

Exploring defining single value indices - SPI

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Abstract

This notebook contains several explorations and developments leading to the SPI framework.

1. Setup

1.1. Import Libraries

1.2. Load Data

In addition to loading the latest version of the ISD, we also exclude a few samples that were identified as survey outliers. Most notably, this includes the samples at RegentsParkFields which were impacted by helicopter flyovers.

| | LocationID | SessionID | GroupID | RecordID | start_time | end_time | latit |
|------|------------------|-------------------|---------|----------|---------------------|---------------------|-------|
| 0 | CarloV | CarloV2 | 2CV12 | 1434 | 2019-05-16 18:46:00 | 2019-05-16 18:56:00 | 37.1 |
| 1 | CarloV | CarloV2 | 2CV12 | 1435 | 2019-05-16 18:46:00 | 2019-05-16 18:56:00 | 37.1 |
| 2 | CarloV | CarloV2 | 2CV13 | 1430 | 2019-05-16 19:02:00 | 2019-05-16 19:12:00 | 37.1 |
| 3 | CarloV | CarloV2 | 2CV13 | 1431 | 2019-05-16 19:02:00 | 2019-05-16 19:12:00 | 37.1 |
| 4 | CarloV | CarloV2 | 2CV13 | 1432 | 2019-05-16 19:02:00 | 2019-05-16 19:12:00 | 37.1 |
| ... | ... | ... | ... | ... | ... | ... | ... |
| 1693 | Noorderplantsoen | Noorderplantsoen1 | NP161 | 61 | 2020-03-11 12:42:00 | 2020-03-11 12:55:00 | NaN |
| 1694 | Noorderplantsoen | Noorderplantsoen1 | NP162 | 63 | 2020-03-11 12:39:00 | 2020-03-11 13:00:00 | NaN |
| 1695 | Noorderplantsoen | Noorderplantsoen1 | NP162 | 62 | 2020-03-11 12:54:00 | 2020-03-11 12:58:00 | NaN |
| 1696 | Noorderplantsoen | Noorderplantsoen1 | NP162 | 64 | 2020-03-11 12:56:00 | 2020-03-11 12:59:00 | NaN |
| 1697 | Noorderplantsoen | Noorderplantsoen1 | NP163 | 70 | 2020-03-11 23:08:00 | 2020-03-11 23:18:00 | NaN |

1.2.1. ISOCoordinate calculation according to Aletta et. al. (2024)

To move the 8-item PAQ responses into the 2-dimensional circumplex space, we use the projection method first presented in ISO 12913-3:2018. This projection method and its associated formulae were recently updated further in [Aletta et al. \(2024\)](#) to include a correction for the language in which the survey was conducted. The formulae are as follows:

$$P_{ISO} = \frac{1}{\lambda_{pl}} \sum_{i=1}^8 \cos \theta_i \cdot \sigma_i E_{ISO} = \frac{1}{\lambda_{pl}} \sum_{i=1}^8 \sin \theta_i \cdot \sigma_i$$

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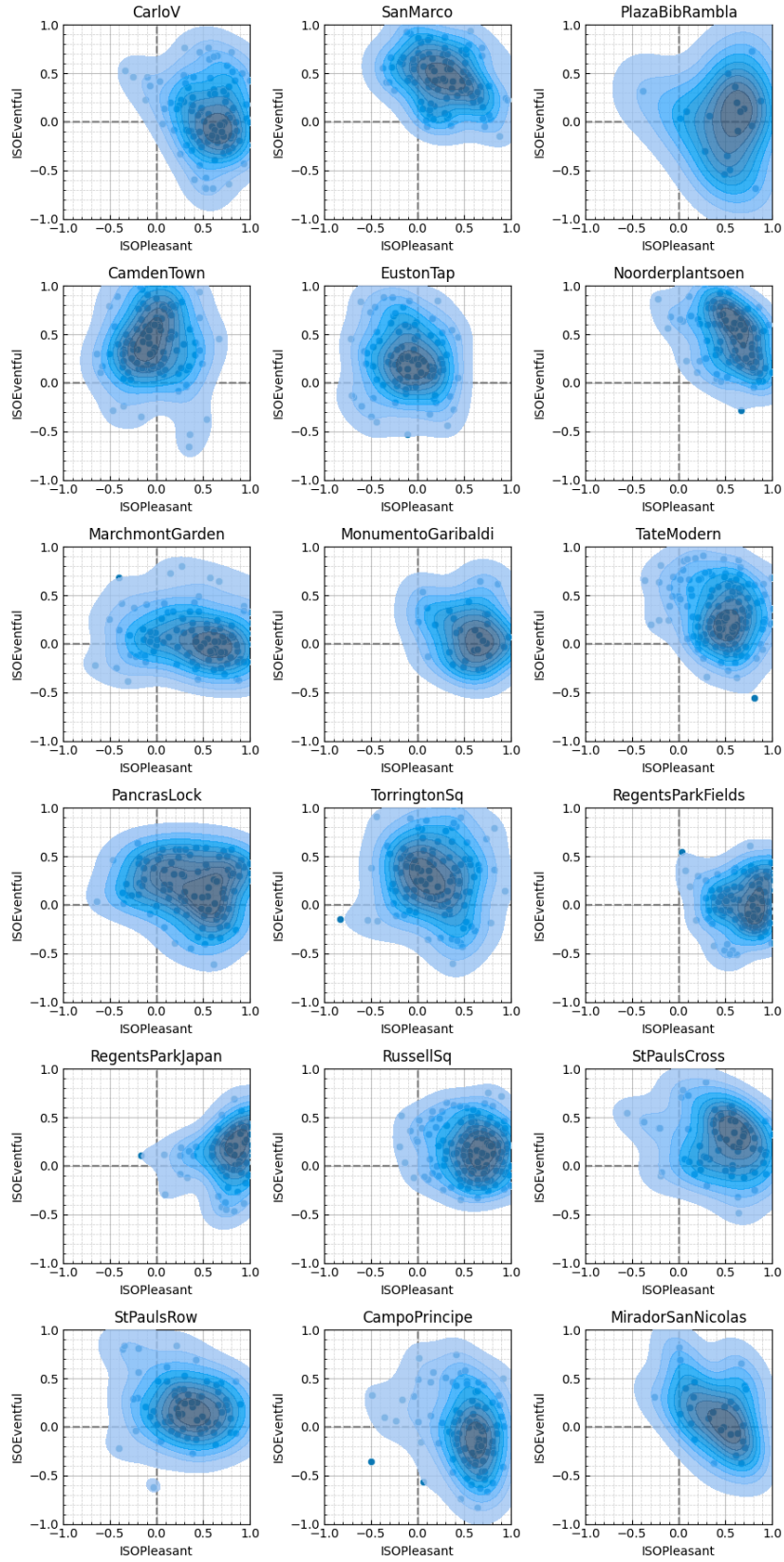
Email address: a.j.mitchell@ucl.ac.uk (Andrew Mitchell)

