3. (Long term) Field planning: effect of plateau rate and well number on NPV

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3. Field planning: effect of plateau rate and well number on NPV

The NPV function:

$$f_{NPV} = \sum_{k=1}^{N} \frac{Rt_k}{(1+i)^k}$$

Where, for year «k»:

$$Rt_k = Revenue_k - OPEX_k - DRILLEX_k - CAPEX_k$$

Known issue: There is an optimal production scheduling and drilling schedule that maximize NPV

Action	Advantages	Disadvantages
Higher HC rates during early times	Gives higher revenue	Gives higher cost (CAPEX, OPEX)
Drill more wells	Allows for higher rates, extends field life	Gives higher cost (DRILLEX, CAPEX, OPEX)

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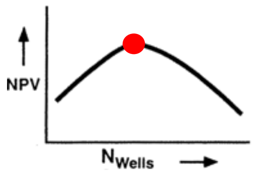
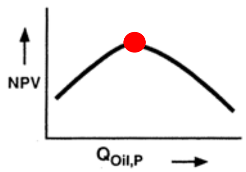
3. Field planning: effect of plateau rate and well number on NPV

Variation of NPV with plateau rate and number of wells:





Choosing between rocks, hard places and a lot more: the economic interface

Helge Hove Haldorsen

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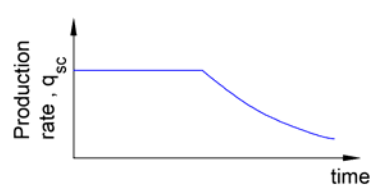
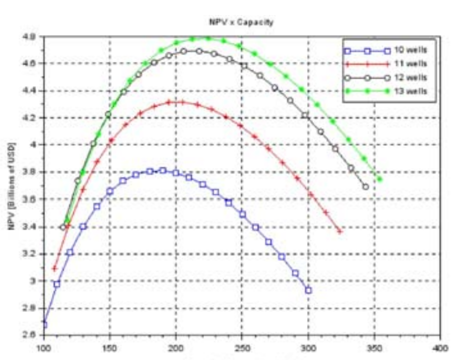
3. Field planning: effect of plateau rate and well number on NPV

- The field will produce initially in plateau mode, with constant rate and then decline
- Constant hydrocarbon price
- All wells are pre-drilled and available from start
- Decision variables: plateau rate and number of wells





OTC-28898-MS

A Cost Reduction Methodology for Offshore Projects

G. C. Nunes, Rio Petroleo Consulting Group; A. H. da Silva and L. G. Esch, Universidade do Estado do Rio de Janeiro

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3. Field planning: effect of plateau rate and well number on NPV

$$NPV_{rev} = q_{p,f} \cdot P_o \cdot \left[\frac{m + i - m \cdot e^{-\left(\frac{q_{ppo}}{q_{p,f}} - 1\right)\frac{i}{m}} - i \cdot e^{-(m+i)\cdot t + \left(\frac{q_{ppo}}{q_{p,f}} - 1\right)}}{i \cdot (m+i)} \right]$$

$$t_p = \left(\frac{q_{ppo}}{q_{p,f}} - 1\right) \cdot \frac{1}{m}$$

$$m = A \cdot N_w \cdot J$$

$$q_{ppo} = N_{wells} \cdot J \cdot (p_i - p_{wf,min})$$

$$A = \frac{B_o}{\left[N \cdot B_{o,i} \cdot \left(c_o + \frac{c_w \cdot S_w + c_f}{S_o}\right) + V_a \cdot \phi_a \cdot B_w \cdot (c_w + c_f)\right]}$$

$$CAPEX_{TOPSIDES} = 33056 \cdot WEIGHT_{TOPSIDES} + 5 \cdot 10^8$$

$$WEIGHT_{TOPSIDES} = 16500 + n \cdot q_p \left(0.01 + \frac{GOR}{10^4} + (0.01 + \frac{GOR}{2 \cdot 10^4}) y_{CO2} + (0.005 + \frac{GOR}{4 \cdot 10^4})(y_{SRU} + y_{H2S})\right)$$

$$CAPEX_{HULL} = 200n \cdot q_p + 20 \cdot 10^6$$

$$CAPEX_{PO+GL} = n2442000 + 8580nh + 5217\sum_{k=1}^{n} \ell_k$$

$$CAPEX_{WI} = n_{WI}1576833 + 3432n_{WI}h + \sum_{k=1}^{n_{WI}} 2128\ell_k$$

$$CAPEX_{XT} = 22 \cdot 10^6\ US\$ / XTree$$

$$CAPEX_{MF} = 32 \cdot 10^6\ US\$ / manifold$$

$$CAPEX_{INST} = \left(\sum_{k=1}^{n+n_{WI}} \ell_k + (n + n_{WI})300 + 1{,}625 \sum_{k=1}^{n+n_{WI}} h_k\right) \cdot C_{INST}$$

