Matrix calculus. Line search.

Seminar

Optimization for ML. Faculty of Computer Science. HSE University

Theory recap. Differential

- Differential $df(x)[\cdot] : U \to V$ in point $x \in U$ for $f(\cdot) : U \to V$:

$$f(x+h) - f(x) = \underbrace{df(x)[h]}_{\text{differential}} + \bar{o}(||h||)$$

$U \to V$	$\mathbb{R}$	$\mathbb{R}^n$	$\mathbb{R}^{n \times m}$
$\mathbb{R}$	$f'(x)dx$	$\nabla f(x) dx$	$\nabla f(x) dx$
$\mathbb{R}^n$	$\nabla f(x)^T dx$	$J(x) dx$	—
$\mathbb{R}^{n \times m}$	$tr(\nabla f(X)^T dX)$	—	—

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- Canonical form of the differential:

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Theory recap. Differentiation Rules

- Useful differentiation rules and standard derivatives:

Differentiation Rules	Standard Derivatives
$dA = 0$	$d(\langle A,\, X\rangle) = \langle A,\, dX\rangle$
$d(\alpha X) = \alpha(dX)$	$d(\langle Ax,\, x\rangle) = \langle (A + A^T)x,\, dx\rangle$
$d(AXB) = A(dX)B$	$d(Det(X)) = Det(X)\langle X^{-T},\, dX\rangle$
$d(X + Y) = dX + dY$	$d(X^{-1}) = -X^{-1}(dX)X^{-1}$
$d(X^T) = (dX)^T$	
$d(XY) = (dX)Y + X(dY)$	
$d(\langle X,\, Y\rangle) = \langle dX,\, Y\rangle + \langle X,\, dY\rangle$	
$d\left(\frac{X}{\phi}\right) = \frac{\phi dX - (d\phi)X}{\phi^2}$	

Theory recap. Differential and Gradient / Hessian

We can retrieve the gradient using the following formula:

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d^2 f(x) = \langle \nabla^2 f(x) dx_1, dx \rangle = \langle H_f(x) dx_1, dx \rangle
$$

Theory recap. Line Search

- Solution localization methods:

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- Inexact line search:
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    - Goldstein conditions
    - Curvature conditions
    - The idea behind backtracking line search

Matrix Calculus. Problem 1

Example

Find $\nabla f(x)$, if $f(x) = \dfrac{1}{2}x^T Ax + b^T x + c$.

Matrix Calculus. Problem 2

Example

Find $\nabla f(X)$, if $f(X) = tr(AX^{-1}B)$

Matrix Calculus. Problem 3

Example

Find the gradient $\nabla f(x)$ and hessian $\nabla^2 f(x)$, if $f(x) = \frac{1}{3}\|x\|_2^3$

Line Search. Example 1: Comparison of Methods

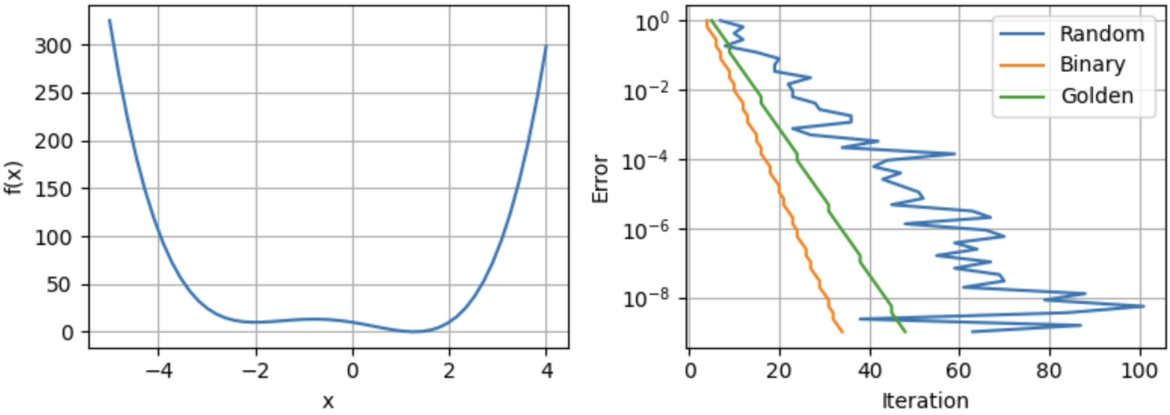

Figure 1: Comparison of different line search algorithms

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Line Search. Example 2: The Brent Method

- Parabolic Interpolation + Golden Search = Brent Method

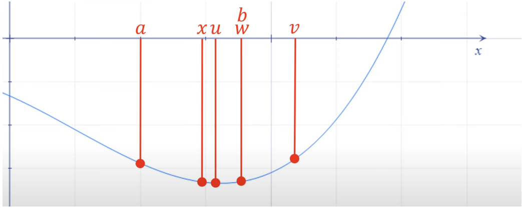
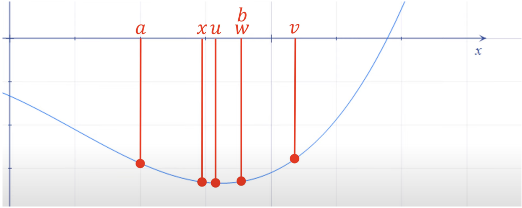


