Package ‘ManifoldOptim’

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Description An R interface to version 0.3 of the 'ROPTLIB' optimization library (see <http://www.math.fsu.edu/~whuang2> for more information). Optimize real-valued functions over manifolds such as Stiefel, Grassmann, and Symmetric Positive Definite matrices.
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Design of C++ code

Overview of important files.

Description

Internal design of the ManifoldOptim portion of the embedded C++ code. Most ManifoldOptim users should not need this. ROPTLIB source code is also included in this package, but is not described here; see Huang et al (2016a) for documentation on that portion of the code.

Details

src/ManifoldOptim/BrockettProblem.cpp: The Brockett problem, written as a module that can be invoked from within the ManifoldOptim package. This serves as an example for package authors who wish to expose modules to their users. Code to invoke this example from outside of the ManifoldOptim package is provided in inst/examples/brockett/cpp_pkg.

src/ManifoldOptim/ManifoldOptim.cpp: Contains the main function ManifoldOptim which takes a problem constructed in R, sets it up in ROPTLIB, runs it, and returns the result.

src/ManifoldOptim/ManifoldOptimModule.cpp: Defines an Rcpp module for ManifoldOptim which exposes C++ classes such as RProblem. This module provides the most common means in which R users will interact with ManifoldOptim.

src/ManifoldOptim/ManifoldFactory.h: The GetManifold function constructs a Manifold object based on its name and dimensions. Manifold classes are defined in ROPTLIB.

src/ManifoldOptim/ProblemAdapter.h: Defines the ProblemAdapter class, which takes a ManifoldOptimProblem, which is defined in the ManifoldOptim API, and plugs it into the ROPTLIB API as an ROPTLIB Problem subclass.

src/ManifoldOptim/RProblem.h: Defines the RProblem class, which allows the objective, gradient, and Hessian functions to be defined in R. When a function in the ROPTLIB library invokes the objective, gradient, or Hessian, this class invokes the appropriate function in R.

src/ManifoldOptim/SolverFactory.h: The GetSolver function constructs a Solver object based on its name, a given Problem, an initial value, and an initial Hessian. Solver classes are defined in ROPTLIB.

src/ManifoldOptim/Util.h: Defines a few utility functions, especially to assist in translating between the ManifoldOptim C++ API and the ROPTLIB API.

src/ManifoldOptim/VariableFactory.h: The GetVariable function returns an optimization variable suitable for a given Manifold, based on its name and dimension. Optimization variables for supported Manifolds are defined in ROPTLIB.
inst/include/ManifoldOptimException.h: Defines ManifoldOptimException, which is a subclass of STL exception.

inst/include/ManifoldOptim.h: For users of the ManifoldOptim C++ API, this is the main header file to include. For an example, see inst/examples/brockett/cpp_sourceCpp/.

inst/include/ManifoldOptimProblem.h: Defines ManifoldOptimProblem, which is the base class for all optimization problems in the ManifoldOptim API. This class facilitates writing problems with Armadillo, which can be instantiated and manipulated in R, and solved through ROPTLIB. This class assumes only that the optimization variable is a one-dimensional vector; the user must reshape it into the appropriate form (e.g. a matrix or list of matrices) when evaluating the objective, gradient, and Hessian functions.

References


get.deriv.params

Get parameters to initialize numerical differentiation

Description

Get parameters to initialize numerical differentiation

Usage

get.deriv.params(EpsNumericalGrad = 1e-06, EpsNumericalHessEta = 1e-04)

Arguments

EpsNumericalGrad

The "epsilon" used to perturb the objective function when computing numerical gradients

EpsNumericalHessEta

The "epsilon" used to perturb the objective function when computing numerical HessEta

Value

List containing input arguments for numerical differentiation
get.manifold.params    Get parameters to initialize manifold

Description
Get parameters to initialize manifold

Usage
get.manifold.params(IsCheckParams = FALSE)

Arguments
IsCheckParams    Should internal manifold object check inputs and print summary message before optimization (TRUE or FALSE)

Value
List containing input arguments for manifold

get.solver.params    Get parameters to initialize solver

Description
Get parameters to initialize solver

Usage
get.solver.params(isconvex = FALSE, DEBUG = 0, Tolerance = 1e-04, Max_Iteration = 1000, IsCheckParams = FALSE, IsCheckGradHess = FALSE, ...)

Arguments
isconvex    Indicator for whether the function is convex (TRUE or FALSE)
DEBUG    Verbosity level in \{0,1,2,3\}. Use 0 for quietest with no messages printed. Use 3 for most verbose,
Tolerance    Tolerance used to assess convergence. See Huang et al (2016b) for details on how this is used,
Max_Iteration    Maximum iterations to be used by the solver (a non-negative integer),
IsCheckParams    Should solver check inputs and print summary message before optimization (TRUE or FALSE),
IsCheckGradHess    Check correctness of the gradient and Hessian functions (TRUE or FALSE).
Additional arguments to pass to the solver. These are not validated by the `get.solver.params` function. Users should refer to the C++ library's user manual for available arguments.

