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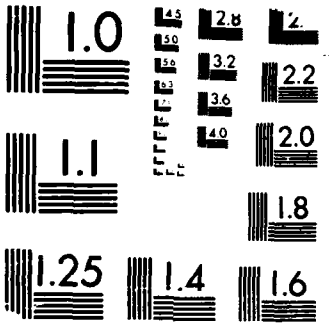

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Statistical smoothing methods: some practical aspects

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THIRD PERIODIC REPORT

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EQUIPMENT

There has been no substantial change to our configuration of equipment since the last Periodic Report. It is hoped to acquire a colour hard copy unit in the fairly near future, and this will be of substantial use to the project.

SCIENTIFIC WORK

Density estimation

The paper [1] referred to in the First Periodic Report has now appeared in print. One of the novel features of our investigation was the use of Computer Algebra to solve this statistical problem, and Professor Silverman was invited to give a presentation on this topic to a Royal Statistical Society workshop on computer algebra in statistics; this was extremely well received.

Edge process models for image reconstruction

Work on this topic has continued, and a considerable amount of additional progress has been made along the lines described in our Second Periodic Report. The scheme for dealing with "loose ends" and "branches" has now been fully worked out, and its effectiveness in overcoming some of the arbitrary elements of previous approaches has been clearly demonstrated by means of a practical example. The new work has been incorporated into a substantial paper [4], which has been submitted for publication. A copy is attached, which please see for further details.

Parsimonious additive models

A very simple and powerful new method for fitting nonlinear regression models has been devised and investigated by Professor Silverman in collaboration with J.H. Friedman of Stanford. The basic idea is to fit a sequence of segmented linear regressions on single variables to the data and then to use a suitable stopping rule to decide when to stop elaborating the model. Finally a backward elimination step is used to resimplify up to an appropriate point. The idea has obvious connections with the CART approach to nonparametric discrimination discussed below, and indeed a logistic version of it may well give be an interesting competitor to CART. Details of this possible development remain to be worked out. A paper [5] on this material was submitted to *Technometrics* and was selected by the editors to be the special discussion paper at the 1988 ASA meetings. A copy is attached.

ICM and Annealing

Further work has been done on the ICM approach to image restoration. The broad conclusions are that worthwhile gains can be achieved using an 'optimal' value of Besag's parameter β rather than the portmanteau value 1.5 and in the absence of specific knowledge about the corrupted scene a second order neighbourhood model with down-weighted diagonals should be used. A substantial technical report describing this work (at present 23 printed pages plus figures) is in a late drafting stage.

Nonparametric discriminant analysis

The development of a computer program to execute the CART method is almost complete. The program can grow and prune classification trees, and now accepts qualitative features as well as quantitative features. A program to draw tree diagrams automatically on Tektronics graphics devices is now in use. Completion of the CART program entails writing code to cope with missing data values, and to estimate the variance of the misclassification cost estimators; this work is in hand.

Image Refinement

Further work has been done on the image refinement problem. The original computer program for computing the refined reconstruction has been improved to allow the points of intersection of object boundaries with pixel edges to move across pixel corners in the later stages of the algorithm. The program now allows a completely automated reconstruction starting from the original signal and producing as end product a refined reconstruction achieving at least a local minimum of the penalised likelihood penalty function.

Indirectly observed images

The work on implementing and investigating the "smoothed EM" algorithm for the reconstruction of indirectly observed images has continued and a paper [6] by Professor Silverman's research student J. D. Wilson has been submitted for publication. A copy is attached. This paper concentrates on the application of our technique to a problem in stereology, and demonstrates that the idea is a considerable improvement over previous methods, and that it provides a generally feasible and attractive approach to a wide range of statistical inverse problems, not just in stereology.

A much more ambitious element of this part of the investigation has been the application of the smoothed EM algorithm to problems in indirect image reconstruction on a pixel grid. The work on the positron emission tomography problem discussed in the Second Periodic Report has been continued, and it is now much clearer which smoothing strategies will work well. A substantial paper describing the smoothed EM approach generally, and in particular its application to this problem, is in preparation.

The joint theoretical work with Johnstone has continued, and a new proof of the key result, using Fano's lemma of information theory, has been obtained. A talk on this work was presented to the Annual IMS Meeting in San Francisco in August 1987. Johnstone and Silverman are now preparing their work for publication, but are planning to make further investigations into the general problem of quantifying the information loss in indirect observation problems. Another question raised by their work is whether a smoothed orthogonal series algorithm might be a competitor to the smoothed EM approach in certain special cases. While the smoothed EM approach is very general, the theoretical work suggests that, if one is fortunate enough to be able to perform a singular value decomposition of the integral operator, a simple orthogonal series approach can achieve the best possible rate of convergence.

Spatial smoothing

Work has been started with Dr A. H. Seheult of the University of Durham on the problem of fitting spatially smooth fertility trends in analysing agricultural field trial data as a means to reduce the variance of estimated treatment effects. The two-dimensional version of this problem is interesting in its own right since much more information is usually available from neighbouring observations when estimating a two

dimensional smooth function than a one dimensional function. Also, the chance of detecting outliers or discontinuities in the fertility process is greatly increased; this particular aspect of the problem is closely related to the problem of edge detection in image analysis.

CONFERENCES

Professor Silverman was invited to present a lecture entitled "Using computer algebra to investigate the smoothed bootstrap" at a Royal Statistical Society workshop on computer algebra in statistics. Professor Silverman gave the opening address at the 17th European Meeting of Statisticians in Thessaloniki, Greece on the subject of "Non-parametric regression", a lecture which included substantial reference to work completed or in progress on this research contract. A paper entitled "Speed of estimation in Positron Emission Tomography" by Professor Silverman and Professor I. Johnstone of Stanford University was presented at the 1987 Joint Statistical Meetings in San Fransisco.

Dr Jennison attended the Tenth International Conference on Information Processing in Medical Imaging, held in June 1987 in Utrecht, Netherlands, where the paper "Statistical image restoration and refinement" by Dr Jennison and Mr M. Jubb was presented. Dr Jennison spent three days visiting the Centre for Mathematics and Computer Science in Amsterdam and gave a seminar on "Topics in image analysis". Dr Jennison presented the paper "Statistical restoration and refinement" at the 17th European Meeting of Statisticians in Thessaloniki.

PUBLICATIONS

[1] Silverman, B. W. and Young, G. A. (1987). The bootstrap: to smooth or not to smooth? *Biometrika*, 74, 469-479.

[2] Brown, T. C. and Silverman, B. W. Edge process models for regular and irregular pixels. Technical Report No. 267, Department of Statistics, Stanford University, Stanford, California.

[3] Jennison, C. and Jubb, M. Statistical image restoration and refinement. To appear in Proceedings of the Tenth International Conference on Information Processing in Medical Imaging, held in June 1987 in Utrecht, The Netherlands.

[4] Brown, T.C., Jennison, C. and Silverman, B.W. Edge process models for regular and irregular pixels. (33 pp.) Submitted for publication.

[5] Friedman, J.H. and Silverman, B.W. (1988). Flexible parsimonious smoothing and additive modeling. *Technometrics*, accepted for publication and reading as a special discussion paper at the 1988 American Statistical Association Annual Meetings.

[6] Wilson, J.D. A smoothed EM algorithm for the solution of Wicksell's corpuscle problem. (37 pp) Submitted for publication.

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