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ON THE DEFINITION, APPLICATION AND METHODOLOGY COMPONENTS OF STEREOLOGY

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Abstract: In this review article, the definition and the scope of stereology have been introduced and discussed. Stereology can be defined as "three-dimensional interpretation of flat images by criteria of geometric probability" in its narrow sense, or as "reconstruction and the knowledge of multi-dimensional geometrical structures and images" in its more general sense. Whether in its narrow or broad definition, stereology is essentially an interdisciplinary branch of science about 2D and 3D structures and images, especially the three-dimensional interpretation of flat images by criteria of geometric probability. Nowadays, stereology has become an essential tool for all experimental scientists and engineers who need to obtain quantitative three-dimensional microstructural information, no matter they are working in materials science, biology, medicine, or other different fields. On the other hand, the design of a stereological experiment is the most difficult and most important component of practical stereology as emphasized by many stereologists. At the end of this review, further readings of stereology and related sciences are suggested.

Key words: stereology; image analysis; quantitative microscopy; mathematical morphology; stochastic geometry; applied mathematics

关于体视学的定义、用途和方法学基本要素

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摘 要:首先引入文献中体视学狭义和广义的定义及领域范围,然后举例介绍了(狭义)体视学的用途。狭义地讲,体视学是由其截面或投影图像和几何概率获取三维结构定量信息的一门科学;广义地,则可认为体视学覆盖了与多维结构或图像的理解、重建及定量分析有关的原理、方法、软硬件研究、制造及应用等所有内容。不同定义中有一点是共同的,即体视学是一门关于多维几何结构及图像的边缘和交叉科学分支,是不同学科中获得三维显微组织结构几何形态信息的基本工具。本文引述了 DeHoff 教授关于体视学方法基本要素的精辟叙述,强调指出对于体视学方法及其应用,取样设计和操作既是极其重要,也是最容易被忽略的,应予以高度重视。本文最后还推荐了一组与体视学有关的书、刊或论文,以及因特网网址和网页,供感兴趣的读者进一步查阅参考。

关键词:体视学;图像分析;定量显微镜学;数学形态学;随机几何;应用数学
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1 Various Definitions of Stereology

On May 12, 1961, the term "stereology" was coined and the International Society for Stereology (ISS) was incorporated by a group of scientists and professors from various disciplines. This marked the establishment of stereology as a formal science.

Different definitions of "stereology" have been presented in different references since then, some of which have been collected by the author as follows:

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(1) Literally, "stereology" means "the knowledge of space", a meaning which is much more general and broad than what Hans Elias had in mind when he introduced the term in 1961.

(2) According to Hans Elias, the first president (1961 – 1967) of the ISS, "stereology is three – dimensional interpretation of flat images, such as sections and projections, by criteria of geometric probability." "stereology deals with shapes, sizes, numbers, orientation in space and densities."

(3) Similarly, according to Robert T. DeHoff in his outstanding Overview Lectures presented at the XICS (Xth International Congress for Stereology) held in Melbourne, "stereology is the methodology that provides meaningful quantitative descriptions of the geometry of real three – dimensional glob structures from measurements that are made on two – dimensional images sampled from the glob."

(4) In ASTM Standard E562 – 89, stereology is defined as "*the methods developed to obtain information about the three – dimensional characteristics of microstructures based upon measurements made on two – dimensional sections through a solid material or their projection on a surface.*" While in ASTM Standards E1245 – 89 and E1268 – 88, the term "stereological methods" is similarly described. Such standard practice is under the jurisdiction of the American Society for Testing and Materials (ASTM) Committee E – 4 on Metallography and is the direct responsibility of Subcommittee E04.14 on Quantitative Metallography. The ASTM Standards have been appropriated worldwide for long.

(5) According to Webster's Dictionary, stereology is "...a branch of science concerned with the development and testing of inferences about the three – dimensional properties... from a two – dimensional point – of – view..."

(6) According to the New Shorter Oxford English Dictionary (Vol.2, 1993, p.3052) or the Oxford English Dictionary (2nd edition, 1989), stereology is "the science of the reconstruction of three – dimensional structures from two – dimensional sections of them." Related words like stereological (a.), stereologically (adv.), and stereologist (n.) are also presented in this dictionary.