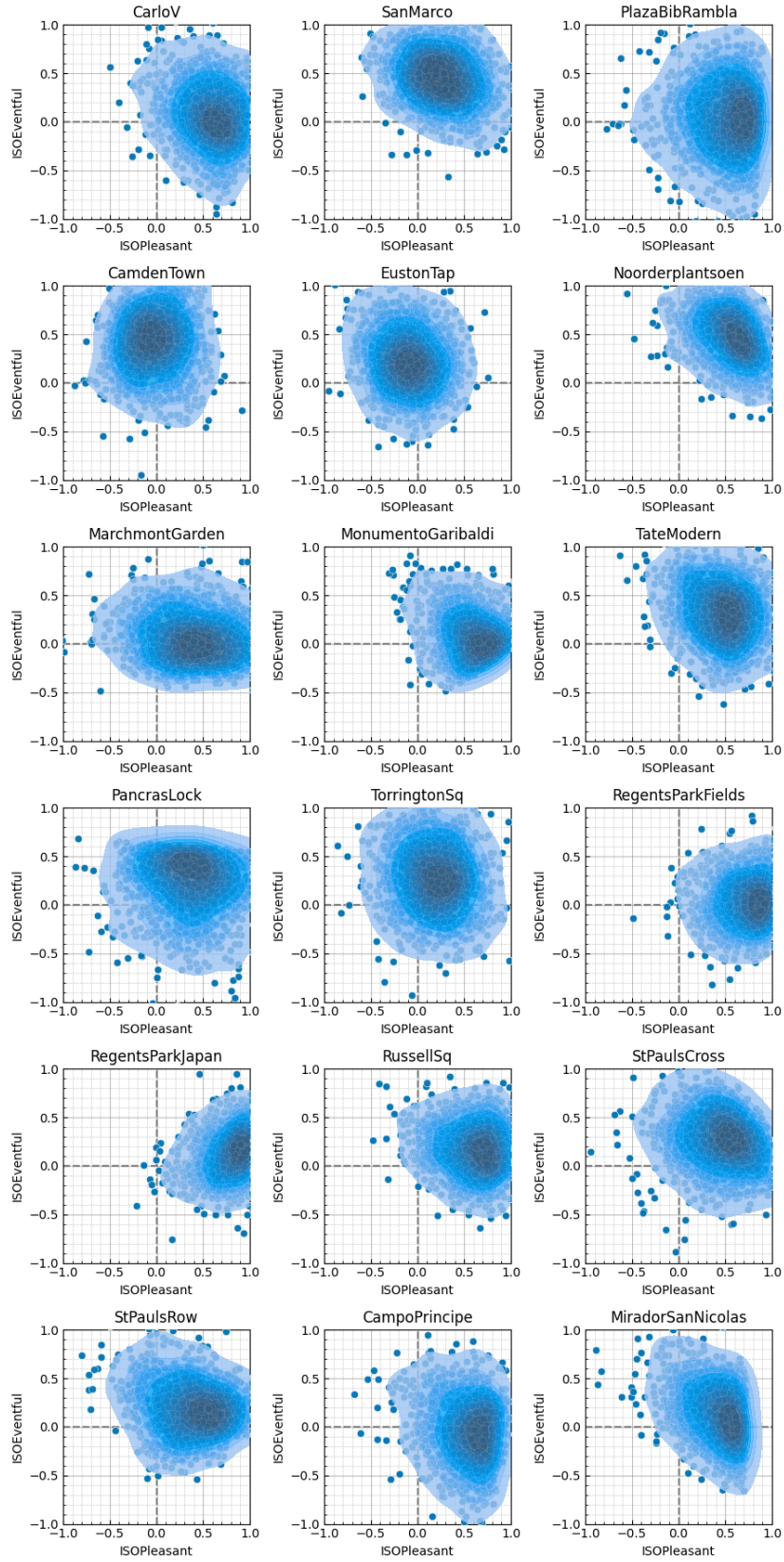
where \$PAQ_i\$ is the response to the (i)th item of the PAQ. The resulting (x) and (y) values are then used to calculate the polar angle () and the radial distance (r) as follows:

```
{'eng': (0, 46, 94, 138, 177, 241, 275, 340),
'arb': (0, 36, 45, 135, 167, 201, 242, 308),
'cmn': (0, 18, 38, 154, 171, 196, 217, 318),
'hrv': (0, 84, 93, 160, 173, 243, 273, 354),
'nld': (0, 43, 111, 125, 174, 257, 307, 341),
'deu': (0, 64, 97, 132, 182, 254, 282, 336),
'ell': (0, 72, 86, 133, 161, 233, 267, 328),
'ind': (0, 53, 104, 123, 139, 202, 284, 308),
'ita': (0, 57, 104, 143, 170, 274, 285, 336),
'spa': (0, 41, 103, 147, 174, 238, 279, 332),
'swe': (0, 66, 87, 146, 175, 249, 275, 335),
'tur': (0, 55, 97, 106, 157, 254, 289, 313)}
```

Table 2: Language-specific angles for projection into the ISO 12913-3:2018 circumplex space.

| | PAQ1 | PAQ2 | PAQ3 | PAQ4 | PAQ5 | PAQ6 | PAQ7 | PAQ8 |
|-----|------|------|------|------|------|------|------|------|
| eng | 0 | 46 | 94 | 138 | 177 | 241 | 275 | 340 |
| arb | 0 | 36 | 45 | 135 | 167 | 201 | 242 | 308 |
| cmn | 0 | 18 | 38 | 154 | 171 | 196 | 217 | 318 |
| hrv | 0 | 84 | 93 | 160 | 173 | 243 | 273 | 354 |
| nld | 0 | 43 | 111 | 125 | 174 | 257 | 307 | 341 |
| deu | 0 | 64 | 97 | 132 | 182 | 254 | 282 | 336 |
| ell | 0 | 72 | 86 | 133 | 161 | 233 | 267 | 328 |
| ind | 0 | 53 | 104 | 123 | 139 | 202 | 284 | 308 |
| ita | 0 | 57 | 104 | 143 | 170 | 274 | 285 | 336 |
| spa | 0 | 41 | 103 | 147 | 174 | 238 | 279 | 332 |
| swe | 0 | 66 | 87 | 146 | 175 | 249 | 275 | 335 |
| tur | 0 | 55 | 97 | 106 | 157 | 254 | 289 | 313 |





1.3. The Soundscape Perception Index (SPI)

The SPI works by assessing the assessed (or calculated) distribution of soundscape responses against a target distribution. This target distribution represents the goal for the soundscape design. Since we consider a location's soundscape perception to be the collective perception of its users, it is crucial that the target includes both the central tendency and the distribution.

1.3.1. Note: Distributions in the circumplex

We should begin by discussing how soundscape circumplex distributions are defined. The circumplex is defined by two axes: P_{ISO} and E_{ISO} which are limited to the range $[-1, 1]$. Typically the distribution of collective perception of a soundscape is also not symmetrical, therefore making it a skewed distribution. A soundscape distribution is thus a two-dimensional truncated skew-normal distribution.

