Math. Forschungsinstitut
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MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

T a g u n g s b e r i c h t 3/1982

ANGEWANDTE STOCHASTISCHE PROZESSE

17.1. - 23.1.1982

Die Tagung fand unter der Leitung von Herrn Prof. Dr. M. Schäl (Bonn), Herrn Prof. Dr. R. Schassberger (Berlin) und Herrn Dr. W. Whitt (USA) statt.

Im Mittelpunkt des Interesses standen stochastische Prozesse, die sich aus konkreten anwendungsbezogenen Modellen ableiteten. Einen wesentlichen Anteil bildeten Modelle aus der Bedienungstheorie, die zur Beschreibung von Systemabläufen im EDV-Bereich dienen. Weiter wurden Fragen aus der Zuverlässigkeitstheorie, Kontrolltheorie, Populationstheorie, dynamischen Optimierung, Testtheorie, Theorie der Punktprozesse, Speichertheorie behandelt.

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Vortragsauszüge

E. ARJAS:

Association of life lengths: a dynamic approach

A random vector $\underset{\sim}{S} = (S_i)_{1 \leq i \leq k}$ of life lengths is said to be associated if for any two increasing functions f and g of S $Cov(f(\underset{\sim}{S}), g(\underset{\sim}{S})) \geq 0$. The usefulness of this notion derives mainly from the fact that if the component life lengths of a system are associated then bounds for the system reliability can be obtained by treating the components as if they were independent.

We give two sets of sufficient conditions for the association. Unlike the earlier conditions, they are dynamic in the sense that they are based on evaluating, at any given time t, the effect the failure of one or more of the system's components would have on the system's future behaviour. Of basic importance here is the concept called "weakened by failures". Mathematically our treatment is based on a description of the failures as a marked point process and it uses results from the corresponding martingale calculus.

(The paper is based on a joint work with Ilkka Norros).

L. ARNOLD:

Stabilization of linear systems by noise

Given the system $\dot{x} = Ax$. It is proved that the biggest Lyapunov number λ_{max} of the system $\dot{x} = (A+F(t))x$ parametrically perturbed by stationary noise F(t) with EF(t) = 0 satisfies $\frac{1}{d}$ trace A $\leq \lambda_{max}$. However, to each $\varepsilon > 0$ there is an F such that $\lambda_{max} < \frac{1}{d}$ trace A + ε, d the dimension of x. In particular, $\dot{x} = Ax$ can be stabilized by noise iff tr A < 0.

A. BARBOUR:

Poisson convergence in Random graphs

The problem of approximating the distribution of the number X_n of labelled copies of a strictly balanced graph H in a realization of $G(n,p_n)$ was first introduced by Erdős and Rényi (1960).

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They were able to show, by making suitable estimates of the factorial moments of X_n, that if $p_n \sim cn^{-k/l}$, where k is the number of vertices of H and l the number of its edges, then X_n converges in distribution to the Poisson with mean c^l/a, a being the order of the automorphism group of H. If $n^{k/l}p_n \to \infty$, such an approach becomes almost impossible. However, using a variant of the Stein-Chen technique, it is possible to show very simply that the total variation distance between the distribution of X_n and the Poisson distribution with mean $\mathbb{E}X_n$ converges to zero, if $n^{k/l+\delta}p_n \to 0$, where $\delta = k\{1-1/(1+\frac{1}{k-2})\}$. For any slower declining sequence (p_n), it is no longer true that $\mathrm{Var}X_n/\mathbb{E}X_n \to 1$, as would be anticipated were a Poisson approximation valid.

H.C.P. BERBEE:

Renewal theory for stationary processes

Suppose a system develops in time. At the so-called renewal epochs a component breaks down and is immediately replaced by a new component. Suppose the system is running already for a long time. We begin to observe it at some arbitrarily chosen renewal epoch. Let $0 < S_1 < S_2 < \ldots$ be the times of successive renewals and let $\xi_n := S_n - S_{n-1}$. It is quite reasonable to assume that $\xi := (\xi_n)$ is strictly stationary. Assuming also independence renewal theory obtains convergence of the expected number of renewals in the interval $(t,t+h]$, $t \to \infty$. To which extent does independence play a role here? Imposing an asymptotic independence condition on ξ, we obtain a quite natural extension of the classical theory. The methods we use are known from ergodic theory. Renewal theory for semi-Markov processes can be obtained from our results.