$$CAPEX_{MOORING} = 130 \cdot 10^6$$

$$CAPEX_{WELLS} = n150 \cdot 10^6 + n_{WI}150 \cdot 10^6$$

Page 116 of compendium

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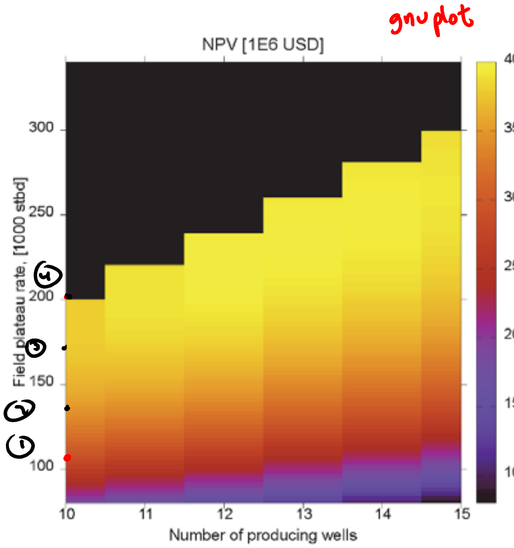
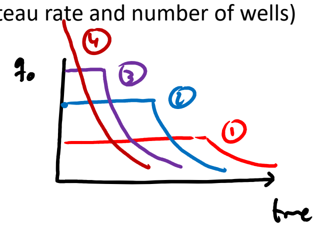
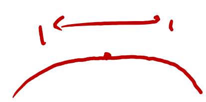
The NPV function as a colour plot (function of both plateau rate and number of wells)

gnu plot







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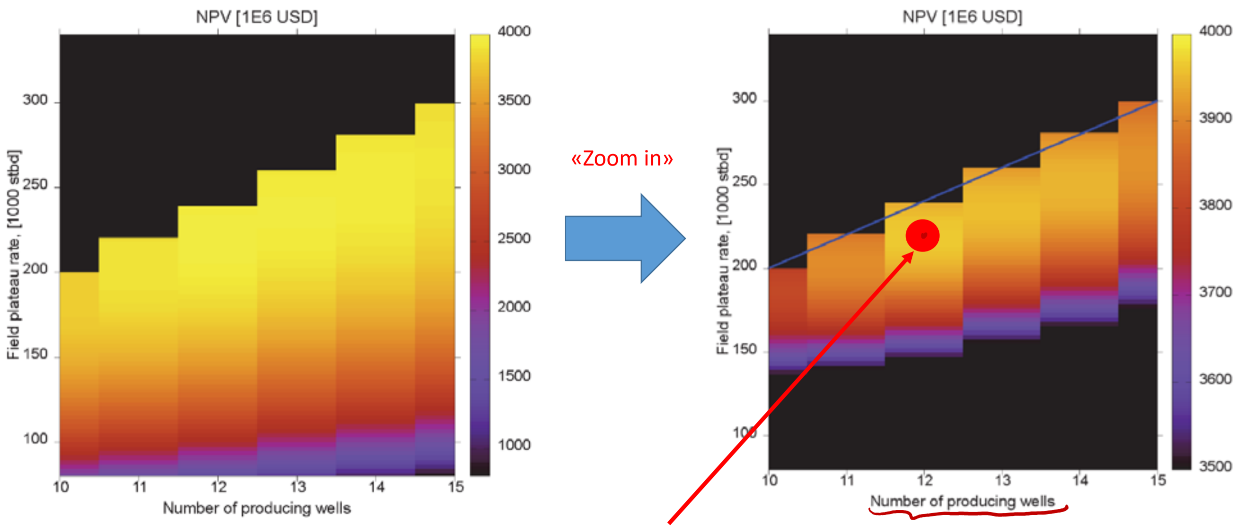
The NPV function as a colour plot (function of both plateau rate and number of wells)