The skew-normal distribution is defined by three parameters: location, scale and shape. The location parameter defines the centre of the distribution, the scale parameter defines the spread of the distribution, and the shape parameter defines the skew of the distribution. The skew-normal distribution is defined as:

$$f(x; a, \omega, \alpha) = \frac{2}{\omega} \phi\left(\frac{x-a}{\omega}\right) \Phi\left(\alpha \frac{x-a}{\omega}\right)$$

where ϕ and Φ are the standard normal probability density function and cumulative distribution function respectively. The skew-normal distribution is thus a generalisation of the normal distribution, with the shape parameter α defining the skew. A positive shape parameter results in a right-skewed distribution, and a negative shape parameter results in a left-skewed distribution.

Truncated skew-normal distribution: <https://www.tandfonline-com.libproxy.ucl.ac.uk/doi/epdf/10.1080/03610910902936>

To generate the truncated skew-normal distribution, we use rejection sampling. This is a method of generating a distribution by sampling from a simpler distribution and rejecting samples that do not fit the target distribution. In this case, we sample from a skew-normal distribution (`scipy.stats.skewnorm`) and reject samples that are outside of the range $[-1, 1]$.

1.3.1.1. Example - Calculating the moments of location's distribution and generating the equivalent distribution using rejection sampling.

Fitted from data. n = 96

Direct Parameters:

xi: [[0.06 0.597]]

omega: [[0.15 -0.058]

[-0.058 0.093]]

alpha: [0.868 -0.561]

Centred Parameters:

mean: [[0.281 0.447]]

sigma: [[0.101 -0.025]

[-0.025 0.07]]

skew: [0.145 -0.078]

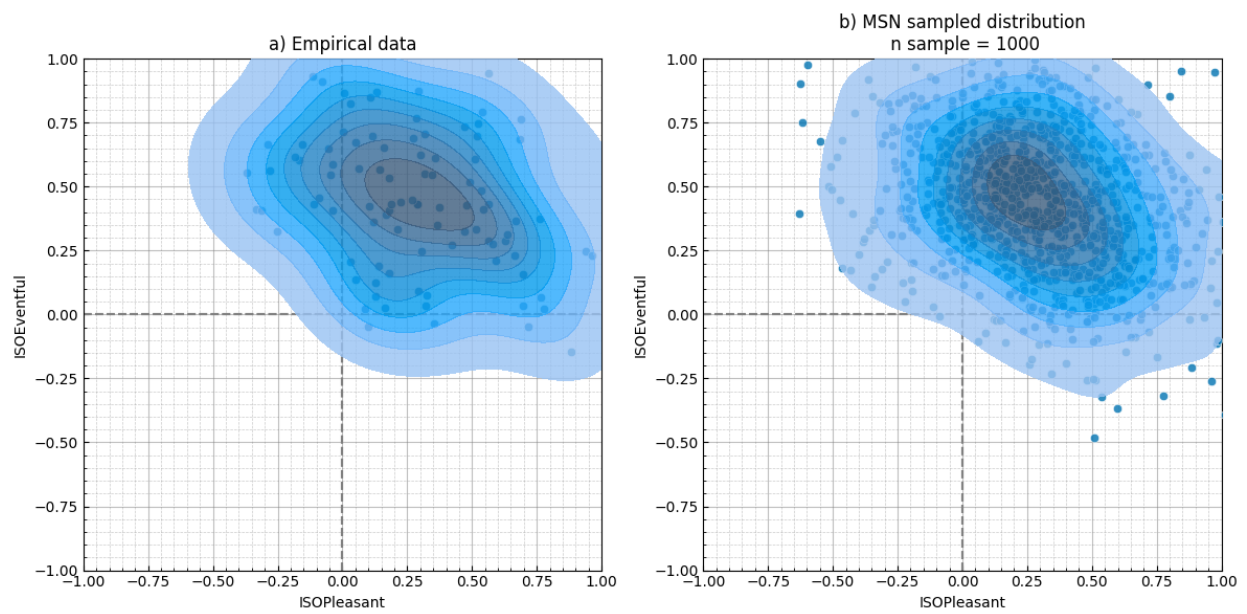
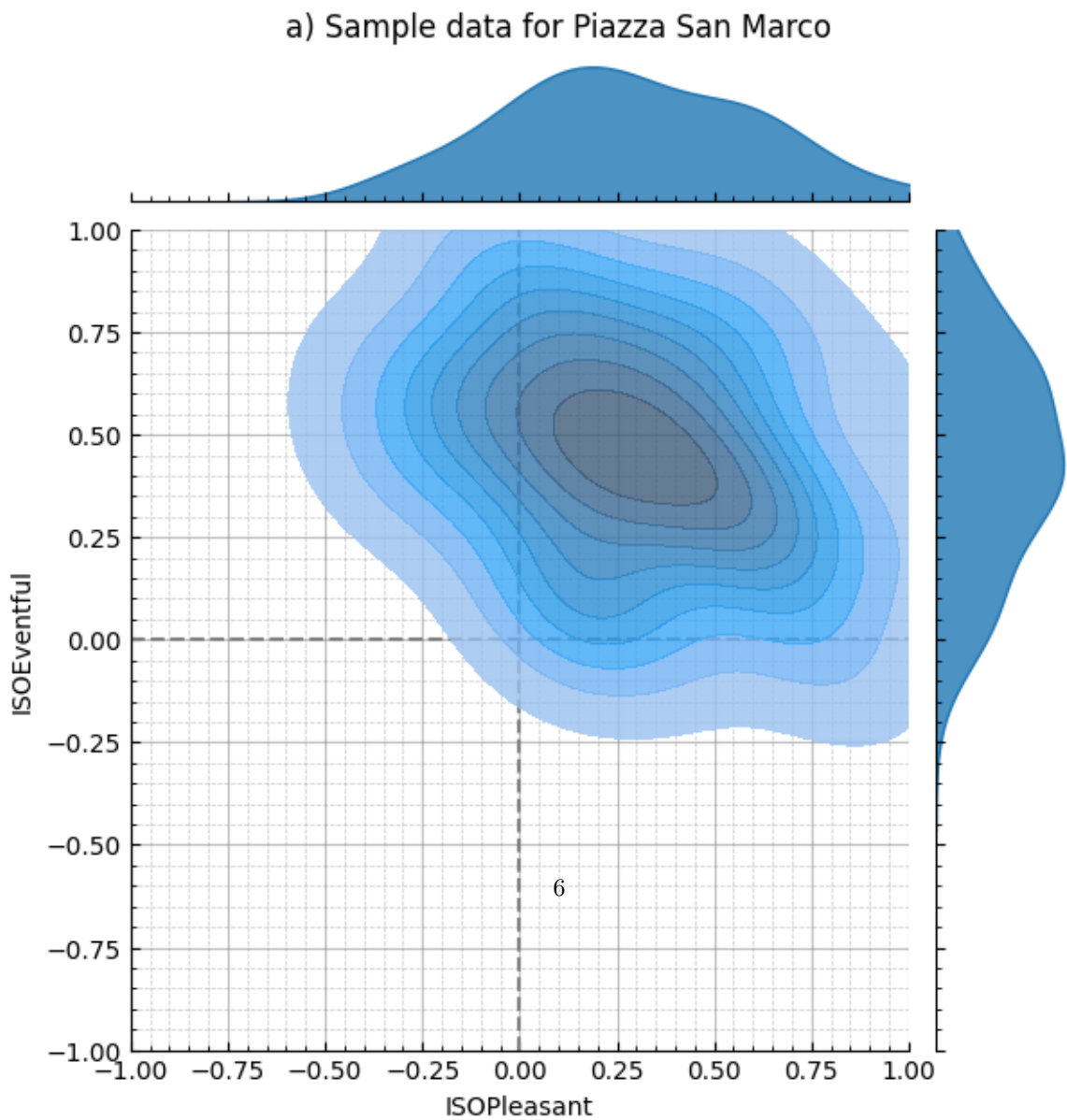


Figure 1: Example of fitting and sampling from a multivariate skew-normal distribution for data from the Piazza San Marco location.



