MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 20/2000

Stochastic Analysis in Finance and Insurance

07.05. - 12.05.2000

The conference was organized by Darrell Duffie (Stanford), Paul Embrechts (ETHZ) and Hans Föllmer (HU Berlin). Forty-seven participants from 12 countries took part. There was a very high success rate on the first round of invitations and very few participants were forced to cancel their participation at the last moment. Thirty lectures were presented. In the evenings we had many informal discussions, and various meetings of the editorial board of *Finance and Stochastics* took place.

The main theme of the conference concerned the use of stochastic calculus within mathematical finance and insurance with special emphasis on integrated risk management methodology. Whereas the basic mathematical theory of "standard" financial markets is well-understood by now, a major concern is which methodology to use by deviation from these "standard" assumptions, as there are markets with frictions, extremes, ... The largest group of lectures (10) was concerned with new developments within mathematics that are relevant for financial applications. The class of general Lévy processes, as an alternative source of information for investment and pricing models, was discussed in several talks (3). The practical usefulness of the various mathematical developments was illustrated in lectures on integrated risk management (10), some of which (2) were presented by participants from the finance and insurance industry. Some insurance-specific lectures (3) highlighted the need for a closer cooperation across the various fields of applications.

The meeting was commented upon by many participants as highly fruitful and stimulating. This bringing together of experts from mathematics, insurance and finance with a strong mathematical focus on stochastic analysis methods is close to unique. Each such meeting at Oberwolfach has had the character of a "milestone" in the development of the field.

We are grateful to the staff of the institute whose friendly and efficient assistance contributed in an essential way to the success. The meeting ended on Friday, May 12, at 15.00.

Abstracts

Ioannis Karatzas

Strategic Market Games in Mathematical Economics

We construct stationary Markovian equilibria in an economy with fiat money, one non-durable commodity, countably many time-periods, and a continuum of agents. The total production of commodity remains constant, but individual agents' endowments fluctuate in a random fashion, from period to period. In order to hedge against such fluctuations, agents find it useful to hold fiat money which they can borrow or deposit at appropriate rates of interest; such activity may take place either at a central bank (which fixes interest rates judiciously) or through a money-market (in which interest rates are determined endogenously).
We carry out an equilibrium analysis, based on a study of Dynamic Programming equations and on properties of invariant measures for the associated optimally-controlled Markov chains. This analysis yields the stationary distribution of wealth across agents, as well as the stationary price (for the commodity) and interest rates (for the borrowing and lending of fiat money), through appropriate balance equations in a way that conserves the money-supply and controls inflation. General results are provided for the existence of such stationary equilibria, and several explicitly solvable examples are treated in detail. (Joint work with W. Sudderth, M. Shubik and J. Geanakoplos)

Thaleia Zariphopoulou

Non-Linearities and Frictions

In my talk I presented the classical Merton's problem with stochastic volatility and the problem of distorted survival probabilities. By employing some novel transformations of solutions to linear partial differential equations, one can represent a class of solutions to market models with frictions in terms of distorted measures in a dynamic setting.

Walter Schachermayer

Utility Maximisation in Incomplete Financial Markets

A classical problem in Mathematical Finance is the maximisation of expected utility at some terminal date T for an agent who is allowed to trade in a financial market.
This problem goes back to the classical work by P. Samuelson and R. Merton in the late sixties and early seventies. In the late eighties Karatzas, Lehoczky, Shreve and Xu as well as He and Pearson developed a duality theory for the treatment of this optimisation problem, where the Legendre-transform of the utility function plays a crucial role.
In our recent work, partly jointly with D. Kramkov, we succeeded to find necessary and sufficient conditions insuring the existence of the optimizers of the primal and the dual problem and their duality relation.The crucial concept is that of "reasonable asymptotic

elasticity": For a utility function $\mathcal{U}$ defined on $\mathbb{R}_+$ we require that $\lim_{x\to\infty} \frac{\mathcal{U}'(x)x}{\mathcal{U}(x)} < 1$ and in case $\mathcal{U}$ is defined (and finitely valued) on all of $\mathbb{R}$ we require in addition that $\lim_{x\to-\infty} \frac{\mathcal{U}'(x)x}{\mathcal{U}(x)} > 1$. These conditions turn out to be necessary and sufficient for the duality theory to work out properly.