Sweet spot: 12 wells and 212 000 stb/d

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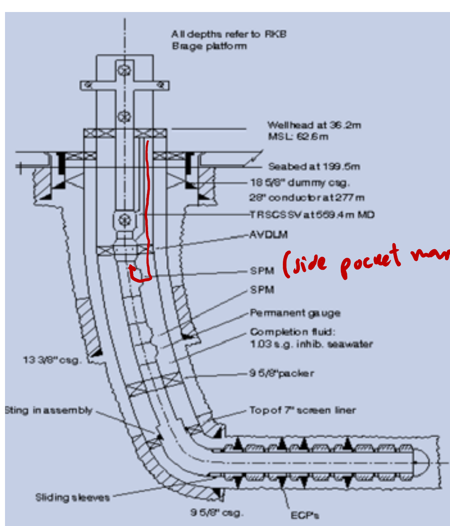
4. (Shorter term) Active choking to prevent well slugging



SPE77650 – Active feedback control of unstable wells at the Brage Field. Dalsmo et al.

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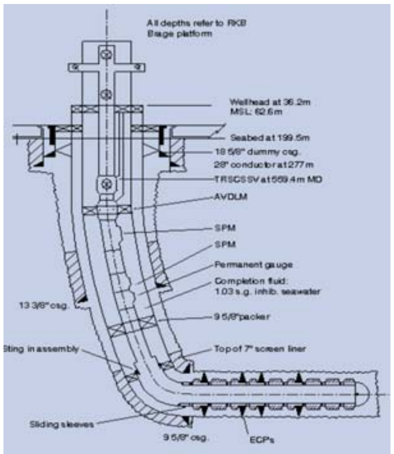
4. Active choking to prevent well slugging



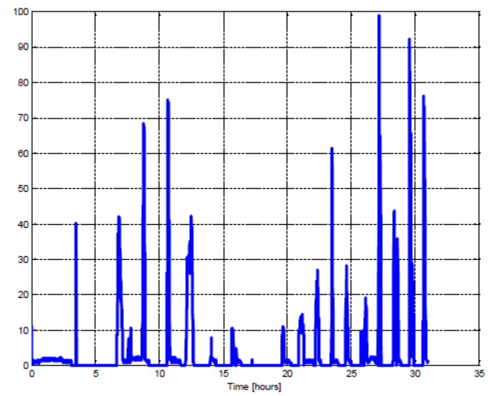


Figure 12: A-21 well test May 11- 12, 2001: *Test separator oil rate* [Sm^3/h]

SPE77650 – Active feedback control of unstable wells at the Brage Field. Dalsmo et al.

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4. Active choking to prevent well slugging

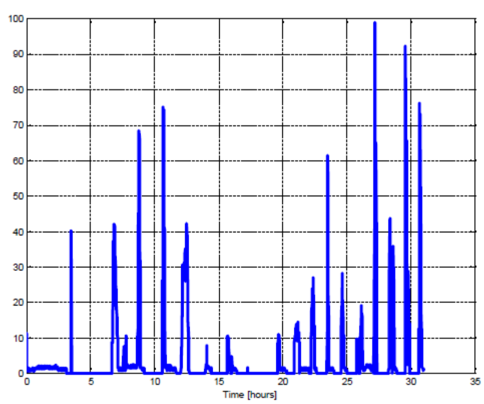

Figure 12: A-21 well test May 11- 12, 2001: *Test separator oil rate* [Sm^3/h]

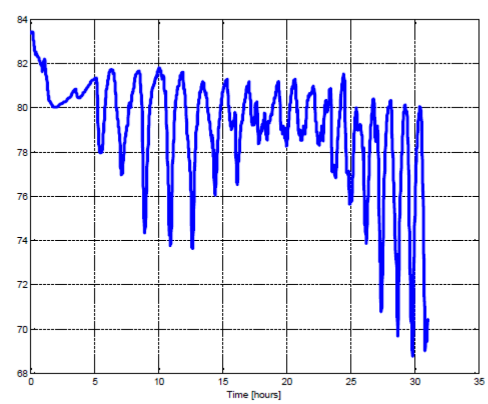

Figure 10: A-21 well test May 2001: *Down hole pressure* [bar]

SPE77650 – Active feedback control of unstable wells at the Brage Field. Dalsmo et al.