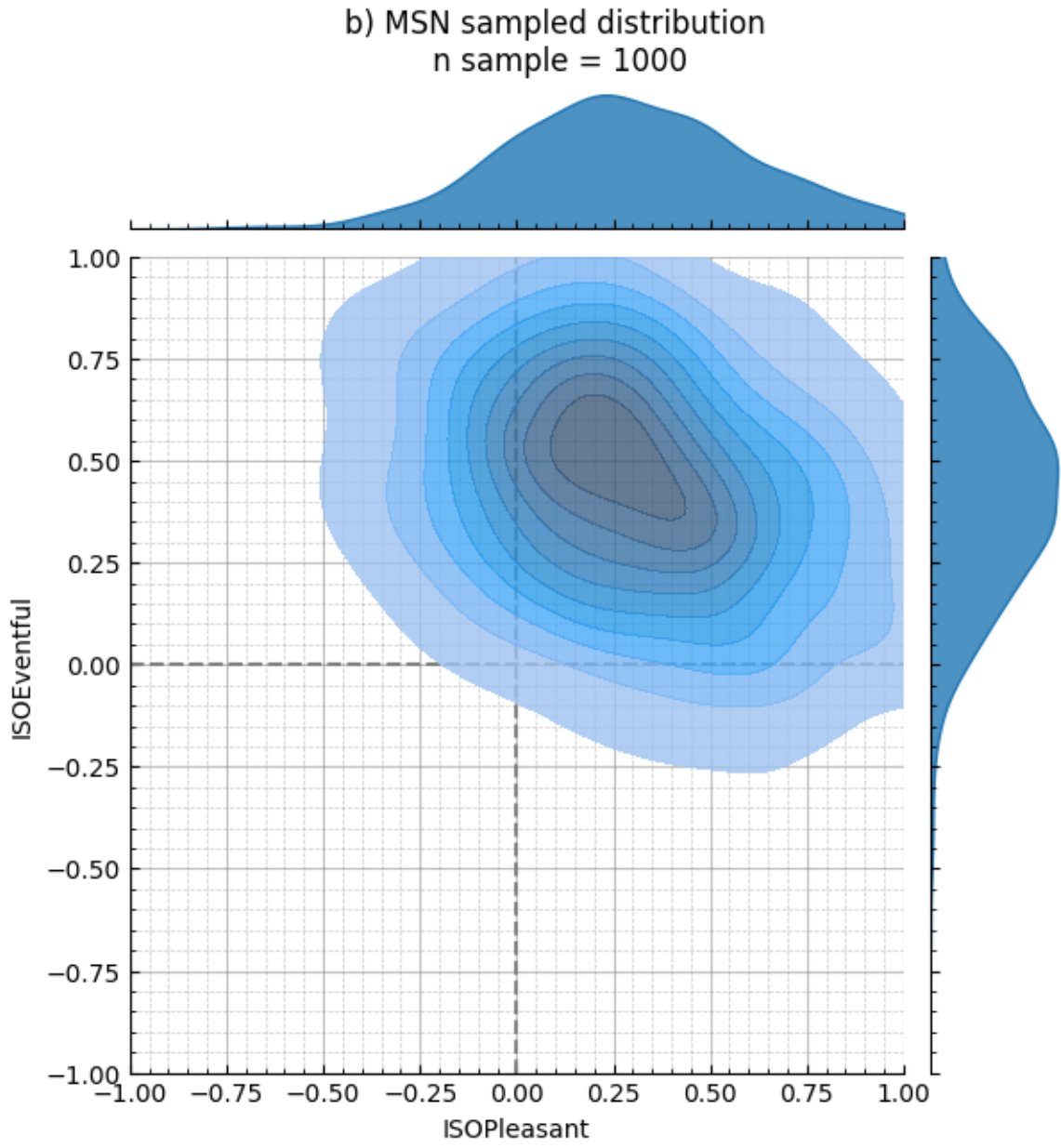


Table 3: Kolmogorov-Smirnov test comparing the empirical test distribution (Piazza San Marco) against three soundscape target distributions.

| Target | D | p |
|--------|------|-------------|
| tgt_1 | 0.66 | 6.94745e-25 |
| tgt_2 | 0.83 | 8.96388e-39 |
| tgt_3 | 0.28 | 8.96388e-39 |

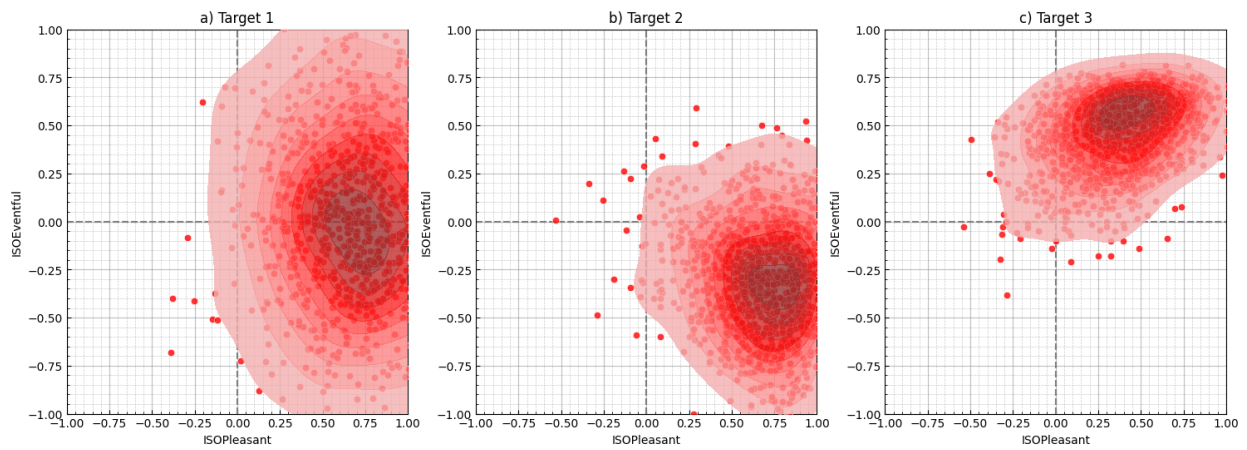


Figure 2: Example of defining and sampling from three arbitrary bespoke targets.