Karl BOSCH ; Guang-Huei HSU:

Finite dams with double level of release

We considered a finite dam with discrete additive input and double level of release. If the current dam content is not greater than a certain bound M, the release is one unit unless the dam is empty; and if the current dam content is greater than M, the release is r (≥ 1) units provided it is available, otherwise the whole con-

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tent will be withdrawn. We derived all the expressions of the distributions of first emptiness with and without overflow, the distributions of emptiness with and without overflow, the time dependent distributions of dam content with and without overflow, and the distributions of overflow times and quantities. If M is equal to the dam capacity, the results are reduced to the case of unit release; and if M = 0, the results are reduced to the case of release r.

Guang-Huei HSU:

<u>The development of queueing theory in the Peoples Republic of China since 1950</u>

In general the development of queueing theory (as well as any science) in the Peoples Republic of China in the last thirty years was interrupted by the cultural revolution (starting in the late sixties) for nearly ten years. In the time before that interruption there were two centers of interest for the chinese mathematicians:
stationary streams without aftereffects and the general multi-server queue. In both directions results were found which were not really noticed by the science community and which were proved again later from people outside of China; but some of the results could not appear since the cultural revolution has started.
After its end the research in the field of queueing theory started with working in the main topics of the time before, but went to related topics of applied stochastic processes also in the last time.

Berichterstatter: H. Daduna

J.W. COHEN:

<u>Boundary value problems for two dimensional random walks on the lattice in the first quadrant, queueing models with two dimensional state space</u>

The analysis of the random walk on the lattice in the first quadrant leads to a type of functional equation for the generating function of the process which could be only analyzed for a few

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very special cases. Recently, it has turned out that the inharrent problem can be formulated and solved as a boundary value problem of the Riemann-Hilbert type. A complete solution can be given for the case of an arbitrary one step displacement distribution with the restriction that the random walk is skip-free to the West, the South-West and the South. The transient analysis and the steady state analysis are extensively discussed. The approach followed is very promising for future research of random walks, in particular for those encountered in queueing models with two-dimensional state space. Two of those models will be discussed, an alternating service model and a joint service model with two customer classes.

H. DADUNA:

Sojourn times in closed networks of queues

We consider GORDON-NEWELL networks with different customer classes. For overtake-free paths we derive the Laplace-Stieltjes transform of a customers sojourn time in such a path.

L. DAVIES:

On a new characterization of the exponential distribution

Let $(X_j)_1^\infty$ be non-negative i.i.d. rvs. and $N \geq 2$ an integer valued rv. which is independent of the $(X_j)_1^\infty$ and is such that LogN is non-lattice and $E(\text{LogN}) < \infty$. Then if $N \min_{1 \leq j \leq N} X_j$ has the same distribution as X_1 it follows that X_1 is exponentially distributed. An extension of the method yields new characterizations of the stable distributions.

B. DOSHI:

An M/G/I que with a hybrid service discipline

We consider the following single server queueing system:
A single server manages two queues, Q1 and Q2. Q1 has nonpreemptive priority over Q2. Q1 is served first-in-first-out and Q2 is served last-in-first-out. On arrival a customer is put in Q1. If the customer is still in Q1 at time T after its arrival, then it is transferred to Q2. The customer arrival process is Poisson and the service times are i.i.d. - The above service discipline is one of

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the desirable ones in queueing systems where a customer may turn 'bad' during its wait in the queue. We are interested in the waiting time distribution for such a queue. To this end we first define an equivalent queueing system. The integral equation satisfied by the waiting time density is then derived using the level crossing arguments. This integral equation is solved using the renewal theory results.

G. FAYOLLE:

Analytic methods in queueing theory

"Functional equations arising in the analysis of two-dimensional queueing models: closed-form formulas by reduction to Riemann-Hilbert-Carleman problems".

Broadly speaking, the unknown functions are the generating functions or Laplace transforms corresponding to the stationary distribution of a stochastic process (number of customers, waiting time, etc...).

