo Mo-  
dos seu Tonos Musicos.

Sequitur hoc ex antedictis, nec opus est multis verbis, singuli enim planetæ singula quodammodo signant loca systematis, motu perihelio, quatenus datur, est singulis, percurrit certum ali- quod intervallum in Scala Musica, certus ejus Clavibus, seu locis Systematis comprehensum: cuiusque ab illa Clave seu loco incepturn, qui capite praecedenti contigit illius motus aphelio, & Saturno quidem & Terra G, at Jovi h, quæ in G altius tranponi potest, Marti f, Vene- ri & Mercurii A, in altiori Systemate. Vide singulos in Notis uita- tis. Non formant quidem intermedios locos, quo his vides notis im- pletos, articulatæ, sicut extremos: quia ab uno extremo, non fabulus & intervallis, sed continua tensione nituntur ab oppositus, media o- minia

HARMONICIS LIB. V. 207

inianæ (infinita in potentia) permeantes actu: id quod aliter à me non posui exprimi, quam per continuum seriem Notarum intermedia-

Saturnus      Jupiter      Mars ferè      Terra

Venus      Mercurius      His locum habet etiam

rum. Venus ferè manet in unisono non æquans tensionis amplitudine vel minimum ex concinnis intervallis.

Atqui signatura diuinarum in communis Systemate Clavum, & for- matio sceleri Octavae, per comprehenditionem certi intervalli concinni, est rudimentum quoddam definitiōis Tonorum seu Modorum: sunt ergo Modi Musici inter Planetas differtur. Scio equidem, ad forma- tionem & definitiōem difformitorum Modorum requiri plura, quæ canthus humani, quippe intervallum, sunt propria: itaque voce quodammodo sum usus.

Liberum autem erit Harmonistæ, sententiam de promere suam: quem quisque planeta Modum exprimat proprius, extremis his ipsi af- signatis. Ego Saturno darem ex uictatis Septimum vel Octavum, quia si radicalem ejus clavem ponas G, perihelius motus ascendit ad g: Jovi Primum vel Secundum: quia aphelio ejus motu ad G accommo- dato, perihelius ad b pervenit; Marti Quintum vel Sextum: non eò tantum, quia ferè Diapente aequatur, quod intervallum communem est omnibus modis: fed ideò potissimum: quia redactus cum catena ad commune Systema, perihelia motu & alesquitur, aphelio ad f aludit: quia radix eñ Toni seu Modi Quinti vel Sexi: Telluri darem Tertiū: et ex- vel Quartum: quia intra septimoniū ejus motus vertuntur; & vero primū illorum Tonorum intervallum est semitonium: Mercurio, inde- verò ob amplitudinem intervalli, promiscue omnes Modi vel Tonos conve- nient: Veneri ob angustum intervallum, planē nullus arbor com- munis Systema, etiam Tertius & Quartus: quia ipsa respectu catena- rum obtinet.

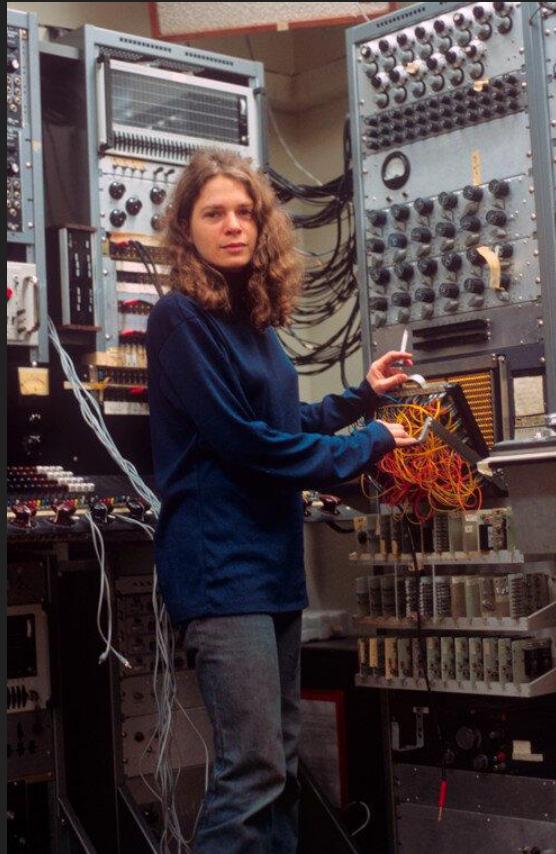
CAPVT VII.

Harmonias universales omnium  
sex Planetarum, veluti communia Contra-  
puncta, quadri formanda.

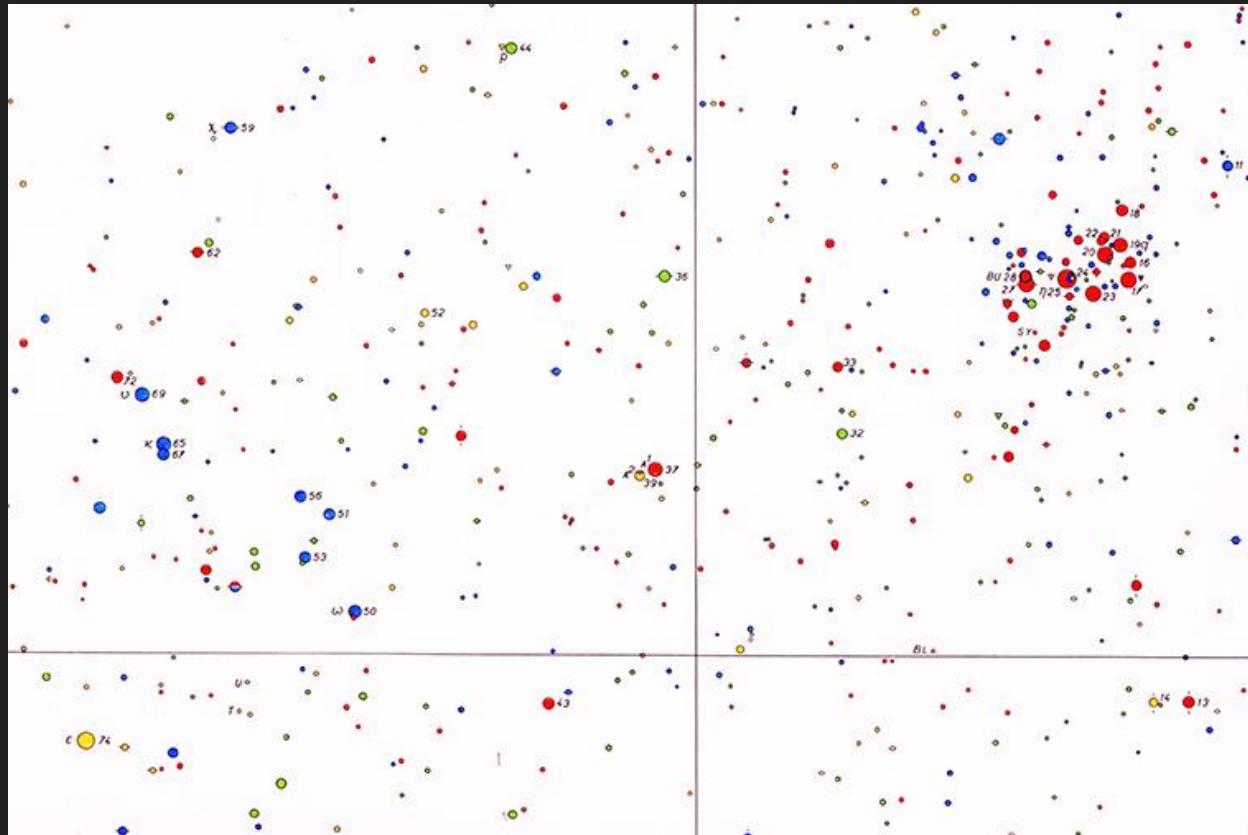
Nuncopus, Vranie, sonitu majore: dum per scalam  
Harmonicanam celestium motuum, ad altiora consendo: quæ ge-  
nus