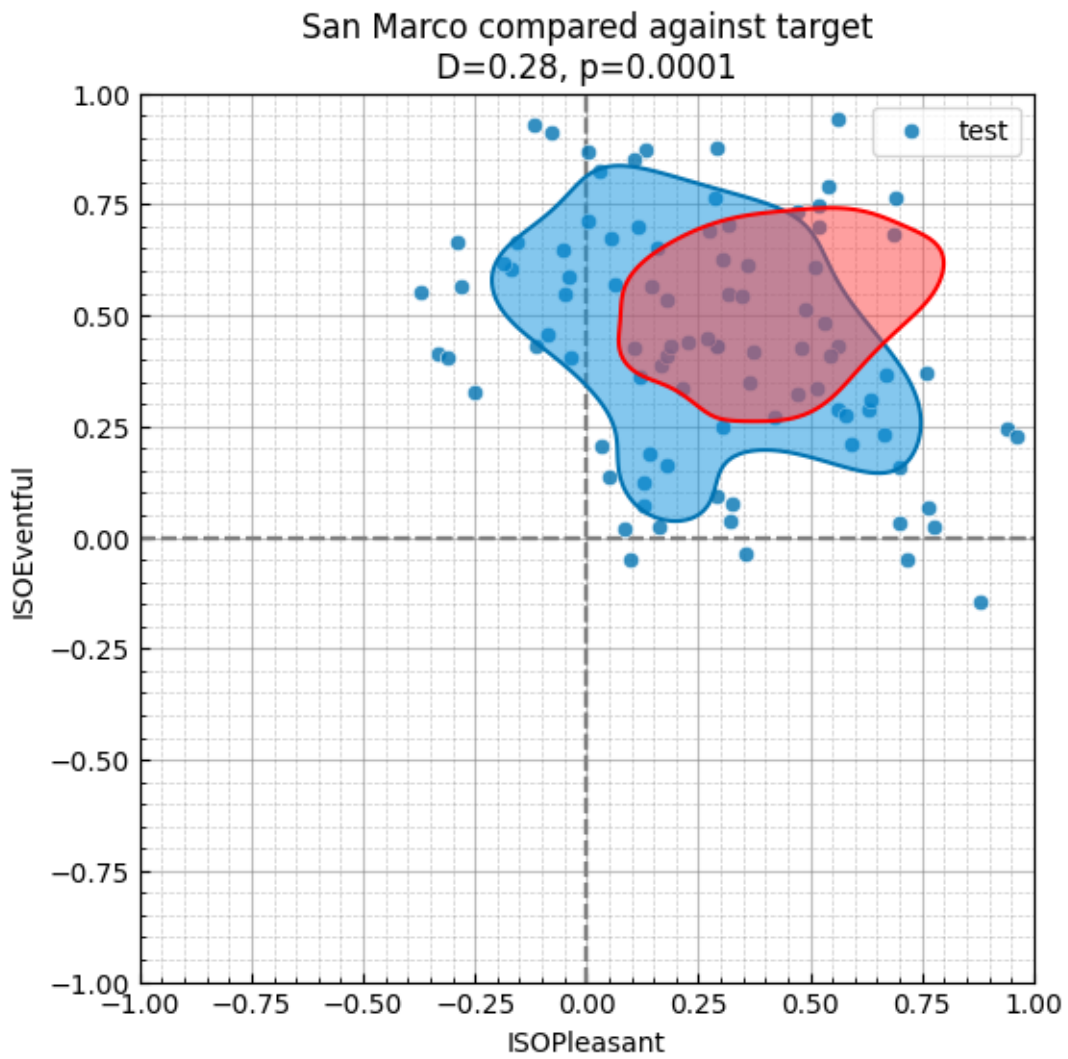


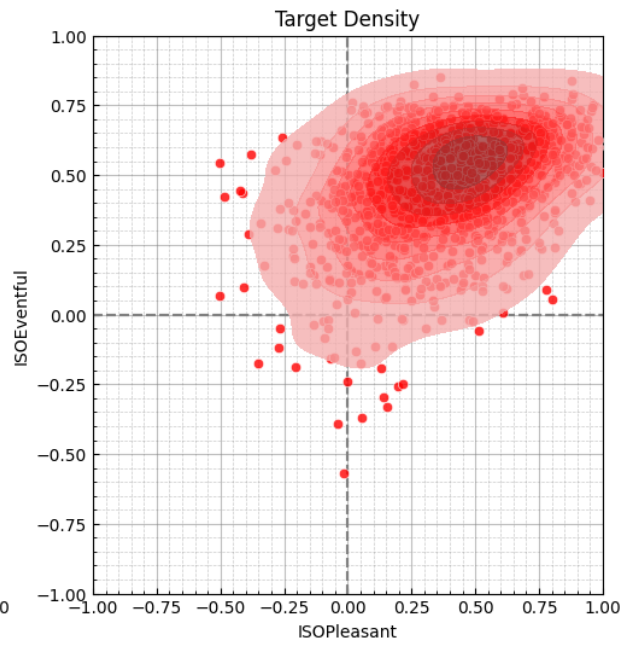
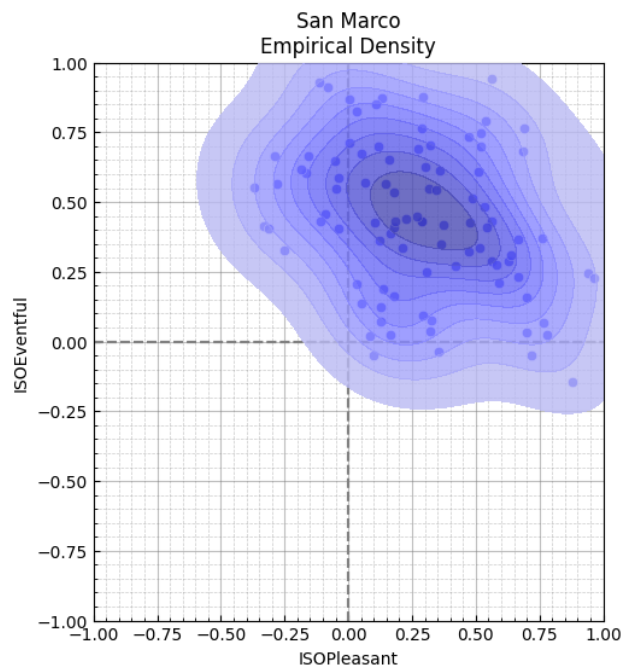
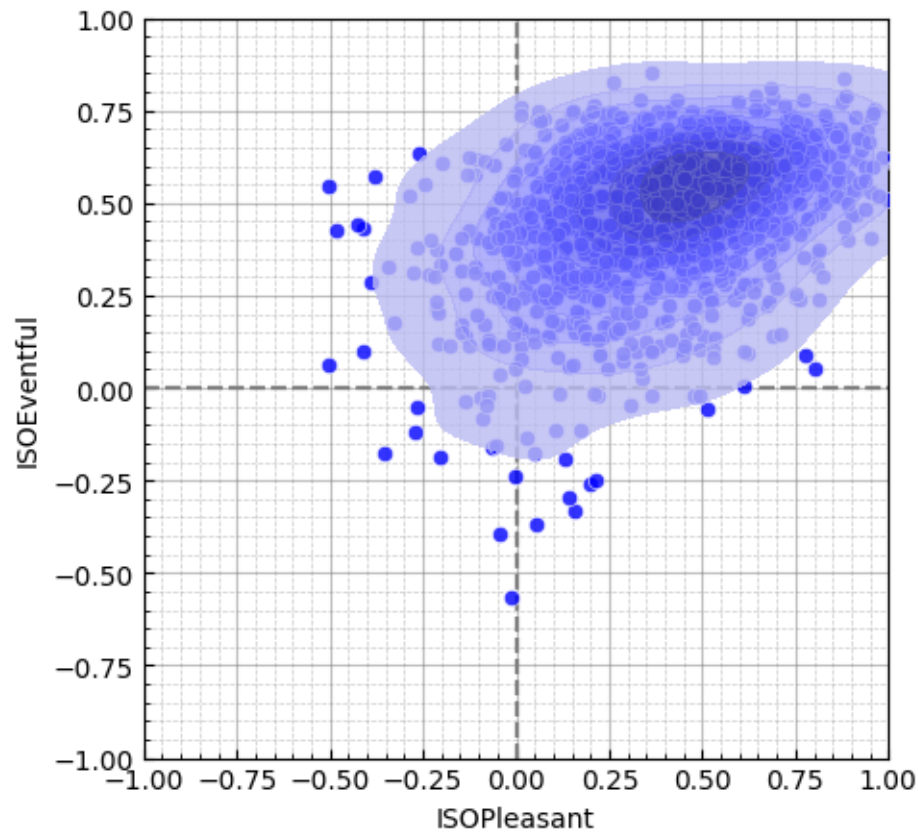
Table 4: SPI scores and rankings for the soundscapes of locations included in the International Soundscape Database (ISD).

