Package ‘ManifoldOptim’

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Type Package

Title An R Interface to the 'ROPTLIB' Library for Riemannian Manifold Optimization

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Description An R interface to version 0.3 of the 'ROPTLIB' optimization library (see <https://www.math.fsu.edu/~whuang2/> for more information). Optimize real-valued functions over manifolds such as Stiefel, Grassmann, and Symmetric Positive Definite matrices. For details see Martin et. al. (2020) <doi:10.18637/jss.v093.i01>. Note that the optional ldr package used in some of this package's examples can be obtained from either JSS <https://www.jstatsoft.org/index.php/jss/article/view/v061i03/2886> or from the CRAN archives <https://cran.r-project.org/src/contrib/Archive/ldr/ldr_1.3.3.tar.gz>.

License GPL (>= 2)

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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.
get.deriv.params

get.deriv.params

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

References


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


Description

Get definitions for simple manifolds
Usage

get.stiefel.defn(n, p, numofmani = 1L, ParamSet = 1L)
get.grassmann.defn(n, p, numofmani = 1L, ParamSet = 1L)
get.spd.defn(n, numofmani = 1L, ParamSet = 1L)
get.sphere.defn(n, numofmani = 1L, ParamSet = 1L)
get.euclidean.defn(n, m, numofmani = 1L, ParamSet = 1L)
get.lowrank.defn(n, m, p, numofmani = 1L, ParamSet = 1L)
get.orthgroup.defn(n, numofmani = 1L, ParamSet = 1L)

Arguments

n  Dimension for manifold object (see Details)
p  Dimension for manifold object (see Details)
umofmani Multiplicity of this space. For example, use numofmani = 2 if problem requires 2 points from this manifold
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:

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

Value

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

References

manifold.optim  


---

**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
• "RBrodyenFamily": 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
• "RTRSR1": Riemannian trust-region symmetric rank-one update
• "RWRBFGS": Riemannian BFGS

See Huang et al (2016a, 2016b) for details.

**Details**

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

**Value**

- `xopt`: Point returned by the solver
- `fval`: Value of the function evaluated at `xopt`
- `normgf`: Norm of the final gradient
- `normgfgf0`: Norm of the gradient at final iterate divided by norm of the gradient at initial 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)

f <- function(x) { X <- 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) mani.defn <- get.stiefel.defn(n, p)

res <- manifold.optim(prob, mani.defn, method = "RTRSR1", mani.params = mani.params, solver.params = solver.params, x0 = x0)
print(res)
head(tx(res$xopt))

## End(Not run)
## Not run:
library(ManifoldOptim)
library(RcppArmadillo)

# ----- Example with objective and gradient written in 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;
};

RCPP_MODULE(Brockett_module) {
    class_<BrockettProblem>("BrockettProblem")
        .constructor<mat,mat>()
        .method("objFun", &BrockettProblem::objFun)
        .method("gradFun", &BrockettProblem::gradFun)
        .method("GetB", &BrockettProblem::GetB)
        .method("GetD", &BrockettProblem::GetD)
    ;
}

prob <- new(BrockettProblem, B, D)
X0 <- orthonorm(matrix(rnorm(n*p), nrow=n, ncol=p))
x0 <- as.numeric(X0)
tx <- function(x) { matrix(x, n, p) }
mani.params <- get.manifold.params(IsCheckParams = TRUE)
solver.params <- get.solver.params(DEBUG = 0, Tolerance = 1e-4,
```r
Max_Iteration = 1000, IsCheckParams = TRUE, IsCheckGradHess = FALSE)
mani.defn <- get.stiefel.defn(n, p)

res <- manifold.optim(prob, mani.defn, method = "RTRSR1",
mani.params = mani.params, solver.params = solver.params, x0 = x0)
print(res)
head(tx(res$xopt))
## End(Not run)

orthonorm

Function to orthonormalize the columns of a matrix.

Usage

```r
orthonorm(u)
```n\n
Arguments

- `u` A matrix

print.ManifoldOptim

Print summary from manifold.optim results.

Usage

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

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.

References


Examples

```r
## Not run:
# --- Example 1: Define a problem in R ---
f <- function(x) { ... }
g <- function(x) { ... }
mod <- Module("ManifoldOptim_module", PACKAGE = "ManifoldOptim")
prob <- new(mod$RProblem, f, g)
```
Product manifold definition

---

Example 2: Define a problem in R without specifying gradient ---

```r
f <- function(x) { ... }
mod <- Module("ManifoldOptim_module", PACKAGE = "ManifoldOptim")
prob <- new(mod$RProblem, f)
```

Example 3: Instantiate a problem written in C++ ---

```r
p <- 5; n <- 150
B <- matrix(rnorm(n*n), nrow=n)
B <- B + t(B) # force symmetric
D <- diag(p:1, p)
Rcpp::sourceCpp("brockett_problem.cpp")
prob <- new(BrockettProblem, B, D)
```

---

Product manifold definition

### Description

Define a product manifold composed of simpler manifolds

### Usage

```r
get.product.defn(...)
```

### Arguments

```
...
```

One or more simpler Manifold definitions

### 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)

tax <- 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**

`Trace(X)`

**Arguments**

- **X** A matrix
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