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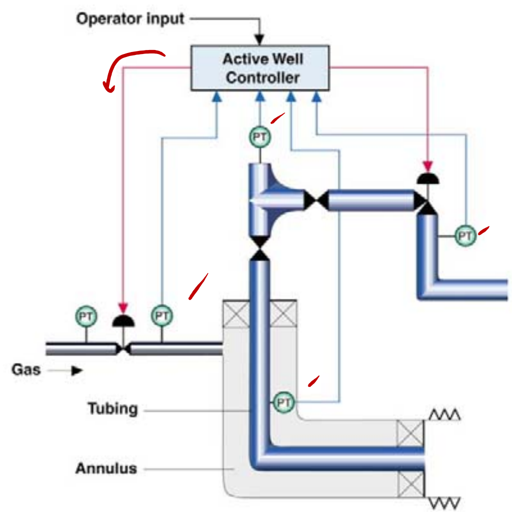
4. Active choking to prevent well slugging



SPE77650 – Active feedback control of unstable wells at the Brage Field. Dalsmo et al.

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4. Active choking to prevent well slugging

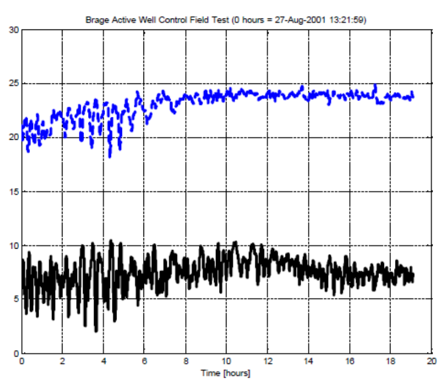

Figure 20: *Test separator oil rate* [Sm3/h] and *test separator water rate* [Sm3/h] (four hours moving average) corresponding to the downhole pressure and the choke opening in Figure 18 and Figure **19** respectively.

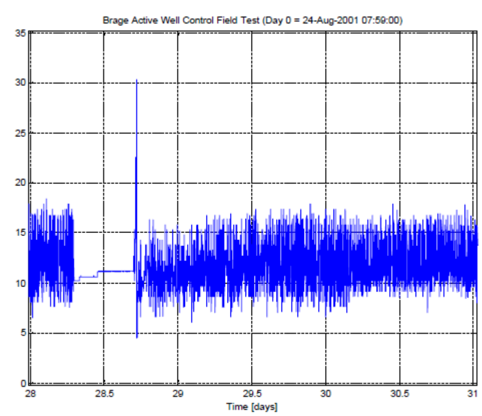

Figure 21: *Choke opening* [%]. As a test, the well is operated manually for a period of time, resulting in constant choke opening.

SPE77650 – Active feedback control of unstable wells at the Brage Field. Dalsmo et al.

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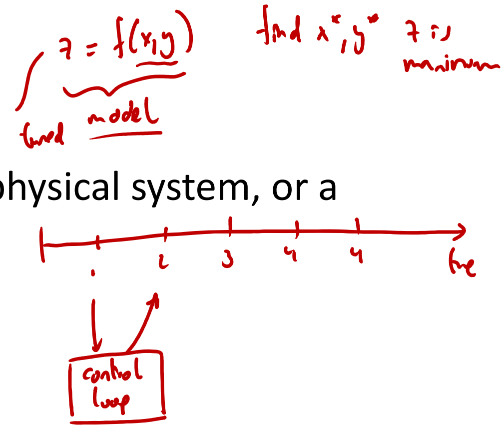
Optimization types



- Parametric (static) – using a model
- Dynamic (control) – using a model, physical system, or a combination of both

Optimization problems

- Linear
- Non-linear
- Integer (e.g. nr. wells)
- Continuous
- Constrained

https://en.wikipedia.org/wiki/Simulation-based_optimization

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Optimization methods

- Simplex
- Derivative-based (gradients, hessians)
- Line search/ Trust region
- Heuristic

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Examples

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Linear problems

Variable non-negativity: $x_1 \geq 0, \quad x_2 \geq 0$

Objective Function:

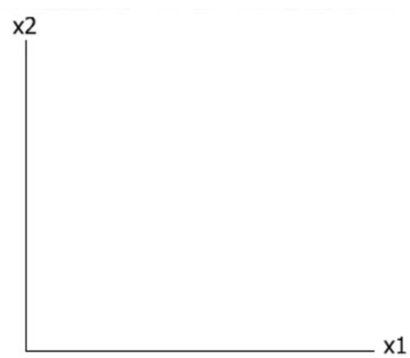
Maximize daily profit: $\text{MAX } z = 15x_1 + 10x_2$

Constraints:

Mountain bike production limit: $x_1 \leq 2$

Racer production limit: $x_2 \leq 3$

Metal finishing machine production limit: $x_1 + x_2 \leq 4$



First let's look at the constraints.

Press the Start button to begin.