| Ranking | SPI_1 (pleasant) | SPI_2 (calm) | SPI_3 (vibrant) |
|---------|-----------------------|-----------------------|-----------------------|
| 1 | 70 RegentsParkFields | 61 CampoPrincipe | 71 SanMarco |
| 2 | 69 CarloV | 52 CarloV | 62 TateModern |
| 3 | 65 RegentsParkJapan | 50 PlazaBibRambla | 60 StPaulsCross |
| 4 | 62 CampoPrincipe | 49 RegentsParkFields | 58 Noorderplantsoen |
| 5 | 61 PlazaBibRambla | 45 MarchmontGarden | 55 PancrasLock |
| 6 | 61 RussellSq | 44 MonumentoGaribaldi | 54 TorringtonSq |
| 7 | 61 MarchmontGarden | 40 RussellSq | 48 StPaulsRow |
| 8 | 61 MonumentoGaribaldi | 38 RegentsParkJapan | 48 RussellSq |
| 9 | 59 PancrasLock | 38 PancrasLock | 47 MiradorSanNicolas |
| 10 | 53 StPaulsCross | 32 MiradorSanNicolas | 43 CamdenTown |
| 11 | 49 TateModern | 30 TateModern | 40 CarloV |
| 12 | 48 StPaulsRow | 30 StPaulsCross | 36 MonumentoGaribaldi |
| 13 | 43 MiradorSanNicolas | 28 TorringtonSq | 34 MarchmontGarden |
| 14 | 38 Noorderplantsoen | 28 StPaulsRow | 33 PlazaBibRambla |
| 15 | 35 TorringtonSq | 17 SanMarco | 33 CampoPrincipe |
| 16 | 33 SanMarco | 16 Noorderplantsoen | 32 EustonTap |
| 17 | 21 CamdenTown | 15 CamdenTown | 27 RegentsParkFields |
| 18 | 15 EustonTap | 13 EustonTap | 27 RegentsParkJapan |

```

RegentsParkFields    70
CarloV                69
RegentsParkJapan     65
CampoPrincipe        62
PlazaBibRambla       61
RussellSq            61
MarchmontGarden      61
MonumentoGaribaldi   61
PancrasLock          59
StPaulsCross         53
TateModern            49
StPaulsRow           48
MiradorSanNicolas    43
Noorderplantsoen     38
TorringtonSq         35
SanMarco             33
CamdenTown           21
EustonTap            15
Name: tgt_1, dtype: int64

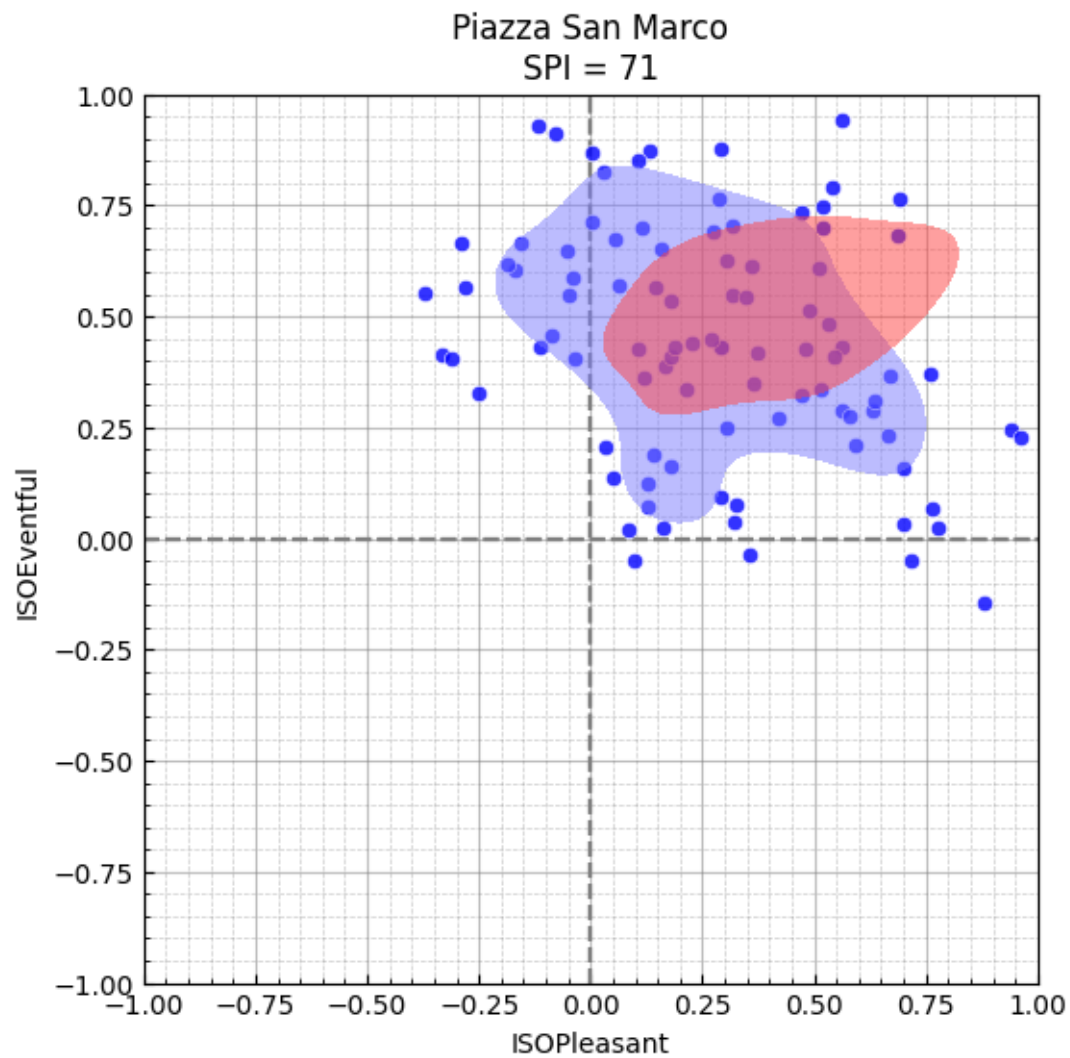
```



