Explanation: Poisson disk sampling

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1 Random Parcellations: Poisson disk sampling

The biological changes of the developing brain furthermore raises the fundamental question of whether the relative size and position of the regions in the developing brain are equivalent to those defined on the adult brain [3]. Additionally, due to the incomplete sulcation in the developing brain, the difficulties in registration poses a limitation on using atlas based segmentations in developmental studies [3]. These challenges and the before mentioned lack of consensus on which parcellation scheme to use, motivates the application of random parcellation schemes such as Poisson disk sampling. Poisson disk sampling defines regions based on a distance threshold between region centres and can be applied to any surface or volume [1]. The principle for generating Poisson disk sampled regions in two dimensions is shown in Figure 1.

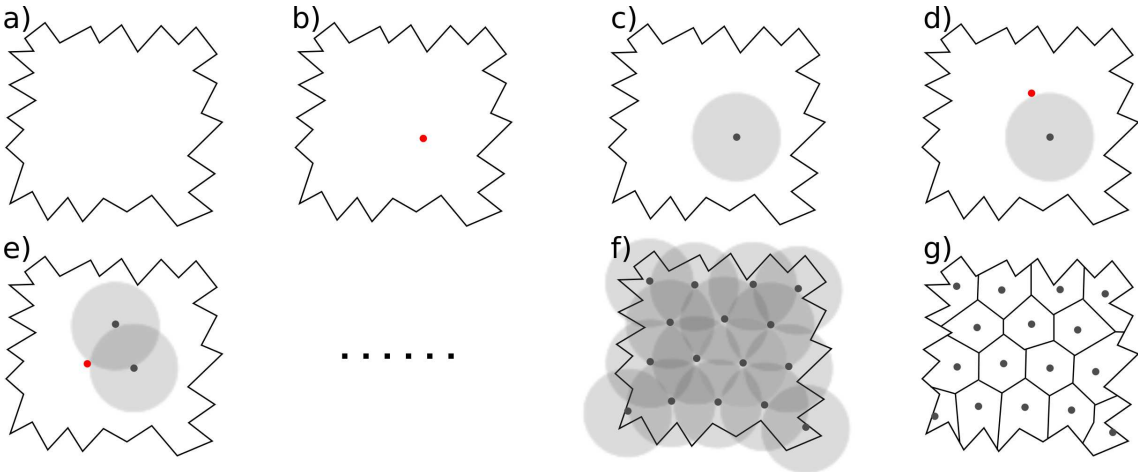

Figure 1: Principle of Poisson disk sampling in two dimensions. The surface (a) is divided into approximately equal sized regions (g) by randomly picking a first region centre (b). Subsequent region centres are placed with the condition that they cannot be closer than a minimum distance (indicated by grey circles) from all previously placed region centres (c-f). After all region centres are placed all points of the surface are assigned to their closest region centre, resulting in a random parcellation of the given surface (g).

In the brain, Poisson disk sampling can be applied to the grey matter structures. All grey matter voxels are stored in a list and initially considered as possible region centres. First a distance threshold r_{min} is defined and an initial region centre c_1 is randomly selected from the set of all grey

matter voxels. Each voxel i with a distance $d^i_{c_1} < r_{min}$ to c_1 is removed from the list of possible region centres. The next region centre is then randomly selected from the set of voxels $\{j\}$ with $r_{min} < d^j_{c_1} < 2 \cdot r_{min}$. This process is repeated until there are no voxels in the list of possible region centres remaining. Subsequently, each voxel in the grey matter structure is assigned to its closest region centre, resulting in a random parcellation of the grey matter volume into approximately equal sized regions. The framework is illustrated in Figure 2.

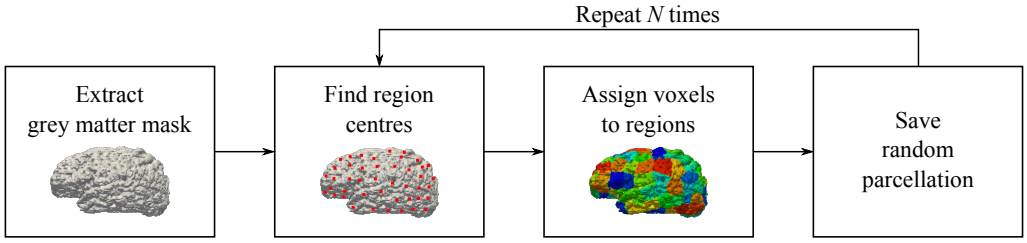

Figure 2: Framework of applying Poisson disk sampling to the grey matter structures of the human brain. The process of generating random parcellations is repeated N times.