# Laurie Spiegel, *Kepler's Harmony of the Worlds* (1977)

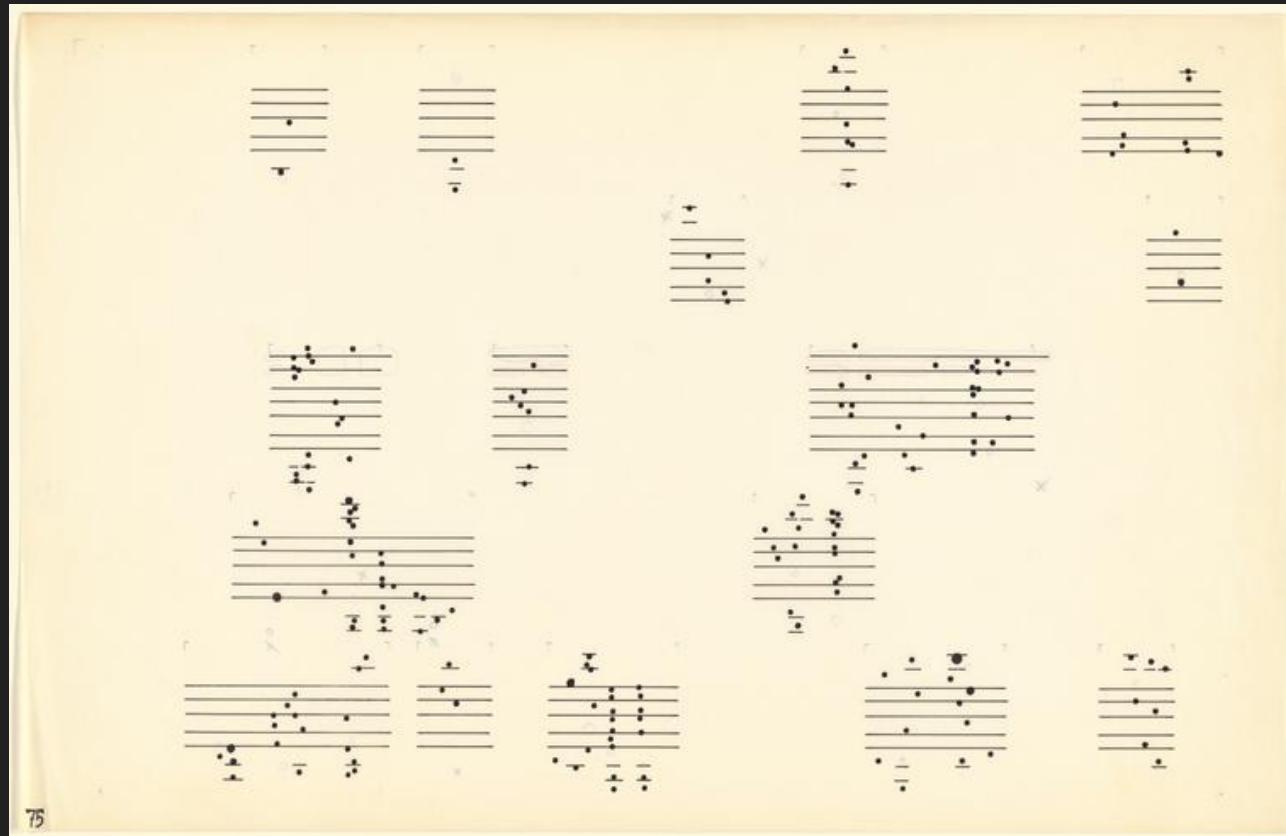
[Audio](#)  
[Video](#)



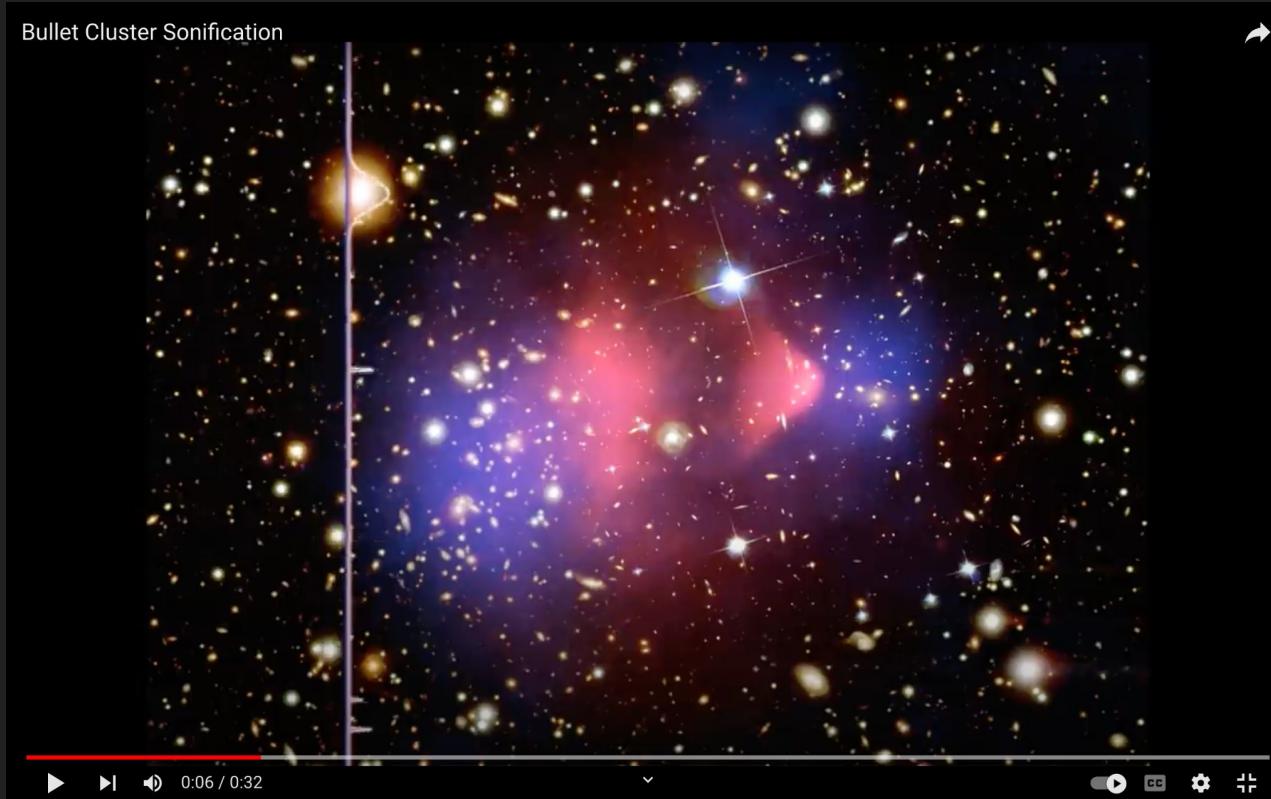
Atlas of stars by Antonín Bečvář (1958) which inspired...