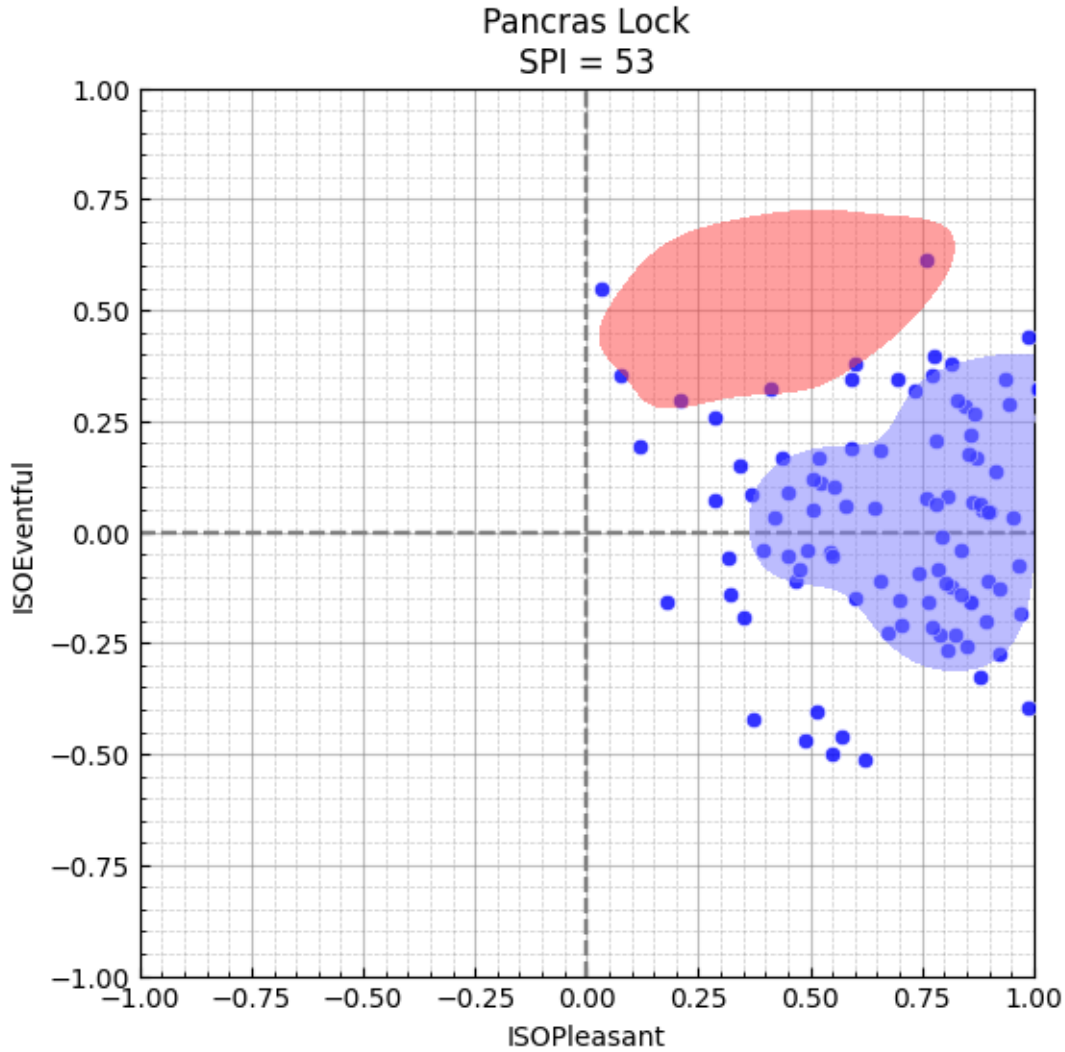
Once the target is defined, we will generate a set of points that represent the target distribution.

Now that our target has been defined, we can calculate the SPI for a given set of responses. We will use the responses from Piazza San Marco in Venice, Italy, as an example.

San Marco SPI = 71



We can compare this against another location, such as St Pancras Lock.



SPI scores assessed against a target should not inherently be considered a measure of the quality of the soundscape - instead it reflects the degree to which the soundscape matches the target. A high SPI score does not necessarily mean that the soundscape is of high quality, but rather that the soundscape is of high quality *according to the target*.

The $SPI_{bespoke}$ thus provides a method for scoring and ranking the success of a soundscape design against the designer's goals. Sticking with our defined target, we can assess all of the locations in the ISD and see which locations best match our target.

| | SPI |
|------------------|-----|
| SanMarco | 71 |
| TateModern | 61 |
| Noorderplantsoen | 61 |
| StPaulsCross | 59 |
| TorringtonSq | 54 |
| PancrasLock | 53 |
| StPaulsRow | 47 |

| | SPI |
|--------------------|-----|
| RussellSq | 46 |
| MiradorSanNicolas | 46 |
| CamdenTown | 43 |
| CarloV | 40 |
| MonumentoGaribaldi | 36 |
| MarchmontGarden | 35 |
| PlazaBibRambla | 35 |
| CampoPrincipe | 33 |
| EustonTap | 31 |
| RegentsParkJapan | 27 |
| RegentsParkFields | 25 |

Assessed against a different target would result in a different ranking:

Fitted from direct parameters.

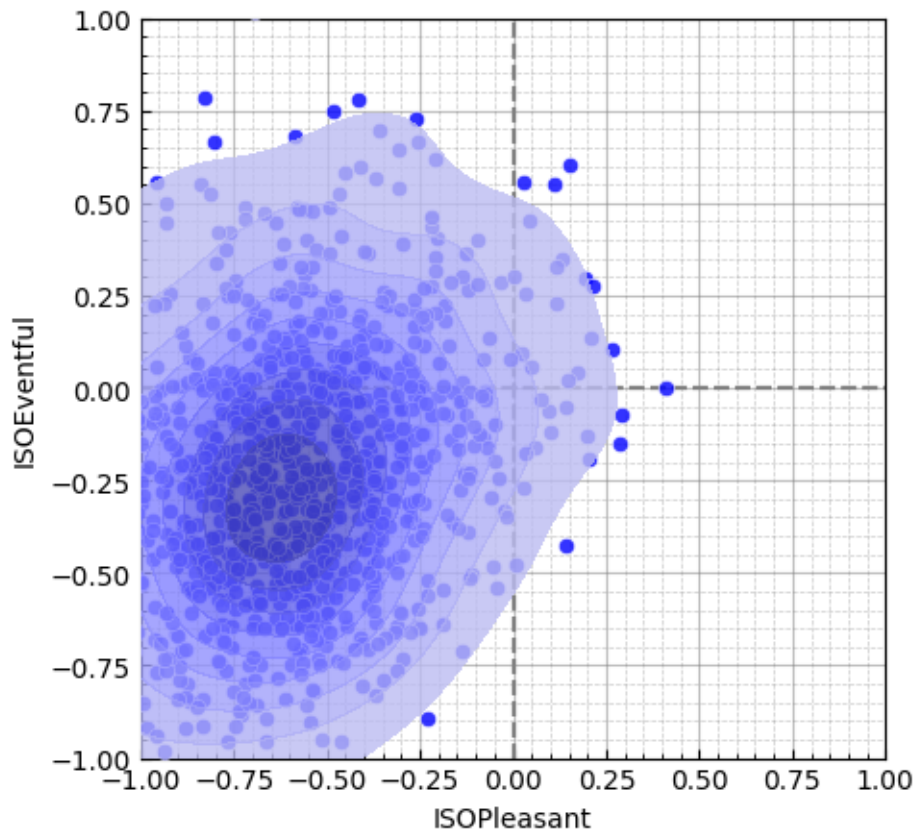
Direct Parameters:

xi: [-0.5 -0.5]