<< | < | Start | Stop | > | >>

http://optlab-server.sce.carleton.ca/POAnimations2007/Graph.html

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Simplex

Variable non-negativity: $x_1 \geq 0, \quad x_2 \geq 0$

Objective Function:

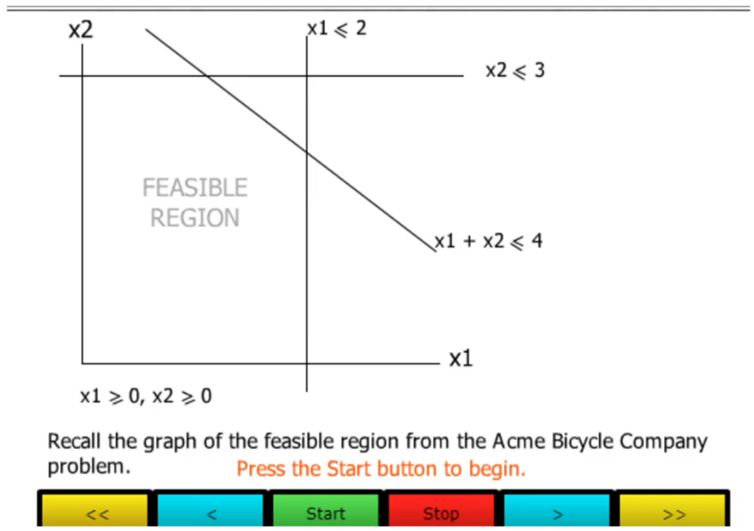
Maximize daily profit: MAX $z = 15x_1 + 10x_2$

Constraints:

Mountain bike production limit: $x_1 \leq 2$

Racer production limit: $x_2 \leq 3$

Metal finishing machine production limit: $x_1 + x_2 \leq 4$



http://optlab-server.sce.carleton.ca/POAnimations2007/TwoPhaseGraph.html

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Branch and bound

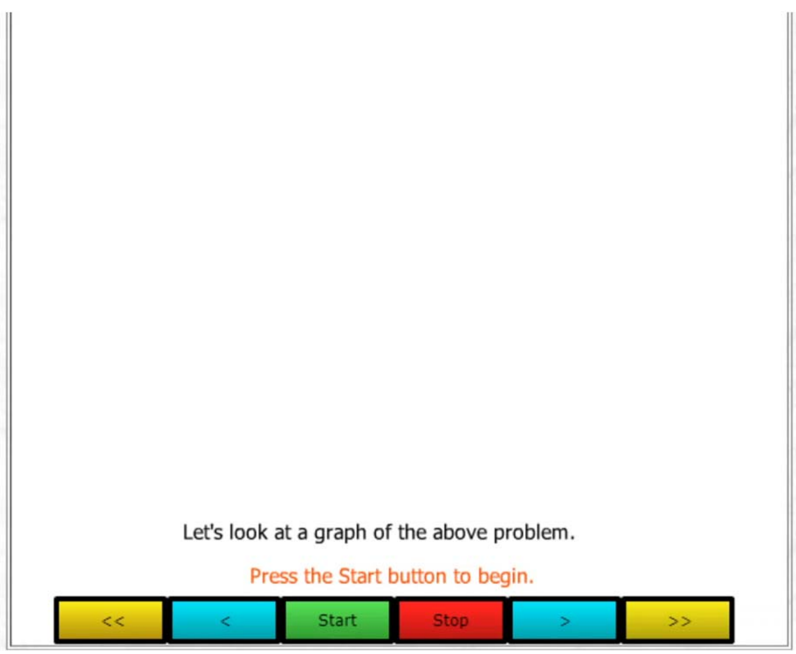
Maximize $Z = 8x_1 + 5x_2$

Subject to:

$x_1 + x_2 \leq 6$

$9x_1 + 5x_2 \leq 45$

x_1, x_2 are integer and non-negative.



http://optlab-server.sce.carleton.ca/POAnimations2007/MILP.html

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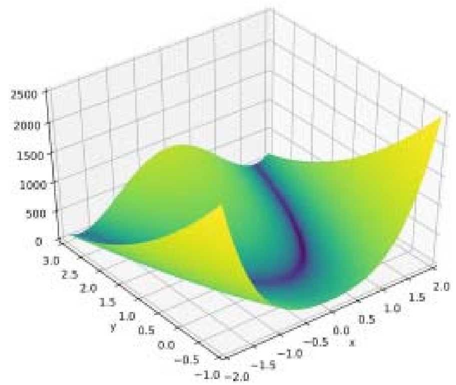
Newton