One benefit of this parcellation scheme lies in the fact that it does not rely on anatomical features or landmarks and can thus be easily applied to neonatal grey matter structures, where the sulcation is incomplete and landmarks are difficult to determine. However, with Poisson disk sampling, the resulting number of nodes may vary due to the random nature of the approach. Figure 3 shows a histogram of the number of region variation for $N = 100$ repetitions of a single grey matter mask parcellated with a target number of 500 regions.

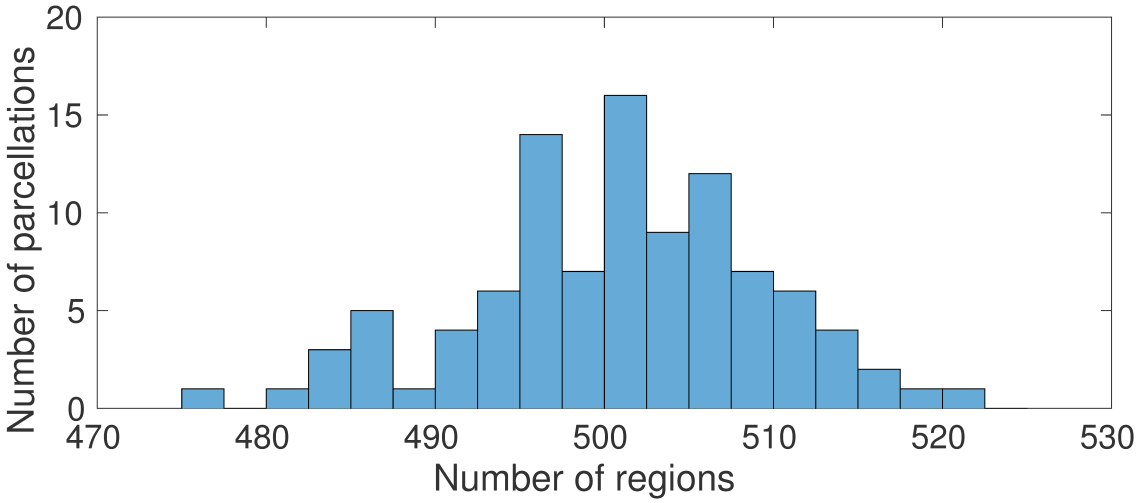

Figure 3: Histogram of Poisson disk sampling, repeated 100 times on the same grey matter mask with a target number of 500 regions. This shows the variation in the total number of regions.

Other random parcellation methods have been proposed. Hagmann et al. [2] used a similar two step approach, where they randomly choose a voxel on the grey-/white-matter boundary and assign its nearest neighbours (voxels) to the first region of interest (ROI) until it reaches a specified size. This procedure is repeated with region centres close to the previously defined ROIs until the entire boundary is assigned. In a second step they reassign all voxels to their closest region centres, which

are given by their centre of mass. A different approach was presented by Tymofiyeva et al. [3], where they treat the brain as a sphere, parcellate the sphere into equally sized regions and apply the mask to the cortex. This approach however does not distinguish between hemispheres and may subsequently lead to regions defined across hemispheres, meaning it is possible for a single region to belong both to the left and right hemisphere of the brain.

References

[1] R Bridson. Fast Poisson disk sampling in arbitrary dimensions. In *ACM SIGGRAPH*, volume 2007, page 5, 2007.

[2] Hagmann et al. Mapping human whole-brain structural networks with diffusion MRI. *PLoS ONE*, 2(7):9, 2007.

[3] Tymofiyeva et al. Brain without anatomy: construction and comparison of fully network-driven structural mri connectomes. *PLoS ONE*, 9(5):e96196, 2014.