John Cage, *Atlas Eclipticalis* (1961) [Watch](#)



# NASA's Chandra X-Ray Observatory: Bullet Cluster Sonification [Link](#)



# Scientists using sonification in their work

[Link](#)

What scientists can learn by listening

latimes.com/science/story/2023-02-03/the-sounds-of-science

Los Angeles Times

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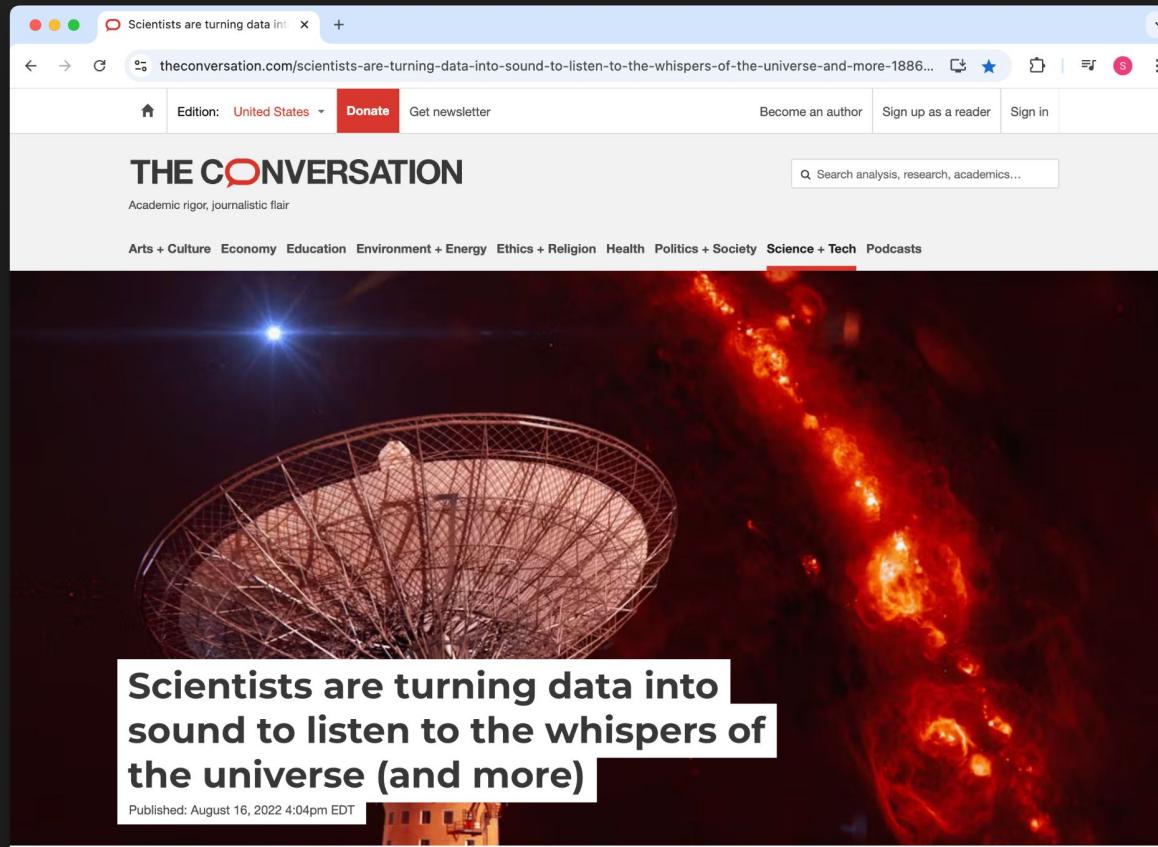
(Scott Gelber / For The Times)

Why just look at your data when you could listen? Scientists are turning their data into sound to gain new insights into things as small as DNA and as large as galaxies.

By Sumeet Kulkarni  
Contributing Science Writer

# Scientists using sonification in their work

[Link](#)



# Artists using sonification in their work

## Chris Chafe

Work

All Current Projects Music Research Sound Art

**All Research**

**All Music**

**Sonification**

**Brain Stethoscope**

**Tomato Music**

**Ping**

<https://chrischafe.net/work/>

## Brian Foo

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**TRACK 1 Two Trains**  
Sonification of Income Inequality on the NYC Subway

**TRACK 2 Rhapsody in Grey**  
Using Brain Wave Data to Convert a Seizure to Song

**TRACK 3 Air Play**  
Smog Music Created With Beijing Air Quality Data

**TRACK 4 Mixed Attraction**  
A Song Mixed Using Data On Race And Attraction

**TRACK 5 Lee and Jackson**  
The Rhythm and Sounds of Two Painters and Their Work

**TRACK 6 Distance From Home**  
Translating Global Refugee Movement to Song

**TRACK 7**

**DATA-DRIVEN DJ**  
by Brian Foo

**Data-Driven DJ** is a series of music experiments that combine data, algorithms, and borrowed sounds.

My goal is to explore new experiences around data consumption beyond the written and visual forms by taking advantage of music's temporal nature and capacity to alter one's mood. Topics will range from social and cultural to health and environmental.

Each song will be made out in the open: the creative process will be documented and published online, and all custom software written will be [open-source](#). Stealing, extending, and remixing are inevitable, welcome, and encouraged. Check out the [FAQs](#) for more information.

MANHATTAN MANHATTAN MANHATTAN

Stage 2 of 3 Seizure Event

## My work

My interest in sonification arose from “seeing sound” in the environment around me - lifting melody from the landscape.

# Weather Box, 2014

[Listen](#)



**QUALITY CONTROLLED LOCAL  
CLIMATOLOGICAL DATA  
(final)**  
**HOURLY OBSERVATIONS TABLE**  
**CENTRAL PARK (94728)**  
**NEW YORK, NY**  
**(03/2014)**

Elevation: 130 ft. above sea level  
Latitude: 40.778  
Longitude: -73.969  
Data Version: VER3