$x_k + \Delta x$ **is a local extremum if:**

$$\nabla f(x_k + \Delta x) = 0$$



https://jamesmccaffrey.wordpress.com/page/2/

Taken from Arnaud Hoffmann

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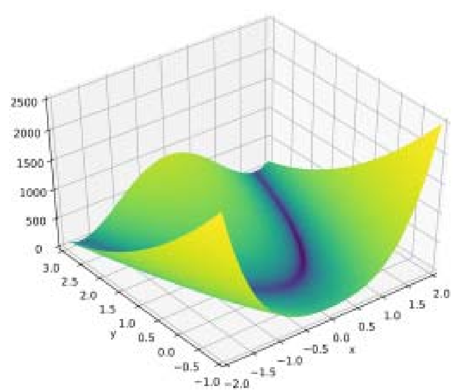
Newton

$x_k + \Delta x$ **is a local extremum if:**

$$\nabla f(x_k + \Delta x) = 0$$

$$\nabla f(x_k) + H \,.\, \Delta x = 0$$ **(Taylor expansion)**

$$H(f) = \begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix}$$



https://jamesmccaffrey.wordpress.com/page/2/

Taken from Arnaud Hoffmann

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Newton

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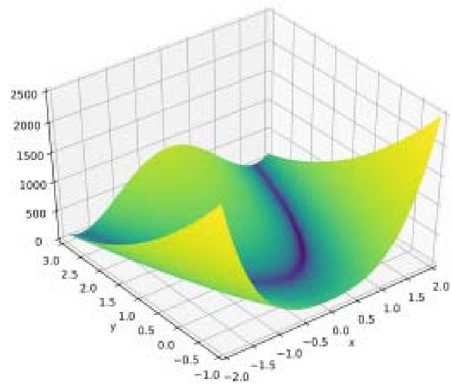
$$H(f) = \begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix}$$

$$\Delta x = -H^{-1} . \nabla f(x_k)$$

$$x_{k+1} = x_k + \Delta x$$



https://jamesmccaffrey.wordpress.com/page/2/

Taken from Arnaud Hoffmann

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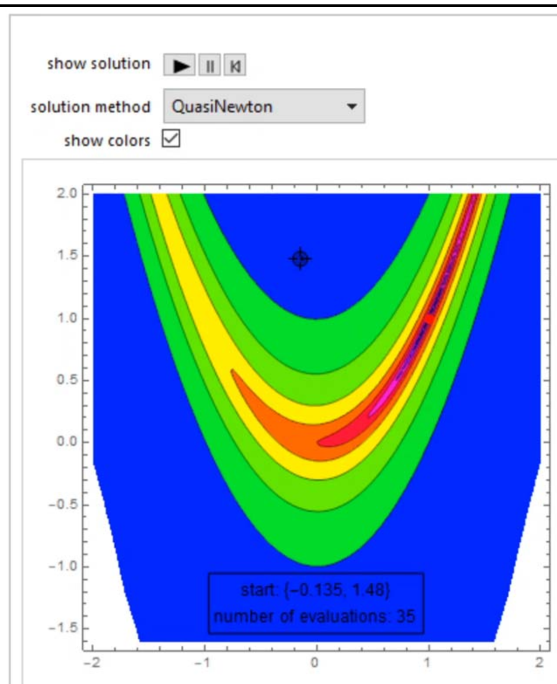
Newton



https://demonstrations.wolfram.com/MinimizingTheRosenbrockFunction/

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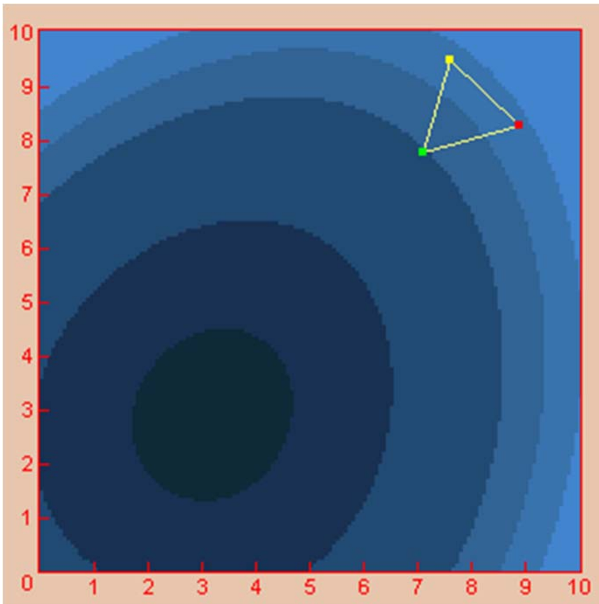
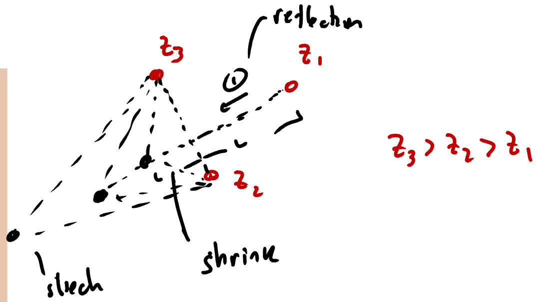
Nelder-Mead