(7) C. Vyvyan Howard, the president (1992 – 1996) of the ISS and also the president (1996 – 1998) of the Royal Microscopical Society (UK), simply referred "stereology" as "geometrical quantification in 3D."

(8) According to Roger E. Miles' multi – dimensions idea, Ewald R. Weibel considered it too narrow the definition of only relating 3D structure to 2D measurements, and modified it as: "stereology is a body of mathematical methods relating n – dimensional parameters defining the structure to s – dimensional measurements obtainable on sections of the structure". However, in most practical applications of stereology, one still has that $n = 3$ and $s = 1$ or 2. Weibel and Miles served as the presidents of the ISS in 1968 – 1971 and 1984 – 1987, respectively.

In summary, stereology can be defined as "*three – dimensional interpretation of flat images by criteria of geometric probability*" in its narrow sense, or as "reconstruction and the knowledge of multi – dimensional geometrical structures and images" in its more general sense. The latter includes not only the reconstruction and visualization of the 3D images itself, but also that of any information and properties of the structures and images. Considering the interdisciplinary nature of stereology and the rapid development of computer – aided image technology, the latter definition is preferred to by the present author and the Chinese Society for Stereology (CSS). Thus, the scope of stereology is extended to related branches of applied mathematics, quantitative microscopy, quantitative fractography, image acquisition, image transformation and processing, image analysis, 3D reconstruction, 3D imaging, 3D modeling, direct exploration in 3D structure, mathematical morphology, stochastic geometry, pattern recognition, CT (computerized tomography), MRI (magnetic resonance imaging), fractal images, and many other related areas.

2 Selected Application Examples of Stereolo-

gy

Stereology has become an essential tool for all experimental scientists and engineers who need to obtain quantitative three - dimensional microstructural information, no matter they are working in materials science, biology, medicine, or other different fields. The followings are only some selected examples of stereology.

2.1 Quantitative metallography in materials science

Stereological methods and image analysis have been widely used in materials science and engineering (MSE), especially in quantitative metallography. The follows are only few examples:

(1) Determining volume fraction by systematic *manual point count* (ASTM Standard E562 - 89).

(2) Determining inclusion content of steel and other metals by automatic image analysis (ASTM Standard E1245 - 89).

(3) Obtaining JK inclusion ratings using automatic image analysis (ASTM E1122).

(4) Assessing the degree of banding or orientation of microstructure (ASTM Standard E1268 - 88).

(5) Determining average grain size (ASTM Standard E112 - 88).

(6) Evaluating the microstructure of graphite in iron casting (ASTM A246).

(7) Determining average grain size using semiautomatic and automatic image analysis (ASTM Standard E1382 - 91).

(8) Characterizing duplex grain sizes (ASTM Standard E1181 - 87).

(9) Stereologically - based image analysis for characterizing second - phase constituents (a proposal to ISO, reference No. ISO/TC 17/SC 7 N 479).

(10) Applications in porous materials and powder metallurgy: common porous materials include *concrete, paper, ceramics with natural or artificially - created* pores, clays, porous semiconductors, chromotography materials, and natural materials like coral, bone, sponges, rocks, and shells, all of which have pores in them. Thus, the amount, the size and its distributions, shapes and topology, spatial locations and patterns of pores need and can be quantitatively characterized by using stereology, combined with image analysis, mathematical morphology, 3D modeling or even fractal geometry sometimes.

(11) Applications in understanding basic ideas in physical metallurgy; different definitions of dislocation density.

It should be emphasized that the ASTM standards are among the most authorized and well - known in materials science and engineering (MSE) fields. Thus, through the efforts of materials scientists and engineers worldwide, application of stereological methodology have been already introduced into laboratory routine and extensively standardized in the MSE fields. Facilities to support such standardized application of stereology have become available easily *nowadays. However, more advanced stereological* methodology are not well known even in the MSE fields. Definitely, further efforts should be made not only by materials scientists and engineers, but also by those create new and better methodology and facilities.

2.2 Quantitative morphology in biology and medicine

Nowadays, stereology has found even more extensive application in biology and madicine studies. For example, unbiased stereology is now being requested for nerve cell counts in neurotoxicology by the US FDA and demanded by many journals before acceptance of studies and articles.

2.3 Combination with CT (computerized tomograpgy) and MRI (magnetic resonance imaging)

Many image processing and analysis systems have been developed for further usage of sectional images obtained by using CT and MRI techniques. For example, the 3DVIEWNIX system (USA), ANALYSE system (USA), Voxel - Man system (Germany), and the Window NT - based 3D imaging and analysis system developed by the Academy of China.

