

# Unconstrained Optimization

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## 1 Program Description

## 2 Testing Results

lets test this out  $1/2$   $1/2$  or  $\frac{1}{2}$  because then if I have a bunch of stuff on another line it doesn't clash like it will if I use the normal math call. I guess I can see how that would be better... Here is the test text to display

## 3 Matlab Code

### 3.0.1 Fminun Routine

```
1  function [xopt, fopt, exitflag] = fminun(obj, gradobj, x0, stoptol, algoflag)
2
3      % get function and gradient at starting point
4      [n,~] = size(x0); % get number of variables
5      f = obj(x0); % get the value of the function at x0
6      grad = gradobj(x0);
7      x = x0;
8      %set starting step length
9      alpha = 0.05;
10
11     while (all(grad(:) > stoptol))
12
13         if (algoflag == 1)      % steepest descent
14             s = srchsd(grad);
15         end
16
17         if (algoflag == 2)
18             % use conjugate gradient method
19         end
20
21         if (algoflag == 3)
22             % use quasi-Newton method
23         end
24
25         % find the proper alpha level
26         minVal = inf;
27         lastStepVal = -inf;
28         while (minVal >= lastStepVal)
29
30         end
```

```

31
32     alphaOpt = alpha;
33     % take a step
34     xnew = x + alphaOpt*s;
35     fnew = obj(xnew);
36     grad = gradobj(xnew);
37     f = fnew
38     x = xnew
39
40 end
41 xopt = xnew;
42 fopt = fnew;
43 exitflag = 0;
44 end
45
46 % get steepest descent search direction as a column vector
47 function [s] = srchsd(grad)
48     mag = sqrt(grad'*grad);
49     s = -grad/mag;
50 end

```

### 3.0.2 Driver

```

1  function [] = fminunDriv()
2  %-----Example Driver program for fminun-----
3      clear;
4
5      global nobj ngrad
6      nobj = 0; % counter for objective evaluations
7      ngrad = 0.; % counter for gradient evaluations
8      x0 = [1.; 1.]; % starting point, set to be column vector
9      algoflag = 1; % 1=steepest descent; 2=conjugate gradient; 3=BFGS quasi-Newton
10     stoptol = 1.e-3; % stopping tolerance, all gradient elements must be < stoptol
11
12
13     % ----- call fminun-----
14     [xopt, fopt, exitflag] = fminun(@obj, @gradobj, x0, stoptol, algoflag);
15
16     xopt
17     fopt
18
19     nobj
20     ngrad
21 end
22
23 % function to be minimized
24 function [f] = obj(x)
25     global nobj
26     %example function
27     %min of 9.21739 as [-0.673913, 0.304348]^T
28     f = 12 + 6*x(1) - 5*x(2) + 4*x(1)^2 - 2*x(1)*x(2) + 6*x(2)^2;
29     nobj = nobj + 1;
30 end
31

```

```

32 % get gradient as a column vector
33 function [grad] = gradobj(x)
34     global ngrad
35     %gradient for function above
36     grad(1,1) = 6 + 8*x(1) - 2*x(2);
37     grad(2,1) = -5 - 2*x(1) + 12*x(2);
38     ngrad = ngrad + 1;
39 end

```

**ME 575**  
**Homework #3 Unconstrained Optimization**  
**Due Feb 7 at 2:50 p.m.**

Description

Write an optimization routine in MATLAB (required) that performs unconstrained optimization. Your routine should include the ability to optimize using the methods,

- steepest descent
- conjugate gradient
- BFGS quasi-Newton

Your program should be able to work on both quadratic and non-quadratic functions of  $n$  variables. To determine how far to step, you may use a line search method (such as the quadratic fit given in the notes), a trust region method, or a combination of these. You will be evaluated both on how theoretically sound your program is and how well it performs.

You should use good programming style, such as selecting appropriate variable names, making the program somewhat modular (employing function routines appropriately) and documenting your code.

You will provide test results for your program on the two functions given here. In addition, you will turn in your function so we can test it on other functions or on different starting points.