Date	Time (LST)	Station Type	Sky Conditions	Visibility (SM)	Weather Type	Dry Bulb Temp		Wet Bulb Temp		Dew Point Temp		Rel Humd %	Wind Speed (MPH)	Wind Dir	Wind Gusts (MPH)	Station Pressure (in. hg)	Press Tend	Net 3-hr Chg (mb)	Sea Level Pressure (in. hg)	Report Type	Precip. Total (in)	Alti- meter (in. hg)		
						(F)	(C)	(F)	(C)	(F)	(C)													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23		
01	0051	11	CLR	10.00		21	-6.1	16	-8.9	-2	-18.9	36	3	270		30.28		30.41	AA		30.49			
01	0151	11	CLR	10.00		22	-5.6	17	-8.1	2	-16.7	42	0	000		30.26		30.40	AA		30.49			
01	0251	11	CLR	10.00		22	-5.6	18	-8.0	4	-15.6	46	6	270		30.25		30.40	AA		30.42			
01	0351	11	CLR	10.00		21	-6.1	17	-8.3	5	-15.0	50	3	VR		30.24		30.39	AA		30.41			
01	0451	11	CLR	10.00		20	-6.7	16	-8.8	4	-15.6	50	0	000		30.24		30.39	AA		30.41			
01	0551	11	CLR	10.00		21	-6.1	17	-8.4	4	-15.6	48	0	000		30.23		30.38	AA		30.40			
01	0651	11	CLR	10.00		21	-6.1	17	-8.2	6	-14.4	52	6	030		30.22		30.37	AA		30.39			
01	0751	11	CLR	10.00		24	-4.4	20	-6.8	8	-13.3	50	5	170		30.23		30.38	AA		30.40			
01	0851	11	CLR	10.00		27	-2.8	22	-5.4	10	-12.2	49	5	170		30.25		30.39	AA		30.42			
01	0951	11	CLR	10.00		28	-2.2	23	-4.9	11	-11.7	49	6	VR		30.23		30.38	AA		30.40			
01	1051	11	CLR	10.00		31	-0.6	25	-3.9	10	-12.2	41	8	170		30.21		30.36	AA		30.38			
01	1151	11	CLR	10.00		35	1.7	28	-2.4	11	-11.7	37	7	150		30.19		30.34	AA		30.36			
01	1251	11	CLR	10.00		35	1.7	28	-2.2	13	-10.6	40	3	VR		30.14		30.29	AA		30.31			
01	1351	11	CLR	10.00		35	1.7	28	-2.4	11	-11.7	37	7	VR		30.12		30.27	AA		30.29			
01	1451	11	CLR	10.00		37	2.8	29	-1.6	12	-11.1	36	5	VR		30.09		30.24	AA		30.26			
01	1551	11	OVC100	10.00		36	2.2	28	-1.9	12	-11.1	37	5	VR		30.09		30.24	AA		30.26			
01	1651	11	OVC100	10.00		37	2.8	29	-1.8	10	-12.2	33	8	270		30.08		30.23	AA		30.25			
01	1751	11	BKN110	10.00		37	2.8	29	-1.7	11	-11.7	34	7	270		30.05		30.20	AA		30.22			
01	1851	11	OVC085	10.00		36	2.2	28	-2.1	11	-11.7	35	0	000		30.07		30.22	AA		30.24			
01	1951	11	OVC080	10.00		36	2.2	28	-1.6	15	-9.4	42	5	270		30.05		30.20	AA		30.22			
01	2051	11	OVC080	10.00		37	2.8	29	-1.4	14	-10.0	39	9	260		30.04		30.19	AA		30.21			
01	2151	11	BKN055 OVC100	10.00		36	2.2	30	-1.0	19	-7.2	50	0	000		30.04		30.19	AA		30.21			
01	2251	11	OVC080	10.00		35	1.7	29	-1.5	18	-7.8	50	3	240		30.02		30.17	AA		30.19			
02	0051	11	SCT100	10.00		36	2.2	29	-1.7	17	-10.0	40	5	VR		30.00		30.15	AA		30.17			
02	0151	11	BKN080	10.00		36	2.2	29	-1.7	14	-10.0	40	9	270		29.99		30.15	AA		30.15			
02	0251	11	BKN080	10.00		35	1.7	28	-2.0	14	-10.0	42	M	M		29.97		30.12	AA		30.14			
02	0351	11	OVC070	10.00		35	1.7	28	-1.9	15	-9.4	44	7	240		29.93		30.09	AA		30.11			
02	0451	11	OVC070	10.00		36	2.2	29	-1.4	16	-8.9	44	5	VR		29.93		30.08	AA		30.10			
02	0551	11	OVC065	10.00		36	2.2	30	-1.3	17	-8.3	46	5	250		29.90		30.05	AA		30.07			
02	0651	11	OVC055	10.00		36	2.2	30	-1.0	19	-7.2	50	3	VR		29.93		30.08	AA		30.10			
02	0751	11	OVC043	10.00		36	2.2	30	-1.1	18	-7.8	48	0	000		29.93		30.08	AA		30.10			
02	0851	11	OVC055	10.00		37	2.8	30	-0.9	17	-8.3	44	0	000		29.93		30.07	AA		30.10			
02	0951	11	OVC060	10.00		38	3.3	31	-0.5	18	-7.8	44	3	290		29.93		30.08	AA		30.10			
02	1051	11	FEW055 OVC065	10.00		38	3.3	31	-0.5	18	-7.8	44	0	000		29.92		30.07	AA		30.09			
02	1151	11	OVC070	9.00		38	3.3	31	-0.3	19	-7.2	46	3	VR		29.91		30.05	AA		30.08			
02	1251	11	SCT100	10.00		39	3.9	32	0.2	21	-6.1	48	6	360		29.86		30.01	AA		30.03			
02	1351	11	OVC110	9.00		39	3.9	32	0.2	21	-6.1	48	0	000		29.83		29.98	AA		30.00			
02	1451	11	OVC095	9.00		39	3.9	33	0.4	22	-5.6	51	5	VR		29.85		29.99	AA		30.02			
02	1551	11	BKN065 OVC080	9.00		40	4.4	34	0.9	23	-5.0	51	8	340		29.85		29.99	AA		30.02			
02	1651	11	FEW039 BKN060 OVC070	10.00		38	3.3	32	-0.0	21	-6.1	50	3	VR		29.87		30.01	AA		30.04			
02	1751	11	SCT036 OVC048	10.00		37	2.8	32	-0.2	22	-5.6	55	0	000		29.87		30.02	AA		30.04			
02	1851	11	BKN043 OVC055	10.00		37	2.8	31	-0.5	20	-6.7	50	3	VR		29.87		30.01	AA		30.04			
02	1951	11	OVC041	10.00		37	2.8	30	-1.1	16	-8.9	42	0	000		29.85		30.00	AA		30.02			
02	2051	11	OVC045	10.00		36	2.2	29	-1.4	16	-8.9	44	7	310		29.87		30.01	AA		30.04			
02	2151	11	OVC046	10.00		35	1.7	29	-1.8	16	-8.9	46	6	VR		29.87		30.01	AA		30.04			
02	2251	11	OVC050	10.00		34	1.1	28	-2.3	15	-9.4	46	1*	M		29.87		30.01	AA		30.04			

I originally sourced and analyzed data by hand! Data from NOAA.gov





My early sonifications were low-tech, rooted in folk music and conveyed intimacy.

# Catskills Songline, 2016

[Listen](#)





[\*Breathe, River\*](#) (2019) incorporated a year's worth of water quality data from the James River in Richmond, VA (obtained from VCU Rice Rivers Center)