Three particular problems are accessed, but the procedure is general:

- A) Two F.I.F.O M/M/1 queues coupled according to the following strategy: service times of the top-jobs in each queue have instantaneous service rates depending on the system state. [Reduction to a Riemann-Hilbert problem]
- B) Joining the shorter of two unbounded F.I.F.O M/M/1 queues. [Reduction to a generalized Riemann-Hilbert problem]
- C) Laplace transform of the stationary waiting time distribution in a simple 3-node-Jackson network with overtaking. [Reduction to a Carleman-problem].

W. FIEGER:

On the orderliness of Markovian point processes.

Let $(N_t : t \in \mathbb{R}^+)$ be a point process (i.e. $N_t(w) \in \{0,1,2,...\}$, $N_t(w)$ nondecreasing in t and continuous from the right) which is Markovian with transition probabilities $p_{mk}(t,s)$. Haezendonck [1980] has shown that $(N_t : t \in \mathbb{R}^+)$ has w.p. 1 only jumps of high 1,

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if

$$(*)\quad \begin{cases} \lim\limits_{s \downarrow t} \frac{1}{s-t} \cdot p_{mk}(t,s) = 0 & \text{uniformly in } t \text{ only} \\ \text{every bounded subset of } \mathbb{R}^+ & \text{for } k \geq m+2,\ m \geq 0. \end{cases}$$

An easy example shows that condition (*) is not necessary. A condition which is under a mild additional condition necessary and sufficient for N_t having only jumps of high 1, is given.

W.-R. HEILMANN:

A stability result for Markovian decision programs

The present paper deals with the stability of discounted stationary Markovian decision programs when the initial distribution, the transition law, the cost function, and the discount factor are subjected to perturbations. We make use of the fact that there are close connections between such a program and certain dual pairs of linear programs in normed vector spaces for which a weak duality theorem can easily be proved. Applying stability results for systems of linear inequalities, we derive one-sided bounds for the magnitude of the change in the value function in terms of the magnitude of the perturbation.

H. HERING:

Random characteristics in branching diffusions

Consider a branching process in which individuals live for a random time, diffuse on a bounded domain (with various possible boundary conditions), and produce offspring according to a generalized age-dependent reproduction process. A random characteristic of an individual is a non-negative real-valued stochastic process starting with the birth of the individual. It may depend on the lifetime, motion, and reproduction process of that individual. Instead of merely counting the number of individuals present at a given time in a given region of ages, positions and offspring produced, form the sum of their characteristics. The asymptotic behaviour of this sum, as time tends to infinity, is qualitatively the same for a large class of characteristics with quite different practical interpretations.

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M. HOFRI:

A queueing analysis of congestion at interleaved storage systems

A popular method to increase the effective rate of main storage access in a large computer is to have it consist of several modules that may be accessed in parallel. While such an organization usually results in a net gain in the storage access rate it also creates new modes of congestion at the storage controller. We shall analyse the processes that describe such a congestion - queue lengths and delays - arising in a controller that maintaines separate register sets to accommodate the request queue of each module. The various processors attached to the main storage are assumed to generate each memory cycle a random number of such requests: the addresses (i.e. required modules) are further assumed to follow a first order Markov chain. We derive several descriptors of the congestion and hence of the quality of service offered by such an organization. The aim throughout is to produce results in a form that can be readily evaluated numerically in terms of the rich collection of parameters used to describe the system and its use of the main storage.

A. HORDYK:

Networks of queues

This talk reports on a joint research with Nico van Dyk. The notions of local balance and reversibility are existent for many years. In this talk we interconnect them via an adjoint process.
The transition rates for adjoint processes are defined by the solutions of the job-local-balance equations, for which generally closed-form-solutions exist. The original process has the job-local-balance property if and only if all adjoined processes are reversible. Moreover, in this case the stationary distributions of the original and of any adjoint process are equal. Also, an algorithmic solution for the stationary distribution can be given then.
The notion of an adjoint process together with Kolmogorov's criterium for reversibility provides a tool for verifying whether specific stochastic networks satisfy the job-local-balance property. Finally, using adjoint processes insensitivity results are easily derived.

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A. IRLE:

Sequential tests for stochastic processes - optimality of the SPRT

The optimality of the SPRT (sequential probability ratio test) in the sense of Wald and Wolfowitz is considered and a rigorous result for continuous time processes with stationary independent increments is given.