Damir Filipović

A General Characterisation of Affine Term Structure Models

Short rate models which yield an affine term structure (ATS) $P(t,T) = \exp(-A(T-t) - B(T-t)r_t)$ have been found convenient both by academics and practitioners. Prominent among them are the Vasićek and the Cox-Ingersoll-Ross (CIR) model.
In this talk we give a complete characterisation of all non-negative Markov short rate processes $r = (r_t)_{t\geq 0}$ implying an ATS. It is shown that r is necessarily a Feller process with an affine generator and vice versa. Such processes are known as CBI-processes and have been well established.
We show how by Laplace-inversion one gets explicit expressions for the price of a European call option on a bond. This explains a known feature of the CIR model. A new ATS model including jumping short rates is presented.

Shigeo Kusuoka

Malliavin Calculus Revisited

Stochastic mesh method by Broadie and Glasserman seems to be efficient, if one tries to compute the value of Carribean type optimal stopping time problems in diffusion models. However, one has to know transition probability densities to apply this method. It is not easy in general to compute the density of random variables, because the density itself is not an expectation of a function of random variables.
It is a natural idea to use Malliavin calculus to describe the density of a certain random variable. But if one applies the usual manner of Malliavin calculus, he will be involved in diffusion processes with values in infinite dimensional spaces.
In this talk, we refine the idea of Malliavin calculus and introduce a new formula, which is associated with Lie algebra generated by vector fields appearing in SDE for the original diffusion processes. Then we construct graded finite dimensional processes. Finally we show that the density can be expressed as an expectation of a function of these diffusion processes.

Thomas Mikosch

Tail Probabilities for Subadditive Functionals acting on Random Walks and Lévy Processes

The ruin probability in insurance mathematics is the tail probability of the distribution of the supremum of a random walk with negative linear drift. Thus, it is the tail probability of a subadditive functional acting on a random walk with negative drift. Instead of a random walk one can consider its continuous-time analogue — a Lévy process, and the overall supremum can be replaced by other subadditive functionals, including the sojourn time of a random walk with negative drift. We assume that the tails of the marginal distributions are heavy-tailed. The drift of the Levy process is not supposed to be linear. Under these assumptions, one can derive the tail probability of the functional acting on the Lévy process. Point process techniques are useful tools for deriving these results which are based on the heavy tail large deviation heuristics that unlikely events happen in the most likely way. The results generalize classical work by Embrechts, Goldie and Veraverbeke (1979) for the overall supremum (ruin probability). As in that paper, the tail probability is expressed in terms of the tails of the Lévy measure.

The talk is based on joint work with Misha Braverman (Beer Sheva) and Gennady Samorodnitsky (Cornell); see www.math.rug.nl\ ~mikosch

Freddy Delbaen

Coherent Risk Measures and Convex Games

For a comonotone coherent risk measure we know (by Schmeidler's theorem), that there exists a convex v such that $\rho(X) = \int_0^\infty v(X > \alpha)d\alpha$. From this follows that for elementary functions X there exists a $Q \in \mathcal{P}$ so that $\rho(X) = E_Q[-X]$ (here $\mathcal{P}$ and ρ are related by $\rho(X) = \sup_{Q\in\mathcal{P}} E_Q[-X]$). The proof uses the Bishop-Philips theorem. The result improves a result of June Parker on exactness properties of the σ-core of a game. There are applications to capital allocation problems. Here is essential that the $\sup\{E_Q[-X] : Q \in \mathcal{P}\}$ is really a maximum.

Paul Glasserman

Portfolio Value-at-Risk with Heavy-Tailed Risk Factors

We consider the problem of calculating the probability of large losses in a portfolio of derivative securities over a fixed horizon. We pay particular attention to the properties:

1) market returns over short horizons are widely observed to be leptokurtic
2) portfolio value is nonlinear in the prices of underlying assets.

To address (1) we model market risk factors using a multivariate t distribution. To address (2) we develop two computational procedures:
- transform inversion based on quadratic approximation to portfolio value.
- a Monte Carlo method that uses the quadratic approximation for variance reduction.