U1		fx   Sonde1_pH_mv	2017 Rice Pier Jan-Dec with qaqc pivot 2 (Autosaved)																											Search Sheet					
		A	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1		TIMESTAMP	volt	LoggerTemp	PAR_Densit	WindSpd	Wind	AirTemp	RH	BP_in	Rain	Sonde1_D	Sonde1_T	Sonde1_Ba	Sonde1_wl	Sonde1_Ca	Sonde1_Wi	Sonde1_Te	Sonde1_Te	Sonde1_Sp	Sonde1_Cond	del1	e1_d	del1	del1	Sonde1_Tu	Sonde1_Ch	Sonde1_Ch	Sonde1_BG	Sonde1_BG	Sonde1_BG	Sonde1_O	Sonde1_O	Sonde1_O	
2	1/1/17 0:00	12.65	8.13	0.006	8.66	223.4	46.74	42.88	30.02	0	120216	73354	5.56	0	12.08	0	6.021	42.84	7.74	0	197.1	21.29	12.81	3.2	0.92	0	0	99.9	12.9	12.9					
3	1/1/17 0:15 12.64	8.08	0.015	9.07	218.1	46.7	42.81	30.01	0	120216	73354	5.56	0	12.08	0	6.014	42.83	7.72	0	197	21.31	12.62	3.15	0.93	0	0	99.7	12.9	12.9						
4	1/1/17 0:30 12.63	8.05	0.006	10.95	228	46.81	42.55	30.01	0	120216	73354	5.56	0	12.08	0	6.024	42.84	7.77	0	197.6	16.99	11.6	2.89	0.87	0	0	100.3	12.9	12.9						
5	1/1/17 0:45 12.63	8.05	0.015	12.4	236.4	47.04	42.56	30.02	0	120216	73354	5.56	0	12.08	0	6.002	42.80	7.75	0	197.4	17.83	11.8	2.94	0.88	0	0	100.1	12.4	12.4						
6	1/1/17 1:00 12.63	8.09	0.028	11.02	230.9	47.29	42.64	30.02	0	120216	73354	5.56	0	12.08	0	5.992	42.79	7.52	0	190.7	26.45	11.73	2.93	0.9	0	0	98.5	12.9	12.9						
7	1/1/17 1:15 12.63	8.15	0.034	10.76	229.4	47.31	42.42	30.01	0	120216	73354	5.56	0	12.08	0	6.045	42.88	7.69	0	195.4	25.58	12.44	3.1	0.93	0	0	99.3	12.5	12.5						
8	1/1/17 1:30 12.62	8.2	0.028	12.29	234	47.47	42.46	30.01	0	120216	73354	5.56	0	12.08	0	6.017	42.83	7.62	0	192.3	32.84	12.96	3.23	0.98	0	0	98.8	12.2	12.2						
9	1/1/17 1:45 12.62	8.27	0.019	12.45	241.6	47.69	42.98	30.01	0	120216	73354	5.56	0	12.08	0	6.099	42.98	7.72	0	195.9	19.9	12.36	3.08	0.92	0	0	99.5	12.5	12.5						
10	1/1/17 2:00 12.61	8.36	0.059	12.99	246.9	47.88	42.94	30.02	0	120216	73354	5.56	0	12.08	0	6.119	43.01	7.74	0	196.1	16.56	12.25	3.06	0.9	0	0	99.8	12.5	12.5						
11	1/1/17 2:15 12.61	8.44	0.062	12.79	243.1	47.85	44.12	30.02	0	120216	73354	5.56	0	12.08	0	6.213	43.18	7.77	0	194.8	13.02	11.9	2.97	0.87	0	0	100	12.5	12.5						
12	1/1/17 2:30 12.61	8.47	0.022	11.66	241.2	47.8	44.17	30.02	0	120216	73354	5.56	0	12.08	0	6.283	43.31	7.8	0	196.1	11.93	11.72	2.92	0.85	0	0	100	12.5	12.5						
13	1/1/17 2:45 12.6	8.5	0.012	10.71	237.6	47.77	44.44	30.02	0	120216	73354	5.56	0	12.08	0	6.324	43.38	7.8	0	196	11.63	12.09	3.02	0.87	0	0	100.1	12.5	12.5						
14	1/1/17 3:00 12.6	8.5	0.019	8.28	247.5	47.6	45.26	30.03	0	120216	73354	5.56	0	12.08	0	6.329	43.39	7.79	0	196.2	11.48	12.45	3.11	0.86	0	0	100.1	12.5	12.5						
15	1/1/17 3:15 12.59	8.5	0.012	10.28	236.2	47.6	45.65	30.04	0	120216	73354	5.56	0	12.08	0	6.317	43.37	7.79	0	196.5	11.39	12.5	3.12	0.91	0	0	100	12.5	12.5						
16	1/1/17 3:30 12.59	8.5	0.025	9.29	227.5	47.6	45.9	30.04	0	120216	73354	5.56	0	12.08	0	6.305	43.35	7.77	0	196.4	11.51	12.73	3.18	0.91	0	0	100.1	12.5	12.5						
17	1/1/17 3:45 12.58	8.49	0.006	9.47	219.5	47.6	46.18	30.04	0	120216	73354	5.56	0	12.08	0	6.293	43.33	7.76	0	196.8	11.34	12.65	3.16	0.9	0	0	100.1	12.5	12.5						
18	1/1/17 4:00 12.57	8.47	0.009	7.491	228.9	47.6	46.26	30.05	0	120216	73354	5.56	0	12.08	0	6.281	43.31	7.76	0	196.7	11.4	12.3	3.07	0.88	0	0	100.1	12.5	12.5						
19	1/1/17 4:15 12.57	8.44	0.006	9.7	247.6	47.74	47.41	30.05	0	120216	73354	5.56	0	12.08	0	6.267	43.28	7.76	0	196.9	11.82	12.74	3.18	0.9	0	0	100.1	12.5	12.5						
20	1/1/17 4:30 12.57	8.38	0.006	9.84	244.1	47.8	48.77	30.05	0	120216	73354	5.56	0	12.08	0	6.224	43.20	7.75	0	195.8	11.55	12.97	3.24	0.91	0	0	100.2	12.5	12.5						
21	1/1/17 4:45 12.56	8.38	0.006	9.35	246.1	47.88	49.76	30.05	0	120216	73354	5.56	0	12.08	0	6.203	43.17	7.75	0	196.3	11.62	13.59	3.39	0.94	0	0	100.2	12.5	12.5						
22	1/1/17 5:00 12.56	8.34	0.015	9.68	241.3	48.1	50.09	30.05	0	120216	73354	5.56	0	12.08	0	6.161	43.09	7.69	0	194.6	15.24	12.74	3.18	0.92	0	0	99.3	12.5	12.5						
23	1/1/17 5:15 12.55	8.51	0.012	8.47	242.2	48.2	49.53	30.05	0	120216	73354	5.56	0	12.08	0	6.179	43.12	7.7	0	193.5	13.89	12.82	3.2	0.93	0	0	99.4	12.5	12.5						
24	1/1/17 5:30 12.55	8.57	0.015	8.19	246.7	48.21	49.83	30.04	0	120216	73354	5.56	0	12.08	0	6.18	43.12	7.76	0	196.2	11.95	12.49	3.12	0.88	0	0	99.9	12.5	12.5						
25	1/1/17 5:45 12.53	8.59	0.012	9.55	250.9	48.27	51.05	30.05	0	120216	73354	5.56	0	12.08	0	6.123	43.02	7.7	0	195.9	13.9	12	2.99	0.86	0	0	99.4	12.5	12.5						
26	1/1/17 6:00 12.53	8.63	0.022	11.11	242	48.28	50.27	30.05	0	120216	73354	5.56	0	12.08	0	6.199	43.16	7.75	0	196.7	12.12	12.09	3.02	0.83	0	0	99.8	12.5	12.5						
27	1/1/17 6:15 12.52	8.68	0.015	10.34	242.3	48.34	50.09	30.05	0	120216	73354	5.56	0	12.08	0	6.227	43.21	7.76	0	197.1	11.54	12.09	3.02	0.85	0	0	99.8	12.5	12.5						
28	1/1/17 6:30 12.52	8.73	0.009	8.01	246.5	48.3	50.73	30.05	0	120216	73354	5.56	0	12.08	0	6.25	43.25	7.74	0	195.6	11.7	11.68	2.91	0.83	0	0	99.6	12.5	12.5						
29	1/1/17 6:45 12.51	8.75	0.012	8.56	249.1	48.47	50.21	30.06	0	120216	73354	5.56	0	12.08	0	6.18	43.12	7.7	0	195.8	13.57	11.83	2.95	0.84	0	0	99.4	12.5	12.5						
30	1/1/17 7:00 12.51	8.77	0.012	7.67	248.4	48.48	50.8	30.06	0	120216	73354	5.56	0	12.08	0	6.118	43.01	7.67	0	196	14.32	11.86	2.96	0.85	0	0	99.1	12.2	12.2						
31	1/1/17 7:15 12.5	8.77	0.015	9.32	242.9	48.72	50.35	30.07	0	120216	73354	5.56	0	12.08	0	6.116	43.01	7.67	0	196.2	13.91	11.95	2.98	0.86	0	0	98.9	12.2	12.2						
32	1/1/17 7:30 12.5	8.82	0.015	12.26	244.8	49.04	49.54	30.07	0	120216	73354	5.56	0	12.08	0	6.091	42.96	7.67	0	196.8	14.16	11.72	2.92	0.83	0	0	98.9	12.2	12.2						
33	1/1/17 7:45 12.5	8.89	0.025	9.28	251.4	48.96	49.61	30.08	0	120216	73354	5.56	0	12.08	0	6.056	42.90	7.68	0	197	14.23	11.88	2.96	0.83	0	0	98.8	12.2	12.2						
34	1/1/17 8:00 12.49	8.92	0.068	10.3	252.6	48.87	49.59	30.09	0	120216	73354	5.56	0	12.08	0	6.003	42.81	7.68	0	197.1	15	11.98	2.99	0.83	0	0	98.7	12.2	12.2						
35	1/1/17 8:15 12.49	8.93	0.036	11.36	250.4	49.07	49.41	30.09	0	120216	73354	5.56	0	12.08	0	5.954	42.72	7.68	0	197.1	17.05	12.22	3.05	0.85	0	0	98.6	12.2	12.2						
36	1/1/17 8:30 12.48	8.9	0.076	12.18	250.7	49.09	49.62	30.1	0	120216	73354	5.56	0	12.08	0	5.918	42.65	7.68	0	197.7	17.84	12.31	3.07	0.87	0	0	98.6	12.2	12.2						
37	1/1/17 8:45 12.49	8.87	0.026	11.27	247.5	48.84	49.94	30.11	0	120216	73354	5.56	0	12.08	0	5.904	42.63	7.68	0	197.9	17.88	12.45	3.1	0.87	0	0	98.7	12.5	12.5						
38	1/1/17 9:00 12.51	8.81	0.044	44.54	8.73	234.7	48.34	50.12	30.12	0	120216	73354	5.56	0	12.08	0	5.927	42.67	7.69	0	198.7	18.76	12.31	3.07	0.86	0	0	98.7	12.5	12.5					
39	1/1/17 9:15 12.52	8.72	0.054	237.1	47.85	50.49	50.13	30.13	0	120216	73354	5.56	0	12.08	0	5.958	42.72	7.68	0	198.7	18.56	12.55	3.13	0.88	0	0	98.8	12.5	12.5						
40	1/1/17 9:30 12.56	8.68	0.015	115.9	8.93	240.8	47.56	51.13	30.13	0	120216	73354	5.56	0	12.08	0	6.034	42.86	7.69	0															

musicalgorithms.org/4.1/app/#

Not Secure | musicalgorithms.org/4.1/app/#/pitch

## Music Algorithms

Pitch Duration Scale Options Play

Pitch

Select Number of Voices: 1 + Add Voice Reset Data

Voice 1 X

Note count: 623

Select set for pitch:  

