

# The Calculus of Variations

- A **functional** maps a function to a value, e.g.

$$G[y] = \int_a^b F(y, y'; x) dx$$

- The calculus of variations can be used to extremise functionals.
- The **variation** of  $G$  is defined to be:

$$\begin{aligned} \delta G &= G[y+\delta y] - G[y] = \int_a^b \delta y \left( \frac{\partial F}{\partial y} \right) dx \quad \text{definition of functional derivative} \\ &= \int_a^b \left[ \frac{\partial F}{\partial y} \delta y + \frac{\partial F}{\partial y'} (\delta y)' \right] dx \quad \text{to first order} \\ &\quad \text{integrate by parts} \\ &= \left[ \frac{\partial F}{\partial y'} \delta y \right]_a^b + \int_a^b \delta y \left[ \frac{\partial F}{\partial y} - \frac{d}{dx} \left( \frac{\partial F}{\partial y'} \right) \right] dx \end{aligned}$$

Fixed endpoints  $\therefore \delta y(a) = \delta y(b) = 0$

- The functional is **stationary** when  $\delta G = 0$ , resulting in the **Euler-Lagrange equation**

$$\Rightarrow \boxed{\frac{\partial F}{\partial y} - \frac{d}{dx} \left( \frac{\partial F}{\partial y'} \right) = 0}$$

$\hookrightarrow$  in the special case where  $F$  has no  $x$ -dependence,  
 $\frac{\partial F}{\partial x} = \frac{\partial F}{\partial y} \frac{dy}{dx} + \frac{\partial F}{\partial y'} \frac{dy'}{dx} + \frac{\partial F}{\partial x} = \frac{\partial F}{\partial x} + y' \frac{\partial F}{\partial y} + y'' \frac{\partial F}{\partial y'}$

$\hookrightarrow$  sub in EL to give  $\frac{dF}{dx} = \frac{\partial F}{\partial x} + \frac{d}{dx} \left( y' \frac{\partial F}{\partial y'} \right)$

$\hookrightarrow$  so when  $\frac{\partial F}{\partial x} = 0$ :

$$\boxed{F - y' \frac{\partial F}{\partial y'} = \text{const}} \quad \text{Beltrami identity}$$

## Fermat's principle

- Fermat's principle states that light chooses a path of stationary time, or equivalently, stationary **optical path length**:

$$P = \int_a^b \mu(x) dl \quad \text{refractive index}$$

- For general 3D motion  $P(y, z) = \int_{x_0}^{x_1} \mu(y, z) \sqrt{1 + y'^2 + z'^2} dx$   
 $\hookrightarrow$  apply EL for both  $y(x)$  and  $z(x)$ .
- For sound waves, we need an expression for the acoustic path length.

## Hamilton's principle

- Lagrangian mechanics examines the motion of a point in **configuration space**, described by **generalised coordinates**  $\{q_i\}$ .
- The **action**  $S$  of a path is a functional of the **Lagrangian**  $L = T - V$ :

$$S = \int_a^b L(\{q_i\}, \{\dot{q}_i\}, \dots; t) dt$$

- Hamilton's principle states that the path in configuration space extremises  $S$  ('least action')

$$\Rightarrow \frac{\partial L}{\partial q_i} - \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) = 0 \quad i=1, \dots, N$$

$\hookrightarrow$  if  $L$  does not explicitly depend on time,  
 $L - \sum_i \dot{q}_i \frac{\partial L}{\partial \dot{q}_i} = \text{const}$

# Calculus Of Variations Lecture Notes Uni Leipzig

**Stefan Hildebrandt, Hermann Karcher**



## Calculus Of Variations Lecture Notes Uni Leipzig:

**Optimal Control Theory** Zhongjing Ma, Suli Zou, 2021-01-30 This book focuses on how to implement optimal control problems via the variational method. It studies how to implement the extrema of functional by applying the variational method and covers the extrema of functional with different boundary conditions involving multiple functions and with certain constraints etc. It gives the necessary and sufficient condition for the continuous time optimal control solution via the variational method. It solves the optimal control problems with different boundary conditions, analyzes the linear quadratic regulator tracking problems respectively in detail, and provides the solution of optimal control problems with state constraints by applying the Pontryagin's minimum principle, which is developed based upon the calculus of variations. And the developed results are applied to implement several classes of popular optimal control problems and say minimum time, minimum fuel, and minimum energy problems and so on. As another key branch of optimal control methods, it also presents how to solve the optimal control problems via dynamic programming and discusses the relationship between the variational method and dynamic programming for comparison. Concerning the system involving individual agents, it is also worth to study how to implement the decentralized solution for the underlying optimal control problems in the framework of differential games. The equilibrium is implemented by applying both Pontryagin's minimum principle and dynamic programming. The book also analyzes the discrete time version for all the above materials as well, since the discrete time optimal control problems are very popular in many fields.