Nicole El Karoui

Portfolio Insurance with American Guarantee

A fund manager guarantees that at any time the investor may retire with a guaranteed floor (for example $\alpha\%$ of the initial investment). When the guarantee holds only at maturity, practitioners use constant proportional basic strategies (cushion strategy) or European option based strategies. We compare these different strategies and show that the Put based strategy is optimal for CARA utilities, if the underlying is the optimal for the unconstrained problem.
Then we show that the American guarantee may be considered in the same way by using American Put on the static position on the Underlying. But this strategy is not self-financing and you are faced with the optimal reinvestment of dividends delivered at the boundary of the American Put.
In the Black-Scholes framework, we give an explicit solution in terms of the American put price or the reflected at the boundary underlying at the early exercise boundary.
To extend this representation to the general case, we use boundary in strike and Gittins index introduced by El Karoui and Karatzas in 1995. As in the European case this strategy is optimal for CARA utility.

Uwe Wystup

Efficient Computation of Option Price Sensitivities using Homogeneity and other Tricks

No front-office software can survive without providing derivatives of option prices with respect to the underlying prices or model parameters, the so-called Greeks.
We present a list of common Greeks and exploit homogeneity properties of financial markets to derive relationships between the Greeks out of which many are model-independent. Our results apply to European style options, rainbow options, path-dependent options as well as options priced in Heston's stochastic volatility and avoid exorbitant and time-consuming computations of derivatives which even strong symbolic calculators fail to produce. (Joint work with Oliver Reiss, Weierstrass-Institute for Applied Analysis and Stochastics, Berlin)

Mark Davis

Optimal Hedging using Closely Correlated Assets

It often happens that options are written on underlying assets that cannot be traded directly, but where some "closely related" asset can be traded. We model this by taking two lognormal processes Y_t (on which the option is written) and S_t (which can be traded) driven by Brownian motions W_t^0, W_t with $EdW_t^0 dW_t = \rho\, dt$. If $\rho = 1$ we can hedge perfectly using S_t the appropriate hedge ratio being

$$\frac{\partial C}{\partial y}(t, Y_t)\frac{\sigma_0 Y_t}{\sigma S_t}, \tag{1}$$

where $C(t, y)$ is the Black-Scholes option value and σ_0, σ are the volatilities of Y_t, S_t resp.

When $\rho < 1$ we have an incomplete market and we address the problem in a utility maximisation framework supposing that the investor's objective is to maximise $E[U(X_T^\pi + h(Y_t))]$, where X_T^π is the portfolio value corresponding to some trading strategy π, $h(\cdot)$ is the option exercise value received at time T and U is a utility function which we take as exponential: $U(x) = -\exp(-\gamma x)$ $(\gamma > 0)$. The investor thus maximises utility taking into account that the random payoff $h(Y_T)$ is to be received at time T. This problem is solved by methods of convex duality. We find that the optimal strategy is similar to (1) but with C replaced by the value function W of a simple stochastic control problem. When $\epsilon = \sqrt{1-\rho^2}$ is small we can get an asymptotic expansion $W(t,y) = C(t,y) + \epsilon^2 D(t,y) + o(\epsilon^2)$ using ideas of Malliavin calculus where D is explicitly computable

Ole Barndorff-Nielsen

Modelling by Lévy Processes for Financial Econometrics and Turbulence

A class of financial models for analysis of observational series is described. In the context of finance the models have the interpretation of being of the stochastic volatility type. However, they are generally applicable and turbulence is another field of application. There are striking similarities, as well as important differences, between the main stylised features of empirical data from finance and turbulence (and there is now an emerging research field termed "econophysics"). These features are discussed and related to models and data sets on stocks, exchange rates, term structures of interest rates and turbulent fluids. A discussion of (real or apparent) scaling phenomena in finance and turbulence is also given.

Frank Riedel

Existence of Equilibria with Hindy-Huang-Krebs Preferences

Standard time-additive utility functionals do not capture the substitutability property of intertemporal consumption.

Hindy, Huang and Krebs therefore introduced a new class of utility functions based on a weighted average of past consumption.

We establish existence of a general equilibrium in economies where agents have preferences of the Hindy-Huang-Krebs-type. Using an infinite-dimensional analogy of the Kuhn-Tucker theorem we characterize efficient allocations. Equilibrium state price densities are semimartingales, but they do not belong, in general, to the space suggested originally by Hindy and Huang.