Figure 2: Idea of Brent Method

Line Search. Example 2: The Brent Method

- Parabolic Interpolation + Golden Search = Brent Method
- The key idea of the method is to track the value of the optimized scalar function at six points a, b, x, w, v, u



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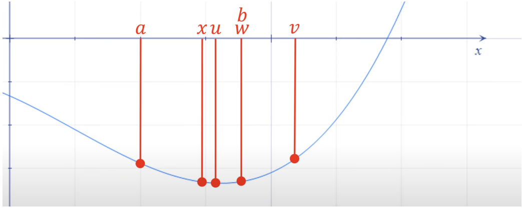

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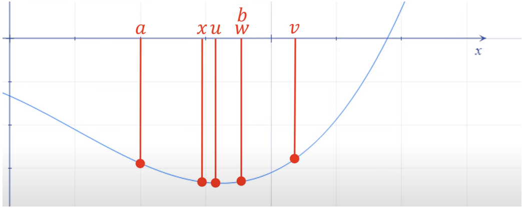

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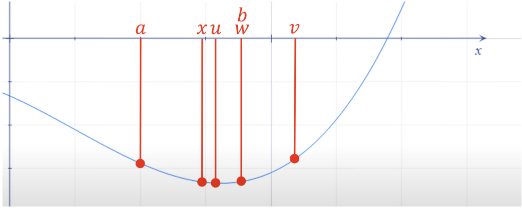
- $[a, b]$ – localization interval in the current iteration
- The pounts x, w and v such that the inequality $f(x) \leqslant f(w) \leqslant f(v)$ is valid
- u – minimum of a parabola built on points x, w and v or the point of the golden section of the largest of the intervals $[a, x]$ $[x, b]$.



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Line Search. Example 2: The Brent Method

A parabola is constructed only if the points x, w and v are different, and its vertex u^* is taken as the point u only if

- $u^* \in [a, b]$

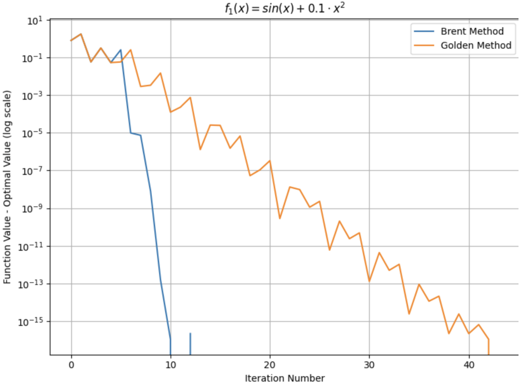

Figure 3: An example of how the Brent Method works

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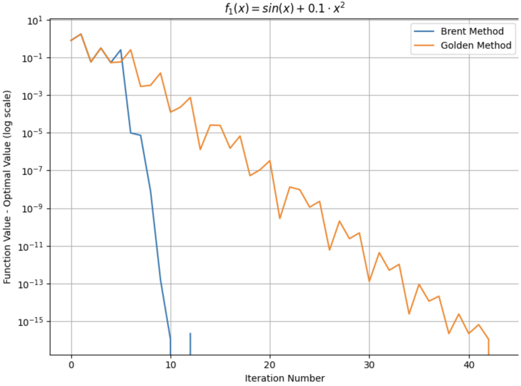

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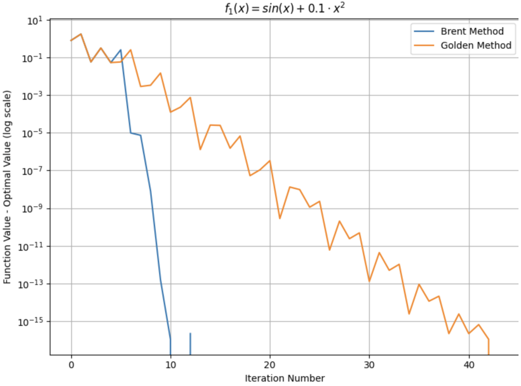

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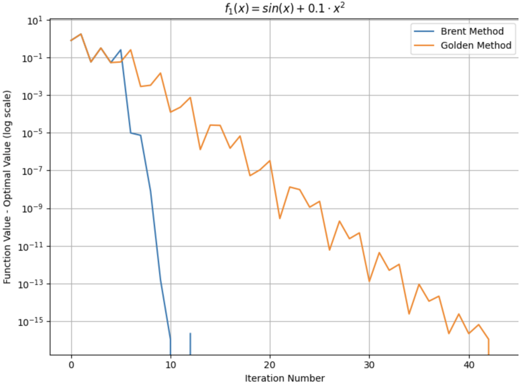
- Example In Colab ♣



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