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6. AUTHOR(S)

Professor Paul Dupuis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Brown University
182 George Street
Providence, RI 02912

8. PERFORMING ORGANIZATION REPORT NUMBER

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13. ABSTRACT (Maximum 200 words)

This report describes work on problems from stochastic systems theory where the noise effects are small. The work has addressed two current needs: extension of the theory to cover practically interesting problems (such as design of data networks), and the development of computational methods for large deviation problems. Problems of particular interest that were dealt with are approximation of rare events in queueing systems and the control of reliable systems. We also discuss a recently developed method for obtaining rate of convergence estimates for a variety of approximations in deterministic and stochastic optimal control.

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Theory & Numerical Methods for Problems in Shape
Reconstruction and Large Deviations

FINAL TECHNICAL REPORT

Principle Investigator

Paul Dupuis

June 1, 1993 – May 31, 1994

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

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Lefschetz Center for Dynamical Systems
Division of Applied Mathematics
Brown University
Providence, RI 02912

Research Results

(a) **Large deviations and control of rare events.** A major concern in stochastic systems theory are problems where the effects of the noise are small. For example, in many modern communications and computer systems one wishes error rates on the order of 10^{-9} or so. Much of the theoretical underpinning of estimates that are available comes from the theory of large deviations. Our work has addressed two current needs: extension of the theory to cover practically interesting problems (such as design of data networks), and the development of computational methods for large deviation problems. There has been virtually no work on numerical problems in this area. Indeed, the classical approach to this theory is so complex that the associated numerical problems would appear impossible. With this in mind, we are developing an alternative approach that in a general setting puts the problem into a control theory framework. In reference [1] above we have applied this approach to prove the existence of a large deviation principle for a very broad class of jump-Markov processes that occur in queueing problems. This vastly widens the class of such systems for which such a principle is known. The proofs use a characterization of the large deviation probabilities as the minimal cost functions of associated stochastic control problem. This characterization is also used as the basis for computational procedures that are developed in reference [4]. The characterizations serve both to motivate and understand convenient computational approximations, and also to prove their convergence.

In the reference [3] we have started to address the theoretical issues associated to a specific class of problems that involve both small noise and control. The problem considered in [3] is that of controlling an already "reliable" system so as to make it as reliable as possible. Here reliability refers to the length of time the state of the system remains in an acceptable operating state. The assumption that the system is already reliable simply means that we are dealing with a system with small noise effects. For such systems the paramount goal is they remain in the acceptable operating region for as long as possible. Owing to the unusual nature of this criteria and the also the smallness of the noise effects, large deviation theory offers an ideal tool for the analysis of such problems. In future work we plan to extend the algorithms developed in [4], which deal with jump processes and no control, to cover a broader range of processes and also processes with control.

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(b) Rates of Convergence in Optimal Control. In [2] we developed a simple method for obtaining rate of convergence estimates for a variety of approximations in deterministic and stochastic optimal control. Heavy use is mad of representations of the approximations as functionals of a controlled Markov process, which of course is a by-product of the "Markov chain approximation method." The method is illustrated through the presentation of a number of examples, including finite difference schemes with several different cost structures.

(c) Work on Shape Reconstruction. Work that has begun but is not nearly finished involves an extension of previous work on the classical problem of shape-from-shading to handle the problem of shape-from-SAR data (synthetic aperture radar data). Many new difficulties, such as the differing geometries of the problems and the presence of significant noise in SAR data, have required significant alterations in the algorithms used previously. This work is still proceeding.

Invited Presentations:

1. Session on Large Deviation Theory, IMS, San Francisco, CA, August 6-8, 1993.

2. Workshop on Stochastic Networks, Institute for Mathematics and its Applications, University of Minnesota, Minneapolis, MN, February 28 - March 4, 1994.

3. Large deviation properties of Markov models for queueing networks, Bell Labs, 6 July, 1994.

References

[1] The Large Deviation Priciple for a General Class of Queueing Systems, I (with Richard S. Ellis). To appear in Trans. of the AMS.

[2] Rates of Convergence for Approximation Schemes in Optimal Control (with Mathew James). Submitted to SIAM J. on Control and Opt.

[3] A Risk-Sensitive Escape Criterion and Robust Limit (with William M. McEneaney). The 33rd IEEE Conference on Decision and Control, Lake Buena Vista, Florida, December 14-16, 1994.

[4] Computational Methods for the Large Deviations Analysis of Jump Markov Processes (with Dennis Jarvis), in preparation.