# 論 文 の 内 容 の 要 旨

論文題目　　Techniques on Mining Effective Parallelism For High-Performance Blue-Noise Sampling

（高性能ブルーノイズサンプリング並列処理技術）

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Stochastic sampling is a core concept for many applications across different fields in signal processing, computer graphics, and computer vision. The sampling process reduces a continuous signal to discrete-time signals, which makes signal processing possible on computers. It is widely accepted that a sample pattern with a blue noise spectrum appears to be better in capturing underlying features of the continuous signal. A blue noise sample pattern means that the power spectrum of the Fourier transform of a sample set appears to have blue noise feature: that it reveals low energy during lower frequency domain while extending to a higher energy level during high-frequency domain. Such sample patterns can help applications avoid aliasing, achieve better visual quality. It also serves as the core algorithm in stippling and halftoning, when the underlying density map is used. Among which the Poisson-disk sampling pattern is proved to be one of the best choices in blue noise sampling pattern. This specific sampling pattern can help the sampling process achieve a high sampling rate while maintaining relatively good quality.

In this thesis, high-performance generation methods of blue noise sampling pattern, especially Poisson-disk sampling will be studied and presented. The contribution of this thesis comes in three part: the first part is a novel method named KD-tree based Randomized Tiling (KDRT) to generate maximal Poisson-disk sample patterns on Euclidean space in multiple dimensions, with state-of-the-art generation rate while maintaining good sampling quality. The second part will focus on how to apply the planar Poisson-disk sample patterns to mesh surfaces, which is also a very important application in computational geometry and computer graphics. A progressive sample projection method based on parallel ray-tracing will be used, which pushed the parallelism and performance of Poisson-disk sampling on the mesh surface to a new level. In the third part,  a novel relaxation-based algorithm optimizing over constrained distances will be proposed to further optimize the blue noise feature of generated samples. A new second-order function will be used to alleviate problems in parallel computing of relaxation based blue-noise samples. while a relaxation based synthesis method based on distance constraints will also be presented as well, in order to satisfy applications requiring sampling with a certain final state.

Maximal Poisson disk sampling is one of the blue noise sampling patterns that can benefit various applications mentioned above. Previous methods often fail to provide enough sampling rate for usage in real-time applications or suffer from a trade-off on sampling quality. To address this problem, we propose a novel tile-based stochastic sampling method, that can provide tremendous improvements on performance (measured by sampling rate) over literature while maintaining the maximal property that most applications could benefit from. The core idea is to clip samples randomly from a predefined sample set, then tile all clips to the sample domain. To eliminate sample conflicts from this operation, a divide-and-conquer method will be applied to all clips of the tile. The method is a two-step process: divide sample space into clips randomly with KD-tree based pattern, then conquer the clips together with our proposed conquering algorithm. We also propose a generally applicable parallelization method for any other maximal Poisson-disk generation method, developed from the conquering algorithm.

Secondly, sampling in Non-Euclidean space is of crucial importance in computer graphics, especially considering sampling 2D manifold, which mostly would be represented as 3D space mesh surfaces. It is often the most important pre-processing step in applications such as re-meshing, texture synthesis, point-based learning and point based reconstruction. Most previous methods can hardly provide enough performance for real-time use, or suffer from a painful trade-off between quality and sampling rate. Meanwhile, methods that can achieve a relatively good sampling rate are often not memory bounded or require atomic operations during parallel processing, which greatly harmed their parallelism. In the second part of the thesis, we developed a straight forward progressive sample projection method for high-performance sample generation on mesh surfaces. It can generate massive Poisson-disk samples on mesh surfaces in a very short time by projecting blue noise sample patterns from 2D planar space onto meshes. This parallel scheme can exploit full parallelism of SIMD hardware such as GPU without deep recursion or atomic operations, which are often required by other methods. The effectiveness of the method can guarantee most usage in real-time applications, while also being progressive with memory usage bounded, thus being flexible for both performance and quality demanding work. The method can be easily applied to adaptive sampling as well, which could be crucial in applications such as stippling.

And finally, for some more demanding work like low aliasing rendering, re-meshing, etc., the Poisson-disk sampled set need further optimization to achieve a better blue-noise quality level. Applications such as object placements require that a precise number of samples should be synthesized instead of a specified Poisson-disk radius. For such conditions, a relaxation-based method will be needed to optimize an Energy function defined on the sample points that can further improve blue noise quality. We developed a novel method to exploits more parallelism from existing relaxation based algorithms by assigning each sample with an "activeness" value calculated from their incident forces received from neighbors. The activeness will dynamically re-distributing tension forces between pairs of current point with its neighbor. The algorithm takes incident forces of each sample as a way to measure whether the sample is stuck in a local balance and cannot be further improved with normal parallel calculation. This mechanism can dynamically detect and resolve such local balance and help the iteration to achieve effective parallelism. We showed that the proposed method can achieve a better global variance than other strategies. We also proposed to use distance constraints, or the edges of Delaunay triangulation of the point cloud to do blue-noise synthesis in this way. A simplified algorithm utilized k-nearest neighbor is also proposed, which is much more GPU friendly.