http://195.134.76.37/applets/AppletSimplex/Appl_Simplex2.html

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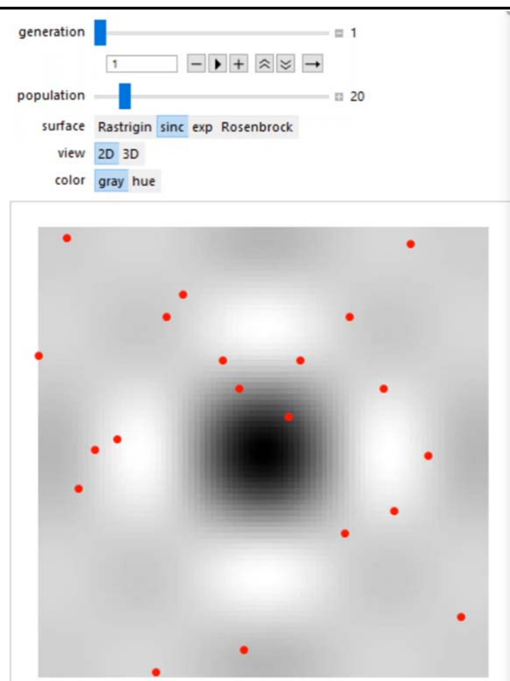
Genetic algorithm



https://demonstrations.wolfram.com/GlobalMinimumOfASurface/

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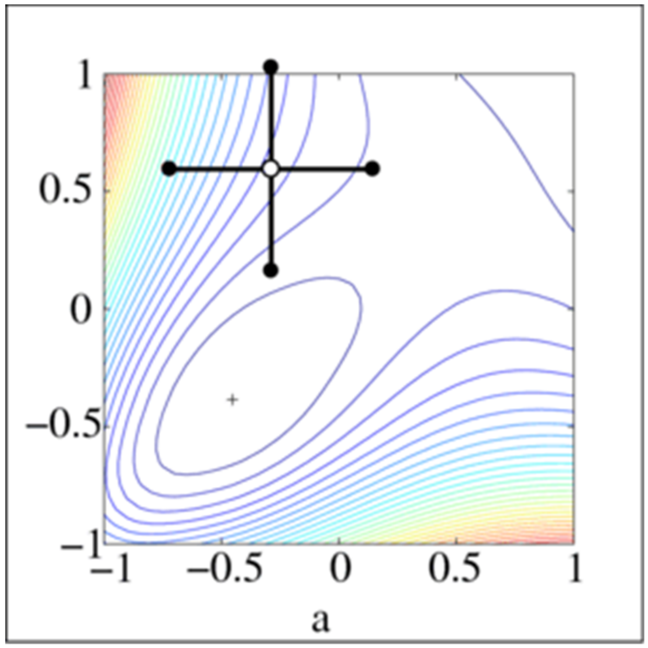
Pattern search



https://en.wikipedia.org/wiki/Pattern_search_(optimization)

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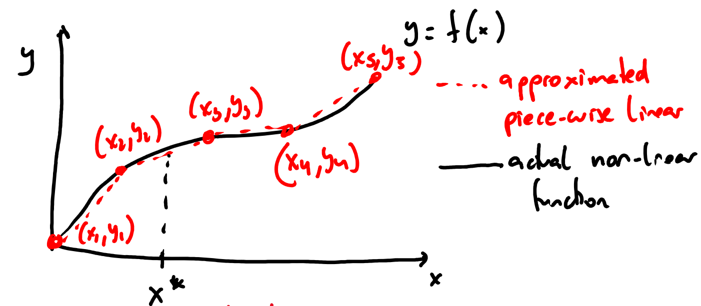
Piecewise linearization



x	y
x_1	y_1
x_2	y_2
x_3	y_3
x_4	y_4
x_5	y_5

for j in (0,4):