2.4 Applications in agriculture

In agriculture, stereological methods may be applied for numerous purposes such as:

(1) Quantifying microstructure in vegetables.

(2) Quantifying organs in animal bodies.

(3) Quantifying spraing in potatoes.

(4) Estimating length of plant roots.

(5) Quantifying regions in agricultural fields.

(6) Quantifying the open space structure in grass swards.

2.5 Other application examples

Applications of stereology can also be found in geoscience, in the measurement of: faults in rocks, pores in soils, mineral grains in rock, biological tissue, and many other science and technology fields.

3 The Fundamental Component of the Stereology Methodology

As understood by the present author, the following descriptions (quoted directly from R. T. DeHoff) are referred to the traditional or narrow definition of stereology.

3.1 Features

The structure of the glob of matter is composed of sets of specific features (particles, surfaces, interfaces, lines, edges, points, ...).

3.2 Properties

Each feature has one or more geometric properties which can be measured. The goal of the exercise is the quantitative estimation of these geometric properties.

3.3 Probes

The glob is sampled with a set of geometric probes – points, lines, planes, volumes –, on which observations and measurements are made.

3.4 Events

The probes interact with specific features in the structure to produce events to be observed (point probe lies in feature, line probe intersects boundary, plane probe transects particle, ...).

3.5 Measurements

Some attribute of each of the observed events of interest is measured. In most cases this is a simple count of the number of events observed.

3.6 Analysis

A mean and standard deviation of the distribution of measured values in the sample is computed. If the sample design is valid, the mean will provide an unbised estimate for the expected value of the measurement for the population of probes.

3.7 Relationship

The fundamental equations of stereology relate the expected values of specific measurements on an appropriate probe set to a corresponding geometric property in the three dimensional glob.

3.8 Design

Each kind of probe has a specific population in the space occupied by the probe. The choice of the subset of probes in this population to be examined for measurement constitutes the design of the stereological experiment.

The design of a stereological experiment, by which is meant the set of choices that are made for the selection of orientations and positions of the fields to be observed and measured, is the most difficult and most important component of practical stereology. An improper design could lead to the expenditure of a great deal of effort to produce very precise estimates of wrong numbers.

For more details, the readers may refer to the following suggested literature, especially those recent publications.

4 Some More Words

As mentioned in section 3, most of the standard stereology measurements of volume, surface area, curve length, curvature densities, are simple point counting upon correct sampling the population, no need of any expensive instruments. Even so, there still exist serious problems in research and application of stereology. As also pointed out by Bente Pakkenberg (the president of the ISS, 1995 – 1999), most applied scientists have only a remote knowledge regarding the field of applied mathematics and even the stereology. Thus, countless hours are still spent in laboratories to obtain based quantitative information of real 3D structures based on 2D-profile analysis. It is of great importance to let the people know those available methodology and facilities in order to make all the scientific results validity and unbiased. On the other hand, it is also important to make more efficient, inexpensive, and ease-to-be-understood methods available. In this point of view, scientific societies like the ISS and the CSS should be more active than anytime before.

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6 Some Useful International and Domestic Scientific Journals

(1) Journal of Microscopy. Oxford, UK. ISSN 0022-2720. The journal is the principal publication of the Royal Microscopical Society and the official journal of the International Society for Stereology.

(2) Acta Stereologica. Ljubljana, Slovenia. ISSN 1580-3139. The official journal of the International Society for Stereology (first appeared in 1982). Its name has been changed to Image Analysis and Stereology from volume 19, No. 1 (March 2000).

(3) Chinese Journal of Stereology and Image Analysis. Beijing, China. ISSN 1007-1482. The official journal of the Chinese Society for Stereology

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4 结论

(1)ICP 时最主要的胎盘组织形态学异常是绒毛间腔狭窄及合体结节增多。绒毛间腔狭窄可能是由于绒毛间质水肿、胎儿毛细血管扩张所致。

(2)ICP 胎盘组织形态学异常与血中甘胆酸水平升高对绒毛组织的不良作用有直接关系。

(3)ICP 胎盘组织形态学异常与胎儿预后不良有关,绒毛间腔狭窄可能是导致宫内缺氧的原因之一。

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