Pitch input:

```
-0.263,  
-0.237,  
-0.26,  
-0.205,
```

Range 20 To 60 ⓘ 

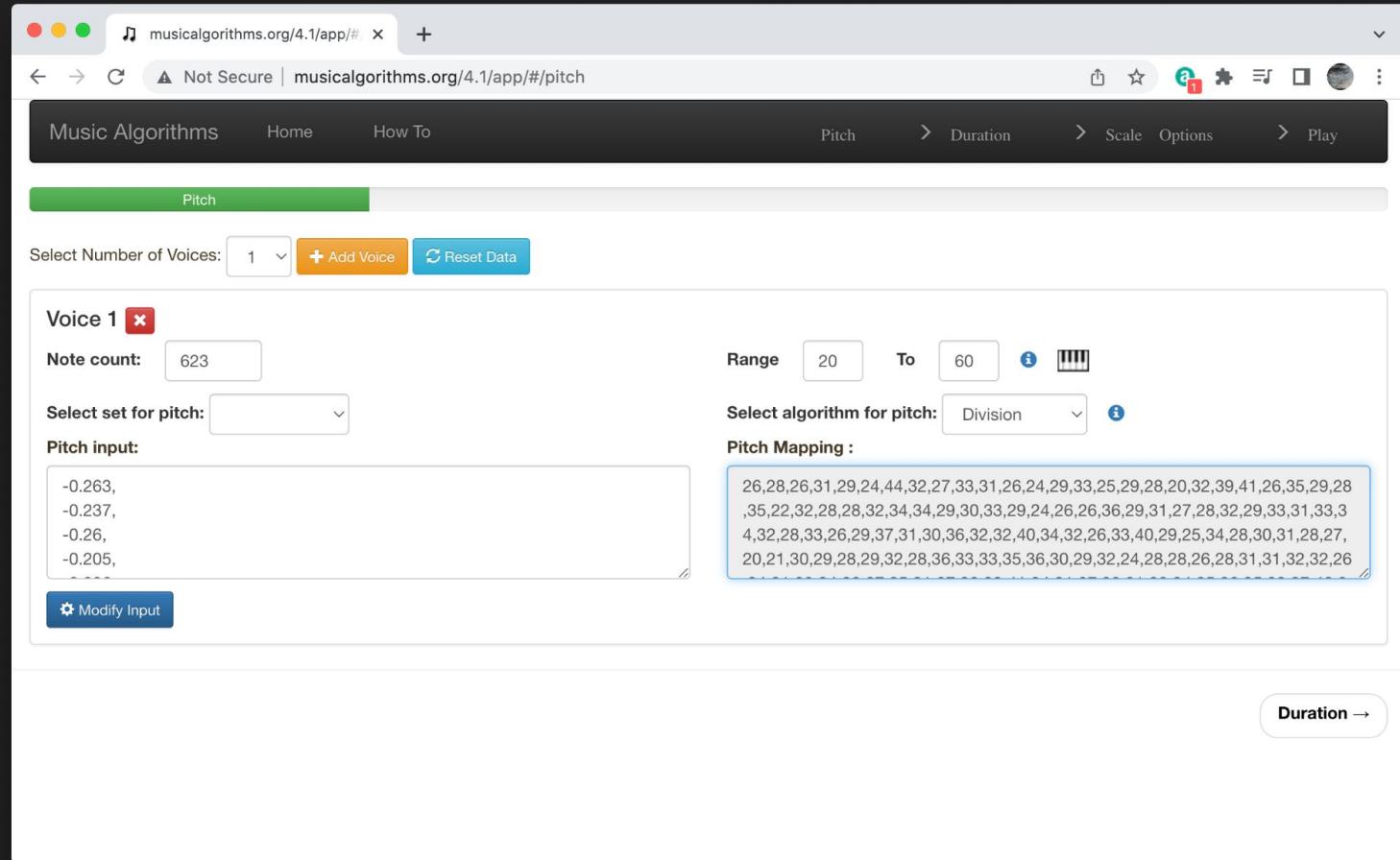
Select algorithm for pitch: Division ⓘ

Pitch Mapping :

```
26,28,26,31,29,24,44,32,27,33,31,26,24,29,33,25,29,28,20,32,39,41,26,35,29,28  
,35,22,32,28,28,32,34,34,29,30,33,29,24,26,26,36,29,31,27,28,32,29,33,31,33,3  
4,32,28,33,26,29,37,31,30,36,32,32,40,34,32,26,33,40,29,25,34,28,30,31,28,27,  
20,21,30,29,28,29,32,28,36,33,33,35,36,30,29,32,24,28,28,26,28,31,31,32,32,26
```

Modify Input

Duration →



The website [Musicalgorithms.org](http://Musicalgorithms.org) aided me in mapping the data to MIDI values

## July - Sept DO

I then pulled the MIDI into a music scoring program before recording the piece with a tenor saxophonist.

(Repeated values are expressed in longer durations or rests.)

JULY 1

4

7

10

13

16

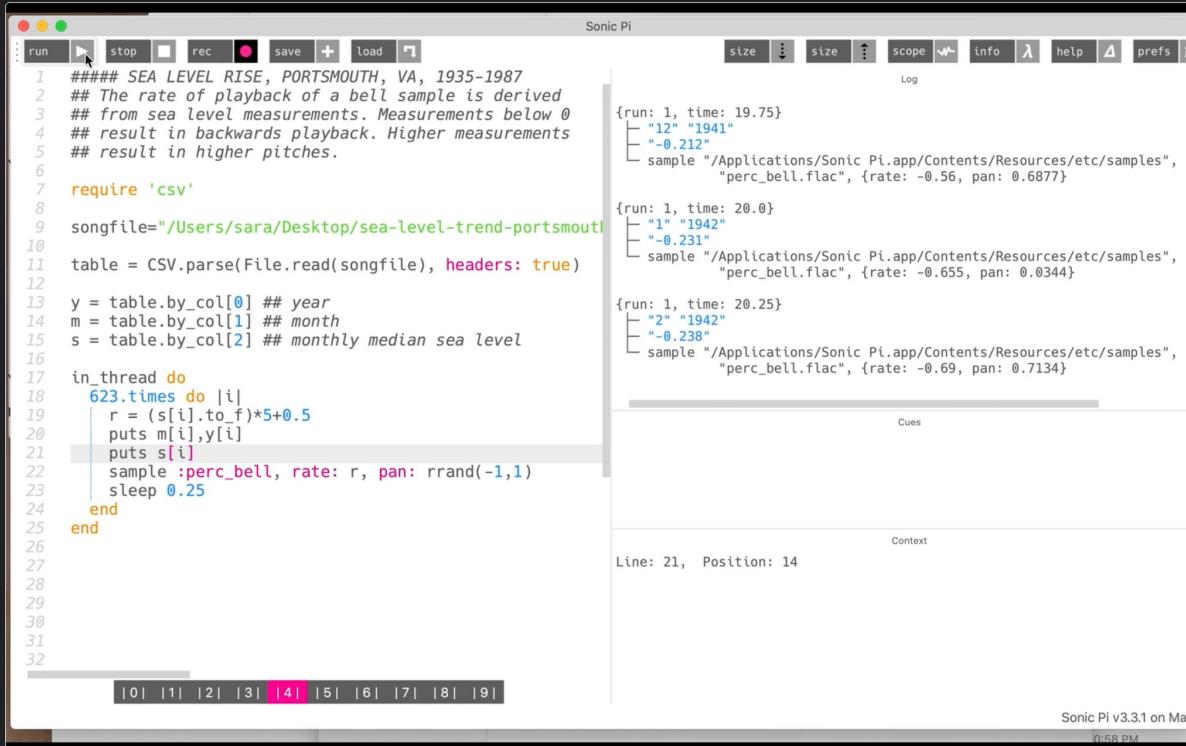
19

22

25

# Sonic Pi software...

[Listen to this sonification sketch](#)



