

# Automatic Differentiation of Optimization Algorithms with Time-Varying Updates

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## Abstract

Numerous Optimization Algorithms have a time-varying update rule thanks to, for instance, a changing step size, momentum parameter or, Hessian approximation. In this paper, we apply unrolled or automatic differentiation to a time-varying iterative process and provide convergence (rate) guarantees for the resulting derivative iterates. We adapt these convergence results and apply them to proximal gradient descent with variable step size and FISTA when solving partly smooth problems. We confirm our findings numerically by solving  $\ell_1$  and  $\ell_2$ -regularized linear and logistic regression respectively. Our theoretical and numerical results show that the convergence rate of the algorithm is reflected in its derivative iterates.

## 1 Introduction

For some parameter  $\mathbf{u} \in \mathcal{U}$ , we consider the following parametric iterative process

$$\mathbf{x}^{(k+1)}(\mathbf{u}) := \mathcal{A}(\mathbf{x}^{(k)}(\mathbf{u}), \mathbf{u}), \quad (\mathcal{R})$$

for  $k \geq 0$ , where  $\mathbf{x}^{(0)} \in \mathcal{X}$  is the initial iterate and  $\mathcal{A}: \mathcal{X} \times \mathcal{U} \rightarrow \mathcal{X}$  is the update mapping. The iterates  $\mathbf{x}^{(k)}(\mathbf{u})$  generated by  $(\mathcal{R})$  depend on  $\mathbf{u}$  due to the dependence of  $\mathcal{A}$  on  $\mathbf{u}$ . The goal of performing the iterations  $(\mathcal{R})$  is mainly to solve the non-linear equation

$$\mathbf{x} = \mathcal{A}(\mathbf{x}, \mathbf{u}), \quad (\mathcal{R}_*)$$

with respect to  $\mathbf{x}$  for each parameter  $\mathbf{u}$ . A simple example is gradient descent with appropriate step size  $\alpha > 0$  where we define  $\mathcal{A}(\mathbf{x}, \mathbf{u}) := \mathbf{x} - \alpha \nabla_{\mathbf{x}} F(\mathbf{x}, \mathbf{u})$  for solving a parametric optimization problem of the form

$$\min_{\mathbf{x} \in \mathcal{X}} F(\mathbf{x}, \mathbf{u}), \quad (\mathcal{P})$$

with a smooth objective  $F: \mathcal{X} \times \mathcal{U} \rightarrow \mathbb{R}$ . In this case  $(\mathcal{R}_*)$  reduces to the optimality condition  $\nabla_{\mathbf{x}} F(\mathbf{x}, \mathbf{u}) = 0$ .

# Automatic Differentiation Of Algorithms

**Andreas Griewank**



## **Automatic Differentiation Of Algorithms:**

Automatic Differentiation of Algorithms George Corliss,Christele Faure,Andreas Griewank,Laurent Hascoet,Uwe Naumann,2002-01-08 A survey book focusing on the key relationships and synergies between automatic differentiation AD tools and other software tools such as compilers and parallelizers as well as their applications The key objective is to survey the field and present the recent developments In doing so the topics covered shed light on a variety of perspectives They reflect the mathematical aspects such as the differentiation of iterative processes and the analysis of nonsmooth code They cover the scientific programming aspects such as the use of adjoints in optimization and the propagation of rounding errors They also cover implementation problems      Automatic Differentiation of Algorithms Andreas Griewank,1991 Mathematics of Computing Numerical Analysis      *Evaluating Derivatives* Andreas Griewank,Andrea Walther,2008-11-06 This title is a comprehensive treatment of algorithmic or automatic differentiation The second edition covers recent developments in applications and theory including an elegant NP completeness argument and an introduction to scarcity      **Automatic differentiation of algorithms : theory, implementation, and application [proceedings of the First SIAM Workshop on Automatic Differentiation, held in Breckenridge, Colorado, January 6-8, 1991/ edited by Andreas Griewank, George F. Corliss** Andreas Griewank,1991      *Recent Advances in Algorithmic Differentiation* Shaun Forth,Paul Hovland,Eric Phipps,Jean Utke,Andrea Walther,2012-07-30 The proceedings represent the state of knowledge in the area of algorithmic differentiation AD The 31 contributed papers presented at the AD2012 conference cover the application of AD to many areas in science and engineering as well as aspects of AD theory and its implementation in tools For all papers the referees selected from the program committee and the greater community as well as the editors have emphasized accessibility of the presented ideas also to non AD experts In the AD tools arena new implementations are introduced covering for example Java and graphical modeling environments or join the set of existing tools for Fortran New developments in AD algorithms target the efficiency of matrix operation derivatives detection and exploitation of sparsity partial separability the treatment of nonsmooth functions and other high level mathematical aspects of the numerical computations to be differentiated Applications stem from the Earth sciences nuclear engineering fluid dynamics and chemistry to name just a few In many cases the applications in a given area of science or engineering share characteristics that require specific approaches to enable AD capabilities or provide an opportunity for efficiency gains in the derivative computation The description of these characteristics and of the techniques for successfully using AD should make the proceedings a valuable source of information for users of AD tools      *ADOL-C* Andreas Griewank,David Juedes,Jay Srinivasan,1991      *Automatic Differentiation* Louis B. Rall,1981      **Principles of Data Assimilation** Seon Ki Park,Milija Zupanski,2022-09-29 Data assimilation is theoretically founded on probability statistics control theory information theory linear algebra and functional analysis At the same time data assimilation is a very practical subject given its goal of

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*Automatic Differentiation in MATLAB for Optimal Control Algorithms* M.M.T. van Lieshout,2008      **Algorithmic**

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**Automatic Differentiation** L. B. Rall,2014-01-15      *SIAM Journal on Scientific Computing* ,2001      Applied Parallel and Scientific Computing Pekka Manninen,Per Öster,2013-02-12 This volume constitutes the refereed proceedings of the 11th International Conference on Applied Parallel and Scientific Computing PARA 2012 held in Helsinki Finland in June 2012 The 35 revised full papers presented were selected from numerous submissions and are organized in five technical sessions covering the topics of advances in HPC applications parallel algorithms performance analyses and optimization application of parallel computing in industry and engineering and HPC interval methods In addition three of the topical minisymposia are described by a corresponding overview article on the minisymposia topic In order to cover the state of the art of the field at the end of the book a set of abstracts describe some of the conference talks not elaborated into full articles      **Automatic Backward Differentiation for American Monte-Carlo Algorithms - ADD for Conditional Expectations and Indicator Functions** Christian P. Fries,2017 In this note we derive a modified backward automatic differentiation a k a adjoint

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