Testing

1) Test your program on the following quadratic function of three variables:

$$f = 20 + 3x_1 - 6x_2 + 8x_3 + 6x_1^2 - 2x_1x_2 - x_1x_3 + x_2^2 + 0.5x_3^2$$

The conjugate gradient and quasi-Newton methods should be able to solve this problem in three iterations. Show your data for each iteration (starting point, function value, search direction, step length, number of evaluations of objective) for these two methods starting from the point  $\mathbf{x}^T = [10, 10, 10]$ . In addition, give data for five steps of steepest descent. At the optimum the absolute value of all elements of the gradient vector should be below  $1.e-5$ . Indicate the total number of objective evaluations and gradient evaluations taken by each method.

2) Test your program on the following non-quadratic function (Rosenbrock's function) of two variables:

$$f = 100(x_2 - x_1^2)^2 + (1 - x_1)^2$$

Starting from the point  $\mathbf{x}^T = [-1.5, 1]$ , show the steps of the methods on a contour plot. Show 20 steps of steepest descent. Continue with the conjugate gradient and quasi-Newton methods until the optimum is reached at  $\mathbf{x}^T = [1, 1]$  and the absolute value of all elements of

the gradient vector is below  $1.e-3$ . Indicate the total number of objective evaluations and gradient evaluations taken by each method.

### MATLAB Stuff

Your function will be called `fminun`. It will receive and pass back the following arguments:

```
[xopt, fopt, exitflag] = fminun(@obj, @gradobj, x0, stoptol, algoflag);
```

#### Inputs:

`@obj` = function handle for the objective we are minimizing (we will use `obj`) The calling statement for `obj` looks like,

```
f = obj(x);
```

`@gradobj` = function handle for the function that evaluates gradients of the objective (we will use `gradobj`, see example) The calling statement for `gradobj` looks like,

```
grad = gradobj(x);
```

Note that `grad` is passed back as a column vector.

`x0` = starting point (column vector)

`stoptol` = stopping tolerance. I will set this to  $1.e-3$ , unless this proves too restrictive. The absolute value of all elements of your gradient vector should be less than this value at the optimum.

`algoflag` = 1 for steepest descent, =2 for conjugate gradient, =3 for quasi-Newton.

#### Outputs:

`xopt` = optimal value of `x` (column vector)

`fopt` = optimal value of the objective

`exitflag` = 0 if algorithm terminated successfully; otherwise =1. Your algorithm should exit (=1) if it has exceeded more than 500 evaluations of the objective.

Attached is an example “driver” routine and example `fminun` routine to get you started. You can copy these from Learning Suite > Content > MATLAB Examples.

### Grading

Grading: Your routine will be graded based on two criteria: 1) Soundness of your methodology and implementation as evidenced by your write-up and code (50%), and performance on test functions (50%). The performance score will be based 70% on accuracy (identifying the optimum) and 30% on efficiency (number of objective evaluations plus  $n$ \*number of gradient evaluations).

Turn in, in one report through Learning Suite:

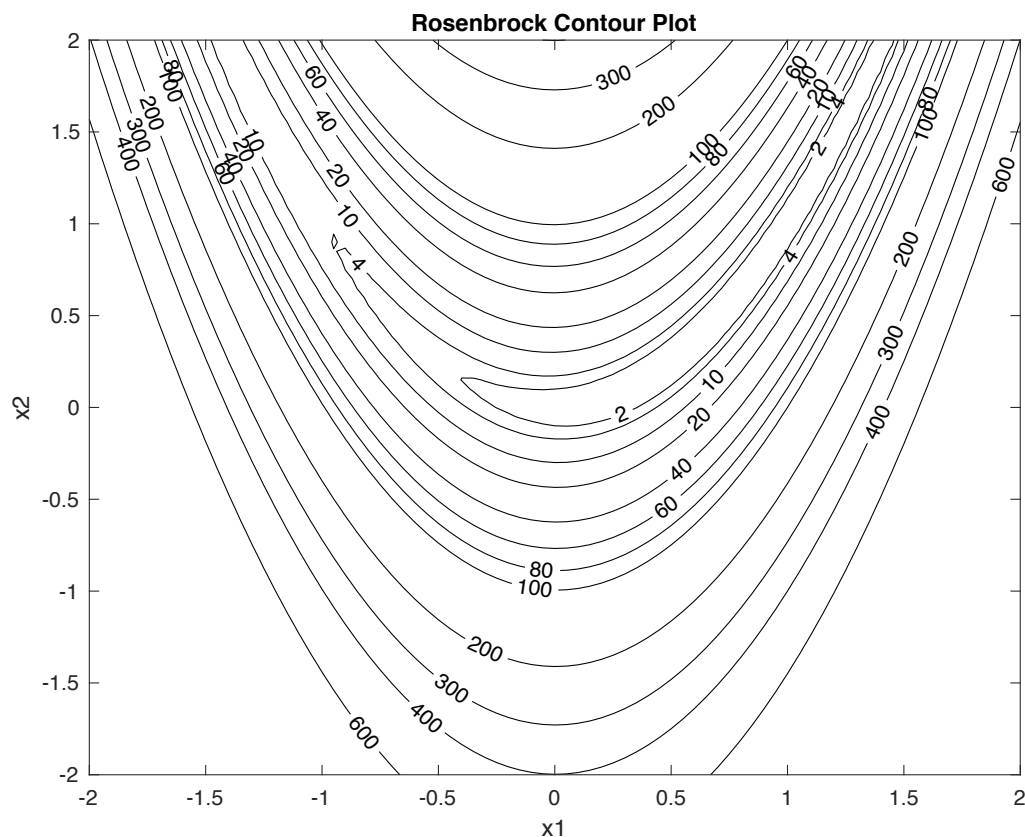
1. A brief written description of your program, including discussion of each of the three methods. This should not be longer than a page (single-spaced). You may include equations if you wish. Discuss how you implemented the methods.
2. The requested results from testing on the two functions.

3. Hardcopy of your MATLAB code.

In addition, email your MATLAB code to Jacob Greenwood ([jacobgreenwood@gmail.com](mailto:jacobgreenwood@gmail.com)). Additional information about this will be provided.

Suggestions:

Get started now! Start with a relatively simple routine and work forward, always having a working program. I would suggest you start off with a relatively straight-forward step length approach (such as the quadratic fit given in class) and then you can get more fancy after you have a program working for all three methods, if you want to. A working, straightforward program is much better than a non-working, fancy program.



Rosenbrock's function. The optimum is at  $(\mathbf{x}^*)^T = [1, 1]$  where  $f^* = 0$ . Start at the point,  $(\mathbf{x}^0)^T = [-1.5, 1]$

## Driver Routine:

```
%-----Example Driver program for fminun-----
clear;

global nobj ngrad
nobj = 0; % counter for objective evaluations
ngrad = 0.; % counter for gradient evaluations
x0 = [1.; 1.]; % starting point, set to be column vector
algoflag = 1; % 1=steepest descent; 2=conjugate gradient; 3=BFGS quasi-Newton
stoptol = 1.e-3; % stopping tolerance, all gradient elements must be < stoptol

% ----- call fminun-----
[xopt, fopt, exitflag] = fminun(@obj, @gradobj, x0, stoptol, algoflag);

xopt
fopt

nobj
ngrad

% function to be minimized
function [f] = obj(x)
    global nobj
    %example function
    f = 12 + 6*x(1) - 5*x(2) + 4*x(1)^2 - 2*x(1)*x(2) + 6*x(2)^2;
    nobj = nobj + 1;
end

% get gradient as a column vector
function [grad] = gradobj(x)
    global ngrad
    %gradient for function above
    grad(1,1) = 6 + 8*x(1) - 2*x(2);
    grad(2,1) = -5 - 2*x(1) + 12*x(2);
    ngrad = ngrad + 1;
end
```

## Example fminun function:

```
function [xopt, fopt, exitflag] = fminun(obj, gradobj, x0, stoptol, algoflag)

% get function and gradient at starting point
[n,~] = size(x0); % get number of variables
f = obj(x0);
grad = gradobj(x0);
x = x0;

%set starting step length
alpha = 0.5;

if (algoflag == 1) % steepest descent
    s = srchsd(grad)
end

% take a step
xnew = x + alpha*s;
fnew = obj(xnew);

xopt = xnew;
fopt = fnew;
exitflag = 0;
end

% get steepest descent search direction as a column vector
function [s] = srchsd(grad)
    mag = sqrt(grad'*grad);
    s = -grad/mag;
end
```