

# OCS Hints for Questions

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## Derivations

Die Antworten sind teilweise unvollständig, einerseits, weil er die Antworten als "Eh Klar" abgestempelt hat, andererseits weil er so schnell durchging, dass ein Mitschreiben nicht mehr möglich war.

1. Draw level lines and arrows
  - objective function is the function we want to minimize
  - constraint set is a set of functions
  - optimal solution: find  $f(x^*) \leq f(x), \forall x \in X$
  - level set: comparable to level lines of terrain, convex function  $\Rightarrow$  convex level set (but there are non convex fct with convex level sets),
2.
  - **Linear:** Objective Function and Constraints may only be linear  
 $\min c^T x, s.t. Ax \leq b, x \geq 0$   
 Polynomial solvable
  - **Non Linear:** Objective Function and Constraints may be non linear  
 $\min \frac{1}{2}x^T Qx + c^T x, s.t. Ax \leq b, Ex = d$   
 Q symmetrical and pos. definite, polynomial solvable
  - **Quadratic:** objective function is quadratic, constraints are linear  
 $\min_{x \in \mathbb{R}} f_0(x)$  (objective),  
 $s.t. f_i(x) \leq i = 0..m$  (constraints)  
 polynomial time
  - **convex set:**  $\alpha x + (1 - \alpha)y \in X, \forall x, y \in X, \alpha \in [0, 1]$
  - **convex fct:**  $f(\alpha x + (1 - \alpha)y) \leq \alpha f(x) + (1 - \alpha)f(y), \forall x, y \in X, \alpha \in [0, 1]$
3.
  - When hessian is strictly positive, it is a strict global maximum
  - **unconst Local minimum:**  $f(x^*) \leq f(x), \forall x$  with  $\|x - x^*\| \leq \varepsilon$
  - **unconst global minimum:**  $f(x^*) \leq f(x), \forall x \in \mathbb{R}$

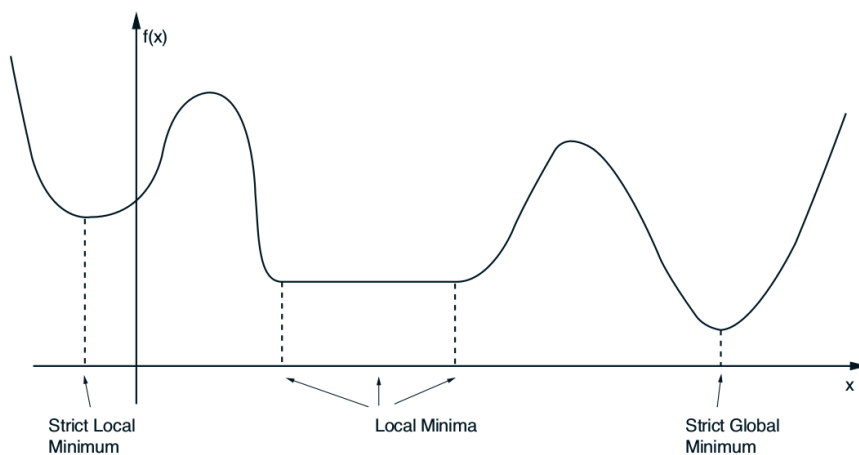


Figure 1: Local/Global minimas

4.
  - If positive and negative Eigenvalues, we can not define convexity
  - First order necessesary optimality condition:  $\nabla f(x^*) = 0$
  - Second order necessesary optimality condition:  $\nabla^2 f(x^*)$  is positive semi definite

## Quadratic function (1)

- ▶ Consider the quadratic minimization problem

$$\min_x f(x) = \frac{1}{2}x'Qx - b'x$$

- ▶  $Q$  is a symmetric  $n \times n$  matrix and  $b$  is a  $n \times 1$  vector
- ▶ If  $x^*$  is a local minimum it must satisfy

$$\nabla f(x^*) = Qx^* - b = 0, \quad \nabla^2 f(x^*) = Q \geq 0$$

- ▶  $Q \geq 0$  implies that  $f$  is convex, and hence the necessary conditions become sufficient
  - ▶  $Q \not\geq 0$  implies that  $f$  does not have local minima
  - ▶ If  $Q > 0$  then  $x^* = Q^{-1}b$  is the unique global minimum
  - ▶ If  $Q \geq 0$  but not invertible then either no solutions or infinitely many solutions
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Figure 2: Different scenarios for  $Q$