The screenshot shows the Sonic Pi application window. On the left, there is a code editor with the following Ruby code:

```
1 ##### SEA LEVEL RISE, PORTSMOUTH, VA, 1935-1987
2 ## The rate of playback of a bell sample is derived
3 ## from sea level measurements. Measurements below 0
4 ## result in backwards playback. Higher measurements
5 ## result in higher pitches.
6
7 require 'csv'
8
9 songfile = "/Users/sara/Desktop/sea-level-trend-portsmouth"
10
11 table = CSV.parse(File.read(songfile), headers: true)
12
13 y = table[0] ## year
14 m = table[1] ## month
15 s = table[2] ## monthly median sea level
16
17 in_thread do
18   623.times do |i|
19     r = (s[i].to_f)*5+0.5
20     puts m[i], y[i]
21     puts s[i]
22     sample :perc_bell, rate: r, pan: rrand(-1,1)
23     sleep 0.25
24   end
25 end
26
27
28
29
30
31
32
```

Below the code editor is a numeric keypad.

On the right side of the window, there is a "Log" pane displaying the execution of the code:

```
{run: 1, time: 19.75}
└─ "12" "1941"
  └─ "-0.212"
    └─ sample "/Applications/Sonic Pi.app/Contents/Resources/etc/samples",
        "perc_bell.flac", {rate: -0.56, pan: 0.6877}

{run: 1, time: 20.0}
└─ "1" "1942"
  └─ "-0.231"
    └─ sample "/Applications/Sonic Pi.app/Contents/Resources/etc/samples",
        "perc_bell.flac", {rate: -0.655, pan: 0.0344}

{run: 1, time: 20.25}
└─ "2" "1942"
  └─ "-0.238"
    └─ sample "/Applications/Sonic Pi.app/Contents/Resources/etc/samples",
        "perc_bell.flac", {rate: -0.69, pan: 0.7134}
```

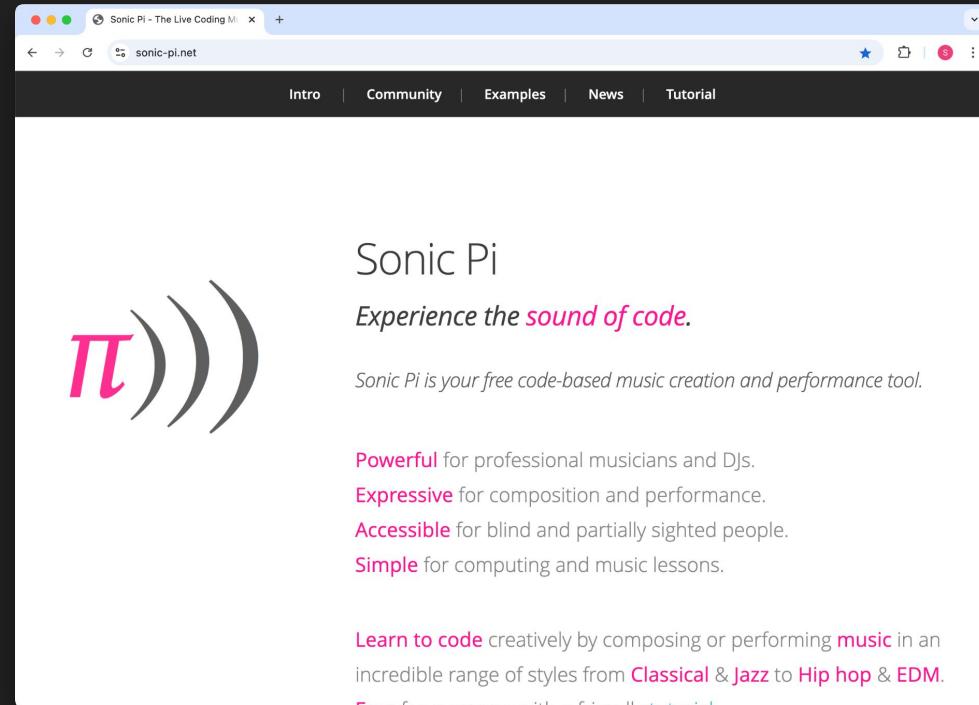
Below the log is a "Cues" section and a "Context" section showing "Line: 21, Position: 14". At the bottom right, it says "Sonic Pi v3.3.1 on Mac 04:58 PM".

In 2021, I started incorporating Sonic Pi, a live coding software, into my work. Sonic Pi is built in Ruby and can easily read spreadsheets with a specialized line of code.



*Forest for the Trees* (2023) incorporated accelerometer data from microcontrollers placed in trees outside the gallery. I used Sonic Pi to trigger sound samples in different ways depending on the data streaming in through OSC (Open Sound Control).

I discovered in Sonic Pi a powerful, open-ended tool for creative sonification and developed a VCUarts class to share my techniques.



My art students worked with FLUXNET data! [Link](#)

The screenshot shows a web browser displaying a VCU news article. The page header includes the VCU logo, the text "WE ARE THE UNCOMMON.", and a "Give" button. The main content features a large headline about students composing electronic music using environmental data. Below the headline is a photograph of a student performing music at a laptop. A caption identifies the student as Max Biscarr, a sophomore kinetic imaging major.

VCU news

APRIL 5, 2024

# The sound of science: VCU students compose electronic music that incorporates environmental data gathered at VCU Rice Rivers Center

The ear, not just the eye, is a powerful route for experiencing and interpreting data, and a course that unites VCUarts and VCU Life Sciences is finding the harmony in nature.

By Brian McNeill

SHARE THIS STORY

Max Biscarr, a sophomore kinetic imaging major, performs an electronic music composition that incorporates air temperature data and soil temperature data collected at the VCU Rice Rivers Center. (Photo by Allen Jones, Enterprise Marketing and Communications)

Students took a field trip to the flux tower at VCU Rice Rivers Center, hosted by Chris Gough



Sonic Pi

run ▶ stop □ rec ● save + load ⚙

size ⬤ size ⬤ scope ⏴ info λ help Δ prefs π

```

1  ### AMERIFLUX ANNUAL MEETING 9/5/2024
2
3  ##### DATA SONIFICATION / SARA BOUCHARD
4  ##### ==> JULY 2023 FLUXNET DATA SONG!!!!
5  ##### Flux tower data from VCU Rice Rivers Center
6
7  require 'csv'
8
9  datafile= "/Users/sara/Documents/art:music/Fluxnet/Ameriflux meeting/Sonification presenta
10
11  ### replace file with your own - use the direct file path
12
13  table = CSV.parse(File.read(datafile), headers: true)
14
15  c = table.by_col[4] #Carbon flux // Data min: -293; Data max: 220
16  m = table.by_col[5] #Methane flux // Data min: -2622; Data max: 4085
17  r = table.by_col[11] #Net radiation // Data min: -92; Data max: 810
18
19
20  live_loop :data_CO2 do
21    stop
22
23    use_synth :pluck
24    1487.times do |i|   ## Number of spreadsheet rows minus 2
25
26      puts i+2    ## Display spreadsheet row in Log
27      puts c[i]    ## Display cell value in Log
28      set :i, i    ## This stores the value of i to sync loop :data_methane
29
30      ## Map raw data to new max/min range
31      ## x = (y[i]-data_min)*(MAP_max-MAP_min)/(data_max-data_min)+MAP_min
32      rad = ((r[i].to_f-(-92))*(1-0)/(810-(-92))+0) ## Since I'm mapping to amount of an eff
33      carbon = ((c[i].to_f-(-293))*(27-0)/(220-(-293))+0) ## Since I'm mapping to 4 octaves
34
35
36      with_fx :bitcrusher, mix: rad do ## Bitcrusher corresponds to radiation data
37        play scale[:ch2], start: numOctaves, A4carbon.to_i, amp: rand(0.2..1), pan: rand(-0.5..0.5)

