Stochastic Calculus of Variations for Stochastic Partial Differential Equations

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This paper develops the stochastic calculus of variations for Hilbert space-valued solutions to stochastic evolution equations whose operators satisfy a coercivity condition. An application is made to the solutions of a class of stochastic pde's which includes the Zakai equation of nonlinear filtering. In particular, a Lie algebraic criterion is presented that implies that all finite-dimensional projections of the solution define random variables which admit a density. This criterion generalizes hypoellipticity-type conditions for existence and regularity of densities for finite-dimensional stochastic differential equations. © 1988 Academic Press, Inc.

1. Introduction

The stochastic calculus of variation is a calculus for functionals on Wiener space based on a concept of differentiation particularly suited to the invariance properties of Wiener measure. Wiener measure on the space of continuous $\mathbb{R}^d$-valued paths is quasi-invariant with respect to translation by a path γ iff γ is absolutely continuous with a square-integrable derivative. Hence, the proper definition of the derivative of a Wiener functional considers variation only in directions of such γ. Using this derivative and its higher-order iterates, one can develop Wiener functional Sobolev spaces, which are analogous in most respects to Sobolev spaces of functions over $\mathbb{R}^n$, and these spaces provide the right context for discussing "smoothness" and regularity of Wiener functionals. In particular, functionals defined by solving stochastic differential equations driven by a Wiener process are smooth in the stochastic calculus of variations sense; they are not generally smooth in a Fréchet sense, which ignores the structure of Wiener measure.

Malliavin [13, 14] initiated the stochastic calculus of variations to resolve, by stochastic methods, questions concerning the existence and

288

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Table of Contents Differential Equations And The Calculus Of Variations

1. Understanding the eBook Differential Equations And The Calculus Of Variations
    - The Rise of Digital Reading Differential Equations And The Calculus Of Variations
    - Advantages of eBooks Over Traditional Books
2. Identifying Differential Equations And The Calculus Of Variations
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Differential Equations And The Calculus Of Variations
    - User-Friendly Interface
4. Exploring eBook Recommendations from Differential Equations And The Calculus Of Variations
    - Personalized Recommendations
    - Differential Equations And The Calculus Of Variations User Reviews and Ratings
    - Differential Equations And The Calculus Of Variations and Bestseller Lists
5. Accessing Differential Equations And The Calculus Of Variations Free and Paid eBooks
    - Differential Equations And The Calculus Of Variations Public Domain eBooks
    - Differential Equations And The Calculus Of Variations eBook Subscription Services
    - Differential Equations And The Calculus Of Variations Budget-Friendly Options
6. Navigating Differential Equations And The Calculus Of Variations eBook Formats

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