D. P. KENNEDY:

A stochastic model of optimal resource allocation

A model of the optimal sequential allocation of a resource between consumption and production is considered. In each period the utility is concave and homogeneous in the amount of the resource consumed. The optimal policy is derived and a system of prices which stimulates this optimal allocation is identified. These prices are shown to be the product of a martingale and a random discount factor. The martingale component has an interesting relationship to the supermartingale representing the conditional expected total future utility. The model may also be viewed as an extension of the classical optimal stopping problem.

T. LINDVALL:

On coupling of diffusion processes

Since the paths of diffusions are continuous, the coupling method is well fitted to be used in the study of one-dimensional such processes. Let $Q_\lambda(t)$, $Q_\mu(t)$ be the distributions of a diffusion $X(t)$, $t \geq 0$, when λ, μ respectively are initial distributions. The coupling method is used to prove that

(i) $\|Q_\lambda(t) - Q_\mu(t)\| \to 0$, except in a few particular cases, and

(ii) $t^\alpha \cdot \|Q_\lambda(t) - Q_\mu(t)\| \to 0$ as $t \to \infty$, under appropriate moment conditions on λ, μ and certain hitting times for X. Here, $\|\cdot\|$ denotes total variation norm.

I. MEILIJSON:

Competing risks on coherent reliability systems

Given a coherent reliability system, let Z be the age of the machine at breakdown and I the set of parts dead by time Z. Under certain assumptions on the structure of the system, the joint di-

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stribution (jd) of the pair (Z,I) determines the lifetime distribution (ld) of each part. As for estimation questions,

(1) If the jd is replaced by the empirical jd of a large sample of machines the ld will have a Gaussian error whose distribution can be identified.

(2) If the ld are assumed to be drawn from an exponential-type family, the parameters can be estimated using the E-M techniques for missing data, and the covariance matrix of the (asymptotically normal) estimate can be identified.

R. SERFOZO:

Convergence of sums of thinned point processes

This is a study of the convergence in distribution of sums of dependent point processes that are becoming uniformly sparse due to a random thinning operation. The operation deletes entire processes as well as single points. Necessary and sufficient conditions are given for the sums to converge; moreover, their limit is necessarily a Cox process (a Poisson with a randomized intensity). In addition, for the case when the operation deletes processes and not single points, sufficient conditions are given for the sums to converge to an infinitely divisible process or a mixture of such processes.

J.H.A. de SMIT:

Multi-server queues with phase-type services

We discuss a general approach to multi-server queues with phase-type services. The analysis relies on a closure property of phase-type distributions which was recently proved by Neuts (2). The essence of our method is the reduction of the state space. This is important for obtaining analytic solutions as well as for direct numerical calculations. The approach has yielded a complete solution for $GI|H_m|s$ (see (1)). Here we shall sketch the application to the case of Erlang service times.

(1) J.H.A. de Smit (1981), The queue $GI|M|s$ with customers of different types or the queue $GI|H_m|s$. Report Dept. of Appl. Math. Twente University of Technology.

(2) M.F. Neuts (1981), Personal commucation.

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N. SCHMITZ:

On the termination property of SPRT's for homogeneous Markov chains

Already A. Wald mentioned that his sequential probability ratio test (SPRT) may be defined also in the case of simple hypotheses on a stochastic process. Moreover it is possible to construct SPRT's also for the case of composite hypotheses by selecting two special distributions from the hypotheses. But an example of a homogeneous Markov chain with 3 states shows that even the termination property may be lost though the occuring measures are pairwise orthogonal. Using a concept of Miller it is, on the other hand, possible to characterize those cases, where the termination property (or the exponential boundedness) is lost. Some generalizations to the case of an infinite state space are indicated.

H.-J. SCHUH:

Uniform bounding of probability generating functions and the evolution of reproduction rates in birds

Many species of birds have a characteristic clutch size which is either fixed at k or is of the form k or k+1 for some appropriate integer k. Using a multitype Galton-W tson process to model a bird population, we show that such behaviour can correspond to maximization of the probability of survival of the species to time t for each finite t. This is also a conclusion which might be drawn from the theory of natural selection and hence provides some mathematical evidence of the force of evolution. The results rest on a bounding of probability generating functions.