5.
  - Descent direction: angle of step and derivation direction  $< 90^\circ$
  - General form of gradient method:
    1. Choose an initial vector  $x^0 \in \mathbb{R}^n$
    2. Choose a descent direction  $d^k$  that satisfies  $\nabla f(x^k)'d^k < 0$
    3. Choose a positive step size  $\alpha^k$
    4. Compute the new vector as  $x^{k+1} = x^k + \alpha^k d^k$
    5. Set  $k = k + 1$  and goto 2

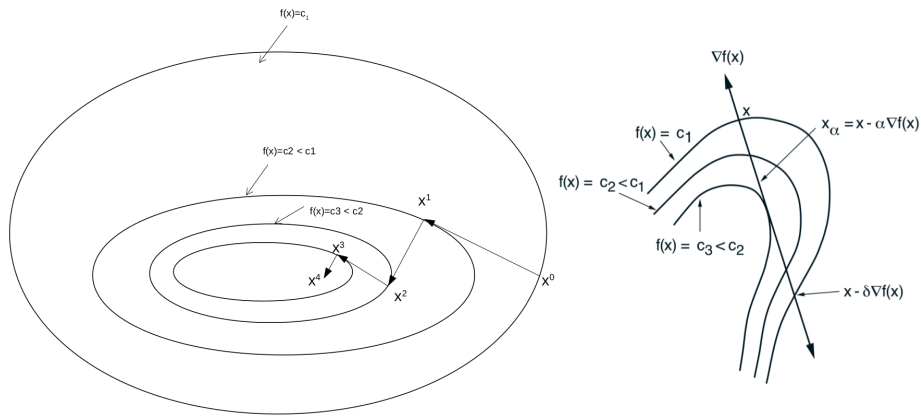


Figure 3: Simple descent direction

6.  $d^k = -D^k \nabla f(x^k)$

- Identity:  $D^k = I$ , = Gradient descent, zig zagging problem, very bad on Rosenbrock Fct
- Hessian:  $D^k = \nabla^2 f(x^k)$ , = Newtons method, very fast convergence, very good on rosenbrock, unstable in despite of initial values (may diverge or find local maxima instead of minima), con: calculation of inverse of hessian - very expensive in large networks
- Diagonal Hessian (approximation of Newton):  $d_i^k \approx \left( \frac{\partial^2 f(x^k)}{(\partial x_i)^2} \right)^{-1}$ , very bad performance on Rosenbrock,
- Gauss Newton method: Too complicated to remember, replace  $D^k$  with non linear least square problem, even better performance on rosenbrock then newton, con: again calculation of inverse, but not of hessian
- **Step size  $\alpha$ :**
  - **Minimization rule:** choose  $\alpha$  such that  $f(x + \alpha d)$  is minimized along  $d$ . Hard if  $f$  is complicated
  - **Limited minimization rule:** iterative: start small and increase size of  $\alpha$  until  $f(x)$  is bigger then before, then choose the previous. Easy to implement
  - **Armijo rule:** it is not sufficient that  $f(x^{k+1}) < f(x^k)$ , thus, the step sizes  $\beta^m$ s for  $m = 0, 1, \dots$  are chosen such that the energy decrease is sufficiently large (dependent on derivation of  $f(x)$ , formula too complicated), or graphical:

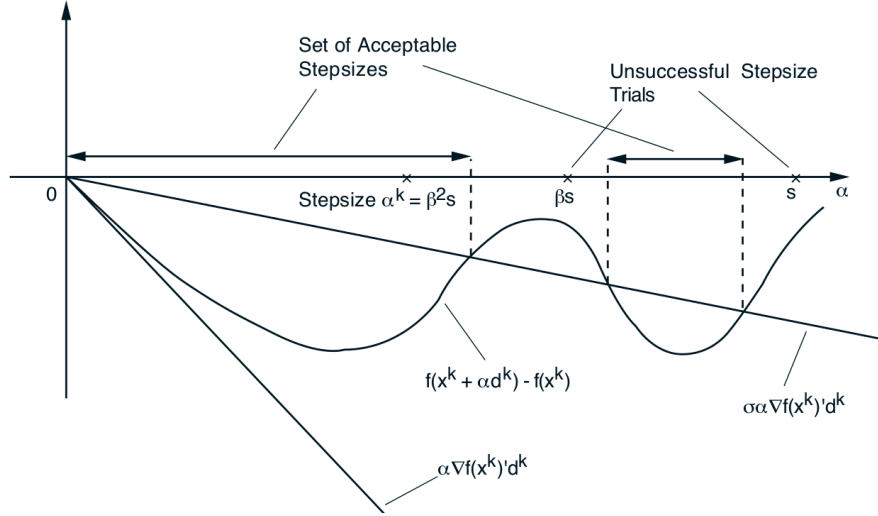


Figure 4: Graphical representation of the idea of Armijo

7.
  - there exists a definite real number such that, for every pair of points on the graph of this function, the absolute value of the slope of the line connecting them is not greater than this real number
  - (There is something missing here)
8.
  - **Linear:**  $\limsup_{k \rightarrow \infty} \frac{e(x^{k+1})}{e(x^k)} \leq \beta$  (blue line)
  - **superlinear:**  $\limsup_{k \rightarrow \infty} \frac{e(x^{k+1})}{e(x^k)^p} < \infty$  (red line)
  - **sublinear:**  $\limsup_{k \rightarrow \infty} \frac{e(x^{k+1})}{e(x^k)} = 1$  (black line)

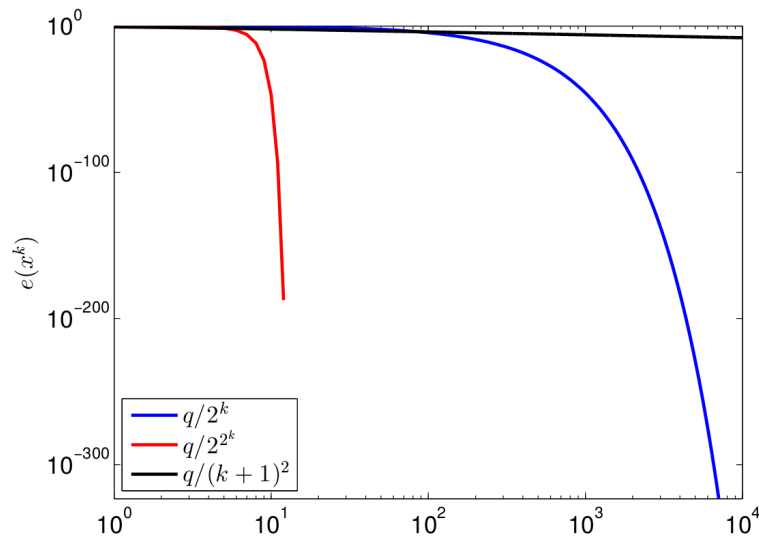


Figure 5: Graphical representation of linear, superlinear and sublinear convergence

9.
  - $\tilde{g}(x, x^k) = g(x^k) + \nabla g(x^k)'(x - x^k)$
  - is affine: because the derivation of the function is independent to a move of constants?!?!?