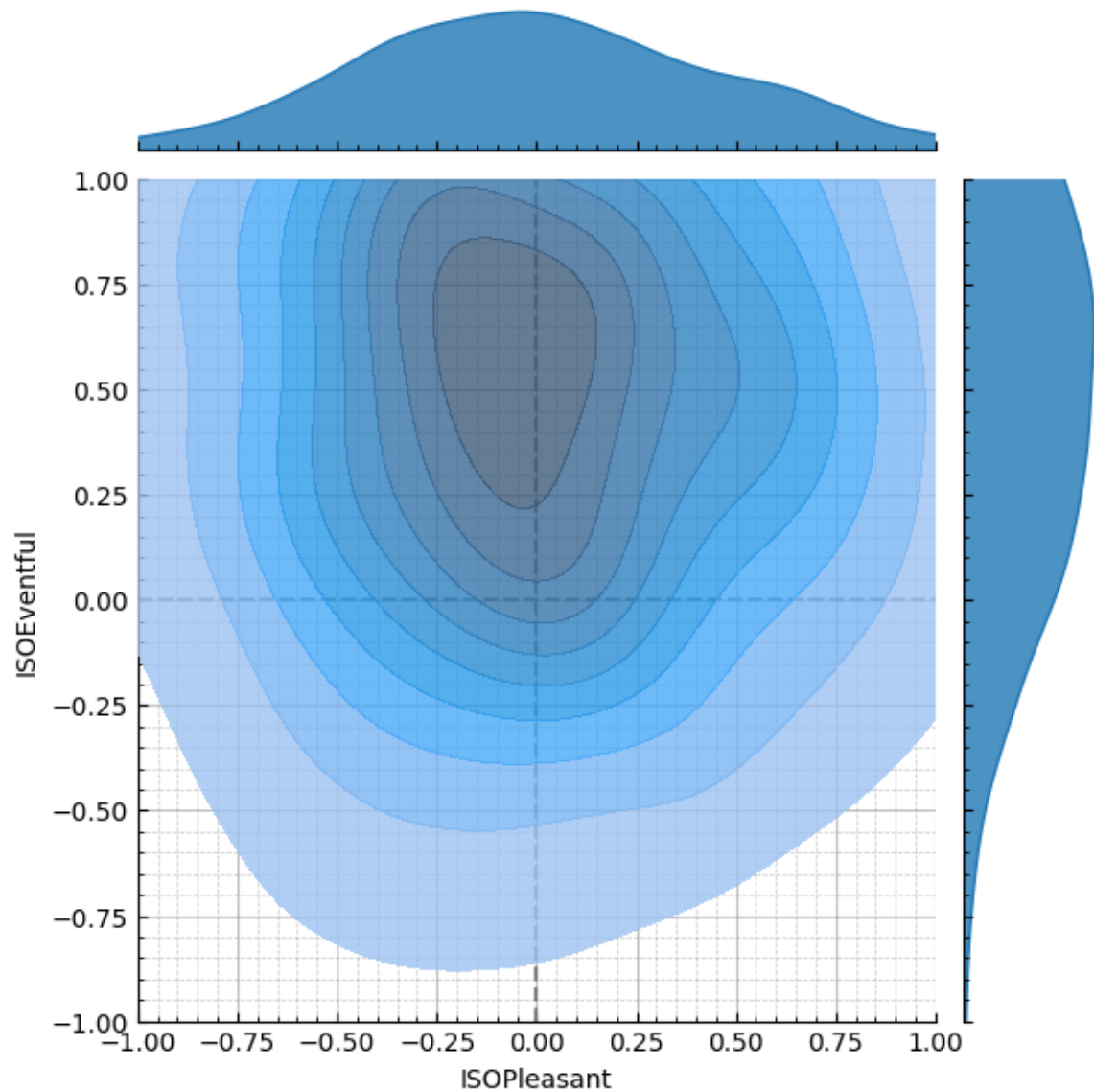
omega: [[0.1 0.]
[0. 0.2]]

alpha: [-0.85 1.5]

None



| | SPI |
|--------------------|-----|
| EustonTap | 30 |
| CamdenTown | 22 |
| MarchmontGarden | 19 |
| TorringtonSq | 19 |
| PancrasLock | 17 |
| PlazaBibRambla | 15 |
| StPaulsRow | 15 |
| CampoPrincipe | 11 |
| StPaulsCross | 11 |
| RegentsParkJapan | 8 |
| RussellSq | 8 |
| CarloV | 8 |
| SanMarco | 8 |
| TateModern | 8 |
| MiradorSanNicolas | 6 |
| MonumentoGaribaldi | 5 |
| Noorderplantsoen | 4 |
| RegentsParkFields | 3 |



References

- Aletta, F., Mitchell, A., Oberman, T., Kang, J., Khelil, S., Bouzir, T.A.K., Berkouk, D., Xie, H., Zhang, Y., Zhang, R., Yang, X., Li, M., Jambrošić, K., Zaninović, T., van den Bosch, K., Lühr, T., Orlik, N., Fitzpatrick, D., Sarampalis, A., Aumond, P., Lavandier, C., Moshona, C.C., Lepa, S., Fiebig, A., Papadakis, N.M., Stavroulakis, G.E., Sudarsono, A.S., Sarwono, S.J., Puglisi, G.E., Jafari, F., Astolfi, A., Shtrepi, L., Nagahata, K., Jo, H.I., Jeon, J.Y., Lam, B., Chieng, J., Ooi, K., Hong, J.Y., Monteiro Antunes, S., Alves, S., de Ulhoa Carvalho, M.L., Michalski, R.L.X.N., Kogan, P., Vida Manzano, J., García Quesada, R., Suárez Silva, E., Almagro Pastor, J.A., Nilsson, M.E., Axelsson, ., Gan, W.S., Watcharasupat, K.N., Jaratjarungkiat, S., Ong, Z.T., Dökmeci Yörükoğlu, P.N., Erçakmak Osma, U.B., Nguyen, T.L., 2024. Soundscape descriptors in eighteen languages: Translation and validation through listening experiments. *Applied Acoustics* 224, 110109. doi:[10.1016/j.apacoust.2024.110109](https://doi.org/10.1016/j.apacoust.2024.110109).