Literature: C.C.Heyde und H.-J. Schuh,
Uniform bounding of...,
J.Appl.Prob.15,243-250 (1978).

F. W. STEUTEL:

Markov chains of finite rank

We study the Markov chain model (first introduced by J.Th. Runnenburg in his thesis) with transition function of the form

$$P(X_{n+1} \leq y \mid X_n = x) = \sum_{j=1}^{r} a_j(x) B_j(y) .$$

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It turns out that the behaviour of this chain is governed by (powers of) matrices of the form

$$(C(u))_{k\ell} = \int w(x;u)\, a_\ell(x)\, B_k(dx) \quad ,$$

for simply, suitably chosen w. Asymptotic properties are then easily obtained by matrix decomposition methods.

We consider the limiting distributions of X_n, of $X_1 + \ldots + X_n$ (central limit theorem), and of $\max(X_1,\ldots,X_n)$ (extreme value theory), and we briefly consider dynamic programming.

H. STÖRMER:

Random variables on separable probability fields

Let $A_1, A_2, \ldots$ be any subsets of a set Ω. It is shown that the separable (countably generated) σ-algebra $\mathfrak{A}_s := \sigma_\Omega(A_1, A_2, \ldots)$ has a structure very similar to the σ-algebra of the Borel subsets of $[0,1)$. Each probability measure P on $(\Omega, \mathfrak{A}_s)$ is uniquely determined by a measure μ_1 on $([0,1), \mathfrak{B}_1 \cap [0,1))$ and a measure μ_2 on a countable space. Under the assumption of independent events $A_1, A_2, \ldots$ with $P(A_i) = 1/2$ for $i = 1,2,\ldots$ (corresponding to the assumption that μ_1 is the Lebesgue measure and $\mu_2 \equiv 0$) it is possible to construct a sequence $X_1, X_2, \ldots$ of random variables with given common distribution.

H. C. TIJMS:

Approximations for waiting times in the M/G/c queue

For the M/G/c queue we present an approximate analysis for the waiting time distribution. Using a recursive relation for the state probabilities we obtain a defective renewal equation for the waiting times. This integral equation can be numerically solved by a stable forward recursion. Also, asymptotic results for the waiting times will be given. Numerical results indicate that the approximations are quite accurate.

J. WESSELS:

Solving queueing systems by iterative approximation with simpler systems

In this talk some experience is communicated with iterative approximation of non-separable queueing networks by separable ones. Two

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aspects which destroy separability are considered. The first aspect is: at one or more nodes the first customer in a busy cycle has a service time distribution which differs from the general pattern. The second aspect is blocking because of finite waiting room in destination nodes.

For small systems the approximative solutions are compared with the exact ones. For the first aspect the results are quite satisfactory. For the second aspect they are promising, particularly with respect to the throughput.

W. WHITT:

Approximations for networks of queues

A simple approximation method for networks of queues will be discussed. We have three steps in our approximation:

1) to find simple summary descriptions (involving two or three parameters) of each of the stochastic processes associated with the network;

2) to have an elementary calculus for transforming the parameters to describe the basic operations of composition (superposition), decomposition (splitting), flow through a queue (overflow,etc.);

3) to apply simple approximations for single queueing stations based on the parameters.

For the second step we use renewal processes as approximating point processes and the moments of the renewal interval as the basic parameters. We suggest some methods for a convenient approximation.

J. WIJNGAARD:

Skip-free Markov decision processes

We consider a countable state Markov decision process which is skip-free to the right. That means that from state n transitions can only take place to the states 0,1,...,n+1. Policy iteration can be very attractive in such a process since the policy evaluation step is relatively simple. But it is also possible to use the skip-free property more directly. The cost going from 0 to n+1 can be divided in the cost going from 0 to n and the

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cost going from n to n+1. This results in a kind of forward recursion. We will pay attention to

1. possibilities to implement the policy evaluation step
2. possibilities to apply this direct forward recursion.

The results with respect to point 1 can be extended to the matrix skip-free case, that is the case where there is a $k > 0$ such that from state n transitions can take place to states $0,1,\ldots,n+k$. Direct forward recursion is not possible in this case.

Berichterstatter: H. Daduna

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