The associated linear price functionals are continuous as long as the underlying filtration is quasi left-continuous. (Joint work with Peter Bank, Humboldt University, Berlin)

Michael Studer

Saddlepoint Approximation for Stochastic Volatility Models

We study the applicability of stochastic Taylor expansions and saddlepoint approximations for the Black-Scholes model and Stochastic Volatility models (SV-models) . We show with explicit examples that the standard Delta-Gamma method in the Black-Scholes model should be replaced by a stochastic Delta-Gamma approximation which can be calculated very easily.

In the case of the SV-models we relate the stochastic Taylor expansion and the saddlepoint approximation, which is known to be very accurate for the approximation of the density of random variables, to approximate the distribution of the SV-model for a short time-horizon. This method is then used to solve problems related with risk-management.

Nizar Touzi

Hedging, Stochastic Target Problems and Geometric Flows

The problem of super-replication of contingent claims has been solved by means of duality. Indeed, for simple versions of this problem, a dual formulation can be derived, and used to characterize the value function as a solution of the associated Hamilton-Jacobi-Bellman equation. This is possible because the dual formulation is in the class of standard control problems for which the dynamic programming principle is well-known. Unfortunately, this approach does not work in more general models. We then suggest a direct treatment of the problem which avoids the passage by the dual formulation.

Let $Z^{\nu}_{t,z}$ be a controlled process with control ν in $\mathcal{U}$, some given control set with convenient properties. The natural generalization of this super-replication problem is written in terms of: $V(t) := \inf\{z \in \mathbb{R}^d : Z^{\nu}_{t,z}(T) \in G \text{ for some } \nu \in \mathcal{U}\}$, i.e. the set of reachability of some target G. We first prove that the family of reachability sets $\{V(t), 0 \le t \le T\}$ satisfies the dynamic programming principle: $V(t) := \inf\{z \in \mathbb{R}^d : \exists \nu \in \mathcal{U}, Z^{\nu}_{t,z}(\theta) \in V(\theta)\}$ for all stopping times $\theta > t$. This allows to prove that the characteristic function of V ($u(t,z) = 0$ if $z \in V(t)$ and 1 otherwise) is a discontinuous viscosity solution of the associated HJB equation, when $Z^{\nu}_{t,z}$ is a controlled Markov diffusion.

The above HJB equation turns out to be of the geometric type. This provides an (unexpected) connection with geometric flows. For example, one can prove that the smooth mean curvature flow has a stochastic representation in terms of a family of reachability sets for convenient dynamics of the controlled Markov diffusion Z^{ν} (Joint work with Mete Soner (Princeton University)).

Monique Jeanblanc

Information and Default Risk

In this paper, we make precise a choice of the information while studying default risk. We give tools in order to compute the intensity of the default process and we provide meth-

ods to compute the conditional expectation of discounted defautable payoffs (terminal and rebate parts). Our main tool is the hazard process, defined in terms of the conditional expectation of the event "default time smaller than t". Given the information of the default free world, we formulate the links between the intensity and the hazard process.
We establish a representation theorem for the martingale of the form of the conditional expectation of discounted defautable payoffs in terms of some Brownian motion and the compensated martingale associated with the default process (Joint work with C. Blanchett, R.J. Elliott, M.Rutkowsky, M.Yor).

Philip Protter

Hedging Non-Redundant Claims

Under a Lévy process setting for the risk neutral measure we present explicit formulas for hedging strategies of some contingent claims which are functions of the terminal value. Using weak convergence and robustness techniques we show also that hedging strategies for a class of look-back options (i.e., path functionals of the risky asset price process which is a solution of a stochastic differential equation driven by a Lévy process) have "smooth" paths, where smooth means left continuous with right limits. Robustness results for the hedging strategies are also given. Results are based on joint work with Jean Jacod, Jin Ma, Sylvie Méléard, and Jianfeng Zhang.