*Felix Klein* Renate Tobies, 2021-06-23 About Felix Klein, the famous Greek mathematician Constantin Carathéodory once said: "It is only by illuminating him from all angles that one can come to understand his significance." The author of this biography has done just this. A detailed study of original sources has made it possible to uncover new connections, to create a more precise representation of this important mathematician, scientific organizer, and educational reformer, and to identify misconceptions. Because of his edition of Julius Plücker's work on line geometry and due to his own contributions to non-Euclidean geometry, Klein was already well known abroad before he received his first full professorship at the age of 23. By exchanging ideas with his most important cooperation partner, the Norwegian Sophus Lie, Klein formulated his Erlangen Program. Various other visionary programs followed in which Klein involved mathematicians from Germany and abroad. Klein was the most active promoter of Riemann's geometric-physical approach to function theory, but he also integrated the analytical approaches of the Weierstrass school into his arsenal of methods. Klein was a citizen of the world who repeatedly travelled to France, Great Britain, Italy, the United States, and elsewhere. Despite what has often been claimed, it must be emphasized that Klein expressly opposed national chauvinism. He promoted mathematically gifted individuals regardless of their nationality, religion, or gender. Many of his works have been translated into English, French, Italian, Russian, and other languages. More than 300 supporters from around the world made it possible for his portrait to be painted by the prominent impressionist Max Liebermann. Inspired by international

developments Klein paved the way for women to work in the field of mathematics He was instrumental in reforming mathematical education and he endorsed an understanding of mathematics that affirmed its cultural importance as well as its fundamental significance to scientific and technological progress Contributions to the Calculus of Variations ,1937

**Contributions to the Calculus of Variations, 1930-** Chicago (Ill.). University. Dept. of Mathematics,1965

**Geometric Analysis and Nonlinear Partial Differential Equations** Stefan Hildebrandt,Hermann Karcher,2012-12-06

This book is not a textbook but rather a coherent collection of papers from the field of partial differential equations Nevertheless we believe that it may very well serve as a good introduction into some topics of this classical field of analysis which despite of its long history is highly modern and well prospering Richard Courant wrote in 1950 It has always been a temptation for mathematicians to present the crystallized product of their thought as a deductive general theory and to relegate the individual mathematical phenomenon into the role of an example The reader who submits to the dogmatic form will be easily indoctrinated Enlightenment however must come from an understanding of motives live mathematical development springs from specific natural problems which can be easily understood but whose solutions are difficult and demand new methods or more general significance We think that many if not all papers of this book are written in this spirit and will give the reader access to an important branch of analysis by exhibiting interesting problems worth to be studied Most of the collected articles have an extensive introductory part describing the history of the presented problems as well as the state of the art and offer a well chosen guide to the literature This way the papers became lengthier than customary these days but the level of presentation is such that an advanced graduate student should find the various articles both readable and stimulating **Annales Scientifiques de L'École Normale Supérieure** École normale supérieure (France),2012

An Illustrative Introduction to Modern Analysis Nikolaos Katzourakis,Eugen Varvaruca,2018-01-02 Aimed primarily at undergraduate level university students An Illustrative Introduction to Modern Analysis provides an accessible and lucid contemporary account of the fundamental principles of Mathematical Analysis The themes treated include Metric Spaces General Topology Continuity Completeness Compactness Measure Theory Integration Lebesgue Spaces Hilbert Spaces Banach Spaces Linear Operators Weak and Weak Topologies Suitable both for classroom use and independent reading this book is ideal preparation for further study in research areas where a broad mathematical toolbox is required

*Continuum Models for Phase Transitions and Twinning in Crystals* Mario Pitteri,G. Zanzotto,2002-06-27 Continuum Models for Phase Transitions and Twinning in Crystals presents the fundamentals of a remarkably successful approach to crystal thermomechanics Developed over the last two decades it is based on the mathematical theory of nonlinear thermoelasticity in which a new viewpoint on material symmetry motivated by molecular theories plays a c **Multifield Problems** A.-M. Sändig,W. Schiehlen,W.L. Wendland,2013-06-29 The simulation of complex engineering problems often involves an interaction or coupling of individual phenomena which are traditionally related by themselves to separate fields

of applied mechanics Typical examples of these so called multifield problems are the thermo mechanical analysis of solids with coupling between mechanical stress analysis and thermal heat transfer processes the simulation of coupled deformation and fluid transport mechanisms in porous media the prediction of mass transport and phase transition phenomena of mixtures the analysis of sedimentation processes based on an interaction of particle dynamics and viscous flow the simulation of multibody systems and fluid structure interactions based on solid to solid and solid to fluid contact mechanisms

Lecture Notes on Pure Mathematics. Convex Sets Fritz John,1948     *Acta mathematica* ,1959     Analytical and Numerical Approaches to Mathematical Relativity Jörg Frauendiener,Domenico J. W. Giulini,Volker Perlick,2006-03-28  
General relativity ranks among the most accurately tested fundamental theories in all of physics Deficiencies in mathematical and conceptual understanding still exist hampering further progress This book collects surveys by experts in mathematical relativity writing about the current status of and problems in their fields There are four contributions for each of the following mathematical areas differential geometry and differential topology analytical methods and differential equations and numerical methods     **Reachable Regions and Optimal Controls** Donald Ray Snow,1964     **Mathematical Reviews** ,1994     **Biographical Memoirs** National Academy of Sciences (U.S.),1958 List of papers contained in v 1 9 is given in National Academy of Sciences Proceedings Index 1915 24 1926     Electromagnetic Fields Jean Bladel,Jean Van Bladel,1964     *Index of conference proceedings received by the BLL.* British Library. Lending Division,1976  
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