```

Line: 18, Position: 1

0|1|2|3|4|5|6|7|8|9|

size ⬤ size ⬤ scope ⏴ info λ help Δ prefs π

Scope

Log

- >> Stopping thread :live\_loop\_data\_methane
- >> Stopping thread :live\_loop\_beat
- >> Stopping all runs...
- >> Completed run 2
- >> All runs completed
- >> Pausing SuperCollider Audio Server

Cues

- /live\_loop/bass []
- /live\_loop/data\_CO2 []
- /live\_loop/beat\_hat []
- /live\_loop/data\_methane []
- /live\_loop/beat []

Link Metronome & Global Time Warp

Link Tap 60.00 bpm 0 ms

Sonic Pi v4.5 on Mac

My contribution to the class “algorave” (link to come)

Learn Sonic Pi + listen to your own data!

Sonic Pi

run stop rec save + load

```

1  ### AMERIFLUX ANNUAL MEETING 9/5/2024
2  ##### DATA SONIFICATION / SARA BOUCHARD
3  ##### Sonification Template
4
5
6  require 'csv'
7  datafile= "/Users/sara/Documents/Sonification presentation/RRC subset - JULY 2023.csv"
8  ### replace file with your own CSV - Can drag and drop
9
10 table = CSV.parse(File.read(datafile), headers: true)
11 #If no spreadsheet headers, change true to false
12
13 c = table.by_col[4] #Carbon flux // Data min: -293; Data max: 220
14 #Important: Count columns starting with 0!
15
16 in_thread do
17   use_synth :pluck
18   1487.times do |i|    ## Number of spreadsheet rows minus 2
19     puts i+2      ## Display spreadsheet row in Log
20     puts c[i]      ## Display cell value in Log
21
22     ## Map raw data to new max/min range
23     ## X = (y[i]-data_min)*(MAP_max-MAP_min)/(data_max-data_min)+MAP_min
24     carbon = ((c[i].to_f(-293))*(90-30)/(220-(-293))+30)
25     #This example maps to a range of MIDI values: 30-90
26
27     play carbon.to_f, amp: rrando(0.3,1), pan: rrando(-1,1)
28     ##Use .to_f for microtones (float numbers), .to_i for chromatic scale (integers)
29     sleep 0.125
30   end
31 end

```

Line: 20, Position: 47

[10] [11] [2] [3] [4] [5] [6] [7] [8] [9]

size i size i scope info λ help π prefs π

Scope

Log

- 53 "4.237929821"
- synth :pluck, {note: 64.7647, amp: 0.9107, pan: -0.84}

=> Completed run 6

=> All runs completed

=> Pausing SuperCollider Audio Server

=> Saving recording to /Users/sara/Desktop/sonification.tac

Cues

- /live\_loop/bass []
- /live\_loop/data\_C02 []
- /live\_loop/beat\_hihat []
- /live\_loop/data\_methane []
- /live\_loop/beat []

Link Metronome & Global Time Warp

Link Tap 60.00 bpm 0 ms

Sonic Pi v4.5 on Mac

Basic sonification template for mapping parameters to pitch.  
 (Can also map to volume or amount of an effect. Output range would be 0-1.)

The screenshot shows the Sonic Pi software interface. The top menu bar includes 'run', 'stop', 'rec', 'save', 'load', 'size', 'scope', 'info', 'help', and 'prefs'. The main code editor on the left contains Ruby code for a sonification template:

```
1  ### AMERIFLUX ANNUAL MEETING 9/5/2024
2  ##### DATA SONIFICATION / SARA BOUCHARD
3  ##### Sonification Template
4
5
6  require 'csv'
7  datafile= "/Users/sara/Documents/Sonification presentation/RRC subset - JULY"
8  ### replace file with your own CSV - Can drag and drop
9
10 table = CSV.parse(File.read(datafile), headers: true)
11 #If no spreadsheet headers, change true to false
12
13 c = table.by_col[4] #Carbon flux // Data min: -293; Data max: 220
14 #Important: Count columns starting with 0!
15
16 in_thread do
```

Below the code editor, it says "Line: 20, Position: 47". A navigation bar at the bottom has buttons for 10, 1, 2, 3, 4, 5, 6, 7, 8, and 9.

The right side of the interface features several panels:

- Scope**: Shows a waveform plot.
- Log**: Displays log messages, including "53", "4.237929821", "synth :pluck, {note: 64.7647, amp: 0.9107, pan: -0.84}", and "=> Completed run 6".
- Cues**: Lists musical cues: "/live\_loop/bass []", "/live\_loop/data\_CO2 []", "/live\_loop/beat\_hihiat []", and "/live\_loop/data\_methane [ ]".
- Link Metronome & Global Time Warp**: Includes "Link", "Tap", "60.00 bpm", and "0 ms" controls.

The bottom left of the interface shows a navigation menu with sections like "Welcome to Sonic Pi", "1 Live Coding", "1.1 Exploring the Interface", "1.3 Learning through Play", "2 Synths", "2.1 Your First Beeps", "2.2 Synth Options", "2.3 Switching Synths", "2.4 Duration with Envelopes", "3 Samples", "3.1 Triggering Samples", "3.2 Sample Parameters", and "3.3 Stretching Samples". A "Docs" button is highlighted.

The bottom right contains a welcome message and a tutorial summary:

**Welcome friend :-)**

Welcome to Sonic Pi. Hopefully you're as excited to get started making your own sounds as I am to show you. It's going to be a really *fun* ride where you'll learn all about music, synthesis, programming, composition, performance and more.

But wait, how rude of me! Let me introduce myself - I'm [Sam Aaron](#) - the chap that created Sonic Pi. You can find me at [@samaaron](#) on Twitter and I'd be more than happy to say hello to you. You might also be interested in finding out more about my [Live Coding Performances](#) where I code with Sonic Pi live in front of audiences.

If you have any thoughts, or ideas for improving Sonic Pi - please pass them on - feedback is so helpful. You never know, your idea might be the next big feature!

This tutorial is divided up into sections around by category. Whilst I've written it to have an easy learning progression

Sonic Pi v4.5 on Mac

Sonic Pi has a fantastic built-in tutorial. But it doesn't cover sonification, so take a look and email me for Ruby templates!

# Why sonify?

What can be gained from experiencing data with our ears?

# Why sonify?

## *Data processing perspective:*

- Our ears are better than our eyes at identifying patterns within large data sets
- Accessibility for the blind
- Real-time feedback

## *Communications perspective:*

- Creates a novel, immersive experience
- Music carries emotional resonance
- Grabs people's attention and helps them remember the story behind the data
- Community-building and support around climate change anxiety + action

# Considerations

Who is the audience? (Scientists or general public?)

How can the presentation best serve the story behind the data?

How closely does the presentation need to adhere to the data? (Depends on audience)

What role can sonification play within the FLUXNET community?

# Resources

Podcast & Sonification Community

[Loud Numbers](#)

Website for creating sonifications

[Two Tone](#)

Live Coding Software

(Platform built in Ruby, can be used for sonification with  
Sara's template)

[Sonic Pi](#)

Additional Articles

[Making Numbers Louder: Telling Data Stories with Sound](#)

Duncan Geere, Miriam Quick, Datajournalism.com

[How a Blind Astronomer Found a Way to Hear the Stars](#)

Wanda Diaz Merced, TED 2016

[Sound the Alarm: Data Sonification as a Tool for Climate Action](#)

Ableton.com

# Thank you!

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