**Details**

Solver-specific parameters may also be added to the object returned from `get.solver.params`, via standard list manipulation. Interested users should refer to Huang et al (2016b) for available options.

**Value**

List containing input arguments for solver

**References**


Arguments

\( n \)  
Dimension for manifold object (see Details)

\( p \)  
Dimension for manifold object (see Details)

\( \text{numofmani} \)  
Multiplicity of this space. For example, use \( \text{numofmani} = 2 \) if problem requires 2 points from this manifold

\( \text{ParamSet} \)  
A positive integer indicating a set of properties for the manifold which can be used by the solver. See Huang et al (2016b) for details.

\( m \)  
Dimension for manifold object (see Details)

Details

The functions define manifolds as follows:

- \( \text{get.stiefel.defn} \): Stiefel manifold \( \{ X \in R^{n \times p} : X^T X = I \} \)
- \( \text{get.grassmann.defn} \): Grassmann manifold of \( p \)-dimensional subspaces in \( R^n \)
- \( \text{get.spd.defn} \): Manifold of \( n \times n \) symmetric positive definite matrices
- \( \text{get.sphere.defn} \): Manifold of \( n \)-dimensional vectors on the unit sphere
- \( \text{get.euclidean.defn} \): Euclidean \( R^{n \times m} \) space
- \( \text{get.lowrank.defn} \): Low-rank manifold \( \{ X \in R^{n \times m} : \text{rank}(X) = p \} \)
- \( \text{get.orthgroup.defn} \): Orthonormal group \( \{ X \in R^{n \times n} : X^T X = I \} \)

Value

List containing input arguments and name field denoting the type of manifold

References


Description

Optimize a function on a manifold.
Usage

```r
manifold.optim(prob, mani.defn, method = "LRBFGS",
    mani.params = get.manifold.params(), solver.params = get.solver.params(),
    deriv.params = get.deriv.params(), x0 = NULL, H0 = NULL,
    has.hhr = FALSE)
```

```r
moptim(prob, mani.defn, method = "LRBFGS",
    mani.params = get.manifold.params(), solver.params = get.solver.params(),
    deriv.params = get.deriv.params(), x0 = NULL, H0 = NULL,
    has.hhr = FALSE)
```

Arguments

- **prob**  
  Problem definition
- **mani.defn**  
  Either a Product manifold definition or one of the Manifold definitions
- **method**  
  Name of optimization method. Currently supported methods are:
  - "LRBFGS": Limited-memory RBFGS
  - "LRTRSR1": Limited-memory RTRSR1
  - "RBFGS": Riemannian BFGS
  - "RBroydenFamily": Riemannian Broyden family
  - "RCG": Riemannian conjugate gradients
  - "RNewton": Riemannian line-search Newton
  - "RSD": Riemannian steepest descent
  - "RTRNewton": Riemannian trust-region Newton
  - "RTRSD": Riemannian trust-region steepest descent
  - "RTRTRSR1": Riemannian trust-region symmetric rank-one update
  - "RWRBFGS": Riemannian BFGS
  See Huang et al (2016a, 2016b) for details.
- **mani.params**  
  Arguments to configure the manifold. Construct with `get.manifold.params`
- **solver.params**  
  Arguments to configure the solver. Construct with `get.solver.params`
- **deriv.params**  
  Arguments to configure numerical differentiation for gradient and Hessian, which are used if those functions are not specified. Construct with `get.deriv.params`
- **x0**  
  Starting point for optimization. A numeric vector whose dimension matches the total dimension of the overall problem
- **H0**  
  Initial value of Hessian. A $d \times d$ matrix, where $d$ is the dimension of $x0$
- **has.hhr**  
  Indicates whether to apply the idea in Huang et al (2015) section 4.1 (TRUE or FALSE)

Details

`moptim` is an alias for `manifold.optim`. 
Value

- **xopt**: Point returned by the solver
- **fval**: Value of the function evaluated at xopt
- **normg**: Norm of the final gradient
- **normgfg**: Norm of the gradient at final iterate divided by norm of the gradient at initiate iterate
- **iter**: Number of iterations taken by the solver
- **num.obj.eval**: Number of function evaluations
- **num.grad.eval**: Number of gradient evaluations
- **nR**: Number of retraction evaluations
- **nV**: Number of occasions in which vector transport is first computed
- **nVp**: Number of remaining computations of vector transport (excluding count in nV)
- **nH**: Number of actions of Hessian
- **elapsed**: Elapsed time for the solver (in seconds)