Andrew Cairns

Pensionmetrics: Optimal Dynamic Asset Allocation for Defined Contribution Pensions

We consider a policy holder who contributes a constant proportion, Π, of their salary, $S(t)$, to their personal fund, $W(t)$. At the time of retirement, T, this fund is converted into an annuity of $P(T) = W(T)/a(T)$, where $a(T)$ is the prevailing annuity rate at the time of retirement.
Assets are modelled using a general one-factor diffusion model for the risk-free rate of interest and a diffusion model for the prices of the n risky assets.
The success of the strategy is related to the replacement ratio $P(T)/S(T)$ through a terminal utility $u(P(T)/S(T))$. We aim to find the asset allocation strategy which maximises the expected terminal utility.
We find that, with non-hedgeable salary risk, it is optimal to invest in a mixture of three portfolios:

A: the minimum-risk asset in the $S(t)$ currency;
B: the minimum risk-asset in the $S(t)a(t)$ currency;
C: a more risky portfolio which is efficient in both currencies.

None of A, B, C depends upon the existence of non-hedgeable salary risk although the precise mix of these three portfolios may do so. We next consider the power terminal utility function and find that the form of the expected future utility can only be of a similar form if salary risk is entirely hedgeable using cash and the n risky assets. In this event it is found that the proportion of the fund plus capitalised future contributions remains constant. The remaining assets shift gradually from portfolio A to portfolio B in an attempt to match partially the pension liability. (Joint work with David Blake (Burbeck) and Kevin Dowd (Sheffield))

Ragnar Norberg

Valuation of Interest Guarantees in Banking and Insurance

Two forms of interest guarantees are considered, one putting an upper bound to the spot-rate at which the interest is currently paid, the other putting an upper bound to the total amount of interest paid during the term of the contract. The contingent claim associated with either type of guarantee is valuated, and the corresponding hedging strategies are determined in two models for stochastic interest, the Vasićek model and a continuous time Markov chain model. Applications are made to standard forms of loans and to participating policies in life insurance. Computational techniques are developed, and numerical examples are provided.

Ludger Overbeck

Credit Portfolio Modeling

In the talk we present the basic probabilistic concepts in modeling the credit risk in large portfolios. Then a new risk capital allocation scheme based on the notion of coherent risk measures is constructed and compared with classical approaches based on variance/covariance analysis. In the last part of the talk we show how this model can be applied to the valuation of CLO (Collaterized Loan Obligations) and similar structured transactions. In this context we also propose some concepts to model the default time as a first hitting time of a simple transformation of a multivariate correlated Brownian motion.

David Lando

Statistical Analysis of Rating Transitions - A Continuous Time Approach

Estimation and hypotheses testing of models of rating transitions and default in continuous time are discussed. An immediate advantage over using discrete, “cohort” methods shows up in the estimation of “rare” transitions. The continuous-time framework is also convenient for studying “non-Markov” behaviour of rating processes. A Cox regression model is used to test dependence of transition intensities on previous state and waiting time in current state. Finally, a word on invariance of intensity functions under real and risk neutral measure is considered.

Chris Rogers

Optimal Capital Structure and Endogenous Default

In a series of recent papers, Leland and Leland & Toft develop models for the pricing of credit-risky corporate debt, using a structural approach in which the value of the firm's assets evolves as a log Brownian motion, and default occurs when the value of the firm's assets falls to some level V_B. This value V_B is chosen by the shareholders, who control the firm until the bankruptcy time; it is chosen to maximise the value of equity. This modelling approach gives considerable qualitative insight into the structure of debt, and the dependence of firm value, debt value, yield spreads ... on debt maturity, leverage, ... One defect of the modelling is that the yield spread decreases to 0 as the time to maturity decreases to 0, which is not observed in practice. What we do in this paper is to extend the modelling to allow the value of the firm's assets to be a log-Lévy process with no upward jumps. This extension significantly increases the difficulty of the analysis but a combination of numerics and analysis allows us to answer most questions of interest (Joint work with Bianca Hilberink).

Ernst Eberlein

Lévy Processes in Risk Management

Brownian motion plays the dominating role as driving process for modelling price movements in standard mathematical finance. In order to achieve a better fit to real-life time series, we suggest to replace Brownian motion by Lévy processes. Generalized hyperbolic Lévy motions are our primary candidates, since they allow an almost perfect fit to data. The consequences for asset price modelling, derivative pricing and interest rate theory are discussed in detail. We also touch a number of related questions.

Huyen Pham

Stochastic Optimization under Constraints

We study stochastic optimization problems in an extended framework including financial models with constrained portfolios on the amount or numbers of shares, labor income and large investor models. We consider general objective functions including deterministic or random utility functions and shortfall risk loss functions. Two types of constraints on the state process are studied: European constraints require that the state process is bounded from below and the terminal state is nonnegative, while American constraints require that the state process is bounded from below at any time by a given stochastic benchmark lower level; such an American constraint appears in the problem of portfolio insurance with American guarantee.