10. **Linear:**

- pointcloud, best fitting by polynomial equations
- Solve least square problem to find optimal parameters
- $\frac{1}{2} \|Ax - z\|^2$

**Non-Linear:**

- Measure distance to beacons to get our own unknown location
- non linear least squares problem
- $\min_x \frac{1}{2} \sum_{i=1}^m (d_i - \sqrt{(x_i - p_1^i)^2 + (x_2 - p_2^i)^2})^2$

**Gauss-Newton:**

- Uses  $(\nabla g(x^k) \nabla g(x^k)')^{-1}$  instead of hessian
- Approximates Current point with parabola and minimizes this subproblem (as plain Newton)

(check this shit out)

11.
  - incremental of gauss newton - incremental growing least squares estimate

- example watertank: many measurements with noise - a very good and fast convergence to correct level is reached
  - extended Kalman Filter: input data behaves according to a function
12.
    - $Q$  positive definite:  $\left(\frac{\sqrt{L/I}-1}{\sqrt{L/I}+1}\right)^n \|x^0 - x^*\|$
    - $Q$  positive semidefinite: not motivated to write formula
    - Best method: conjugate gradient method (by Polyak) see next question
  13.
    - Motivation: converge faster than GD but avoid Newton overhead
    - Q-conjugate if:  $d^i Q d^j = 0, \forall i, j$  with  $i \neq j$
    - Algorithm: Use Gram-Schmidt to find conjugate direction, calculate new search direction (easy as all but one coefficient are zero), choose  $\alpha^k$  by minimization method, algorithm terminates after at most  $n$  steps.

(I think this is the algorithm where every single dimension is differentiated and optimized - hence the  $n$  termination)
  14.
    - Heavy-ball: Idea is like in physics: a ball uses its momentum it gained beforehand to overcome small increases or flat areas of its way
    - Problem: function needs to be strongly  $\mu > 0$  convex and twice continuously differentiable
    - Nesterov overcomes the twice diff. and the  $\mu > 0$  problem by a dynamic choice of overrelaxation param  $\beta^k = \frac{t_k-1}{t_k+1} \rightarrow 1$
  15. in subspace reduce to eq, what is a subspace?
  16. First pages of slide 10
  17. middle/end of pages slide 10 - start in interior and just take small steps  
 - > we can ignore constraint under these conditions
  18. ~~too fast~~
  19. see figure 6
  20. see figure 7
  21. see figure 7



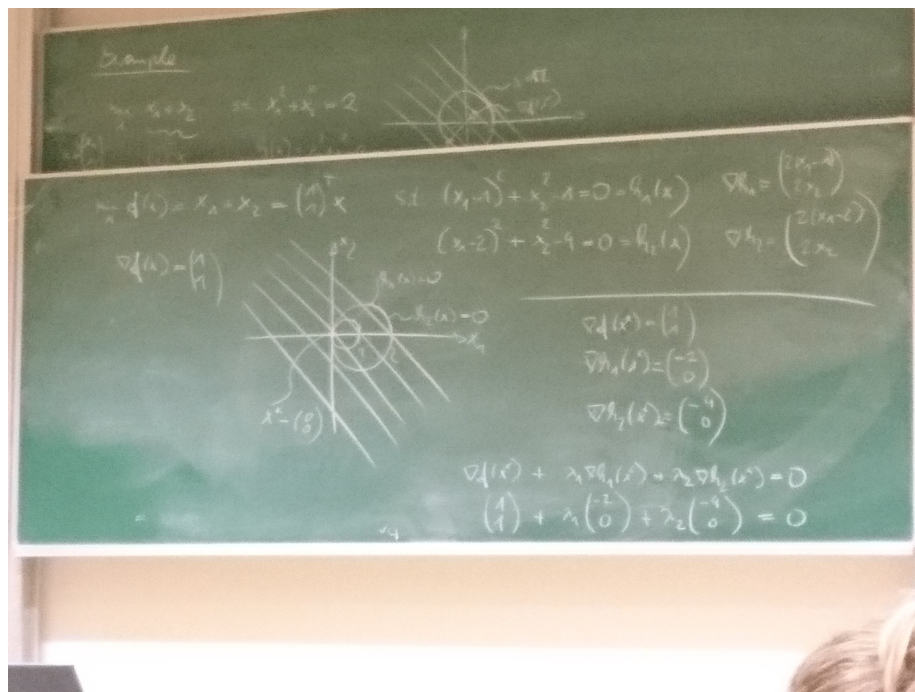


Figure 6: Example1, 24.01.2017