References


Examples

```r
## Not run:
# ------ Example with objective and gradient written in R ------
set.seed(1234)

p <- 5; n <- 150
B <- matrix(rnorm(n*n), nrow=n)
B <- B + t(B)
D <- diag(p:1, p)

tx <- function(x) { matrix(x, n, p) }
f <- function(x) { X <- tx(x); Trace( t(X) %*% B %*% X %*% D ) }
g <- function(x) { X <- tx(x); 2 * B %*% X %*% D }

mod <- Module("ManifoldOptim_module", PACKAGE = "ManifoldOptim")
prob <- new(mod$RProblem, f, g)

x0 <- as.numeric(orthonorm(matrix(rnorm(n*p), nrow=n, ncol=p)))
mani.params <- get.manifold.params(IsCheckParams = TRUE)
solver.params <- get.solver.params(IsCheckParams = TRUE)
```
### Example with objective and gradient written in C++

```c++
set.seed(1234)
p <- 5; n <- 150
B <- matrix(rnorm(n*n), nrow=n)
B <- B + t(B)  # force symmetric
d <- diag(p:1, p)

# The problem class is written in C++. Get a handle to it and set it up from R
Rcpp::sourceCpp(code = 
  //[[Rcpp::depends(RcppArmadillo,ManifoldOptim)]
#include <RcppArmadillo.h>
#include <ManifoldOptim.h>

using namespace Rcpp;
using namespace arma;

class BrockettProblem : public MatrixManifoldOptimProblem
{
public:
  BrockettProblem(const arma::mat& B, const arma::mat& D)
    : MatrixManifoldOptimProblem(false, true), m_B(B), m_D(D) { }

virtual ~BrockettProblem() { }

double objFun(const arma::mat& X) const {
  return arma::trace(X.t() * m_B * X * m_D);
}

arma::mat gradFun(const arma::mat& X) const {
  return 2 * m_B * X * m_D;
}

const arma::mat& GetB() const { return m_B; }
const arma::mat& GetD() const { return m_D; }

private:
  arma::mat m_B;
  arma::mat m_D;
};
```
Orthonormalize the columns of a matrix

Description

Orthonormalize the columns of a matrix

Usage

orthonorm(u)

Arguments

u A matrix
print.ManifoldOptim

---

**Description**

Print results

**Usage**

```r
## S3 method for class 'ManifoldOptim'
print(x, ...)
```

**Arguments**

- `x` A ManifoldOptim object output by manifold.optim.
- `...` Not currently used

---

**Problem definition**

**Description**

Define a problem for ManifoldOptim to solve.

**Details**

A problem definition contains an objective function $f$ and a gradient function $g$. The gradient $g$ is computed as if $f$ is defined on a Euclidean space. If $g$ is not specified it will be computed numerically, which is potentially much slower.

The easiest way to define a problem is completely in R. Example 1 below illustrates how to construct a problem using a given $f$ and $g$. Example 2 constructs the same problem without providing $g$. The Rcpp Module framework (Eddelbuettel, 2013) creates underlying C++ objects necessary to invoke the ROPTLIB library.

The performance of solving an RProblem may be too slow for some applications; here, the C++ optimizer calls R functions, which requires some overhead. A faster alternative is to code your problem in C++ directly, and allow it to be manipulated in R. An example is provided in this package, under tests/brockett/cpp_standalone/. Example 3 below shows how to instantiate this problem.

Package authors may want to use ManifoldOptim within a package to solve a problem written in C++. In this case, the author would probably not want to use sourceCpp, but instead have the problem compiled when the package was installed. An example is provided within this package; tests/brockett/cpp_pkg/driver.R instantiates the problem defined in:

`src/ManifoldOptim/BrockettProblem.cpp`. 
Product manifold definition

Description

Define a product manifold composed of simpler manifolds

Usage

gget.product.defn(...)  

Arguments

... One or more simpler Manifold definitions
Product manifold definition

Value

List containing manifold definitions for the product manifold

Examples

```r
mani.defn1 <- get.product.defn(get.sphere.defn(n=5), get.spd.defn(n=5))
mani.defn2 <- get.product.defn(
  get.stiefel.defn(n=10, p=5),
  get.stiefel.defn(n=7, p=3),
  get.grassmann.defn(n=10, p=5)
)

## Not run:
# --- Estimate jointly: Sigma in SPD manifold and mu in sphere manifold ---
library(mvtnorm)
n <- 400
p <- 3
mu.true <- rep(1/sqrt(p), p)
Sigma.true <- diag(2,p) + 0.1
y <- rmvnorm(n, mean = mu.true, sigma = Sigma.true)

tx <- function(x) {
  idx.mu <- 1:p
  idx.S <- 1:p^2 + p
  mu <- x[idx.mu]
  S <- matrix(x[idx.S], p, p)
  list(mu = mu, Sigma = S)
}

f <- function(x) {
  par <- tx(x)
  -sum(dmvnorm(y, mean = par$mu, sigma = par$Sigma, log = TRUE))
}

mod <- Module("ManifoldOptim_module", PACKAGE = "ManifoldOptim")
prob <- new(mod$RProblem, f)

mu0 <- diag(1, p)[,1]
Sigma0 <- diag(1, p)
x0 <- c(mu0, as.numeric(Sigma0))

mani.defn <- get.product.defn(get.sphere.defn(p), get.spd.defn(p))
mani.params <- get.manifold.params()
solver.params <- get.solver.params(isconvex = TRUE)

res <- manifold.optim(prob, mani.defn, method = "LBFGS",
  mani.params = mani.params, solver.params = solver.params, x0 = x0)

## End(Not run)
```
Trace

*Compute the trace of a square matrix*

**Description**

Compute the trace of a square matrix

**Usage**

\[ \text{Trace}(X) \]

**Arguments**

- \( X \) A matrix
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