We first prove existence and uniqueness to the optimization problems. In a second step, we develop a dual formulation under minimal assumptions on the objective function, which are analogous to the asymptotic elasticity condition of Kramkov and Schachermayer.

Kerry Back

Models of Large Informed Traders

Developments and extensions of the model of Kyle (Econometrica, 1985) are considered. The model discussed are: a single large informed trader with a single risky asset, a single large informed trader trading a call option and the underlying asset, multiple large informed traders with a single risky asset.

Richard D. Phillips

Capital Allocation in a Financial Intermediary: To the Line and Through the Layer

The issue of capital allocation in a financial intermediary has a long and somewhat controversial history in the actuarial and finance literature. In the actuarial literature, the proposed approaches are usually ad hoc with little theoretical structure to support the conclusions. In the finance literature, various authors have argued the allocation of capital within a financial intermediary is unnecessary since the capital is available to support all the various business units of the firm (Allen 1993; Phillips, Cummins and Allen 1998). Other authors, (most notably Merton and Perold 1993 and Perold 1999) have argued capital allocation is important but the allocation methods they propose do not yield unique results. In the talk I review the issue of capital allocation methods and then discuss two recent papers which derive theoretically appealing solutions to the capital allocation problem (Myers and Reed 2000 and Butsic 1999).

Peter Bank

Optimal Consumption Choice with Intertemporal Substitution

We consider the problem of finding an optimal consumption plan when markets are complete and when preferences for consumption are given by Hindy-Huang-Krebs utilities. Such preferences account for the economically indicated property of local substitution by replacing the rate of consumption-which “usually” appears as the argument of the felicity function- with the so-called level of satisfaction. This level is given as a weighted average of the investor’s past consumption and causes, thus, the utility functional to be no longer time-additive. We start by deriving Kuhn-Tucker-like first order conditions for optimal plans. These conditions are then used to prove that the optimal consumption plan consists in “tracking” some optional process which we call the minimal level of satisfaction. We relate this level to the state-price density via a stochastic backward equation which, in some special cases, allows an explicit solution. As a consequence, the Hindy-Huang-Krebs utility maximization problem also can be solved explicitly. It turns out that, depending on the respectively chosen stochastics, optimal consumption can occur in gulps at rates, or in singular form (Joint work with Frank Riedel).

Rüdiger Kiesel

Dimensions of Credit Risk

Knowing the relative riskiness of different types of credit exposure is important for policy-makers designing regulatory capital. To analyze the risk structure of credit exposures we extend a rating-based portfolio credit risk model to include spread risk. We investigate the econometric properties of the spread risk process and propose an estimator for its long horizon volatility. Using our extended portfolio credit risk model we show that, for high quality debt, most risk stems from spread changes

David Heath

Arbitrage: Now you see it, now you don't

Consider a discrete-time financial market ($0 \leq t \leq T$) with one riskless security and N risky securities. We suppose prices are positive and the initial state is known. Let $\mathcal{S} = (0, \infty)^N$ and $\Omega = \mathcal{S}^T$, $\mathcal{F}$ =Borel sets of Ω. Let $\mathcal{P}$ denote the set of all probabilities on $(\Omega, \mathcal{F})$, $\mathcal{P}^N$ those for which there is no arbitrage, and $\mathcal{P}^A$ those for which there is. We show that under the topology of weak convergence, $\mathcal{P}^N$ is dense in $\mathcal{P}$ and $\mathcal{P}^A$ is dense in $\mathcal{P}$ (Joint work with Eric Thorlacius Swiss Re).

Claudia Klüppelberg

Optimal Portfolios with Bounded Capital-at-Risk

We consider some continuous-time Markowitz type portfolio problems that consist of maximizing expected terminal wealth under the constraint of an upper bound for the capital-at-risk. In a Black-Scholes setting we obtain closed form explicit solutions and compare their form and implications to those of the classical continuous-time mean variance problem. We also consider some more general price processes which allow for larger fluctuations of the returns. This is joint work with Susanne Emmer and Ralf Korn.

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