→ if $x_j \le x^* \le x_{j+1}$

$$y^* = y_j + \left(\frac{y_j - y_{j+1}}{x_j - x_{j+1}}\right)(x^* - x_j)$$

to avoid using "if" (logical operator) we can use, for example

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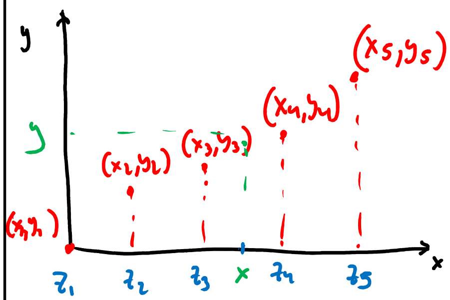
Piecewise linearization



$X = z_1 x_1 + z_2 x_2 + z_3 x_3 + z_4 x_4 + z_5 x_5$

$y = z_1 y_1 + z_2 y_2 + z_3 y_3 + z_4 y_4 + z_5 y_5$

z_i is a SOS2 set

$\sum z_i = 1$

$0 \leq z_i \leq 1$

adjacency condition

if $i \neq 0$ then only $i+1$ or $i-1$ can be $\neq 0$

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Handling constraints

- Lagrange multipliers
- Barrier functions

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Handling constraints

- **Lagrange multipliers**
- Barrier functions

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Lagrange multipliers example: Constrained gas-lift optimization (single well)

$q_{or} = f(q_{ginj})$

$q_{ginj} \leq q_{gTOTAL}$

create Lagrange function

$L(q_{ginj}) = f(q_{ginj}) - \lambda (q_{ginj} - q_{gTOTAL})$

$\frac{df(q_{ginj})}{dq_{ginj}} - \lambda = 0 \Rightarrow \frac{df(q_{ginj})}{dq_{ginj}} = \lambda$

subjected to : $\lambda \geq 0$

$\lambda \cdot (q_{gTOTAL} - q_{ginj}) = 0$

$q_{ginj} \leq q_{gTOTAL}$

at maximum:

$\frac{dL}{dq_{ginj}} = 0$

two solutions:

① $\lambda = 0$ then

$\frac{df(q_{ginj})}{dq_{ginj}} = 0$

$q_{ginj} < q_{gTOTAL}$

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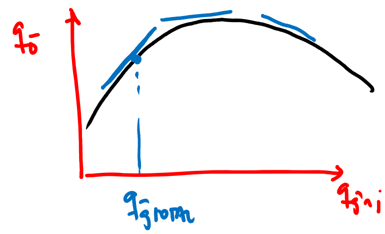
Lagrange multipliers example: Constrained gas-lift optimization (single well)

(2) $\lambda > 0$

$$\lambda \left(q_{g\,rom} - q_{g\,inj} \right) = 0$$

$$q_{g\,rom} = q_{g\,inj}$$

$$\frac{d f(q_{g\,inj})}{d q_{g\,inj}} = \lambda$$



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Lagrange multipliers example: Constrained gas-lift optimization (multiple wells)

$q_o = \sum_{i=1}^{N} f_i(q^i_{g\,inj})$ "N" wells

$\sum_{i=1}^{N} q^i_{g\,inj} \leq q_{g\,rom}$

$$\Rightarrow \quad L(q^i_{g\,inj}) = \sum_{i=1}^{N} f_i(q^i_{g\,inj}) - \lambda \left(\sum_{i=1}^{N} q^i_{g\,inj} - q_{g\,rom} \right)$$

maximum is achieved when $\nabla L = 0 \Rightarrow \frac{\partial L}{\partial q^i_{g\,inj}} = 0$

deriving with respect to "i"

$$\frac{\partial f_i(q^i_{g\,inj})}{\partial q^i_{g\,inj}} - \lambda = 0 \quad \Rightarrow \quad \frac{\partial f_i(q^i_{g\,inj})}{\partial q^i_{g\,inj}} = \lambda$$

$\lambda \geq 0$ $\quad \lambda \left(q_{g\,rom} - \sum_{i=1}^{N} q^i_{g\,inj} \right) = 0$ $\quad q_{g\,rom} \geq \sum_{i=1}^{N} q^i_{g\,inj}$

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Lagrange multipliers example: Constrained gas-lift optimization (multiple wells)

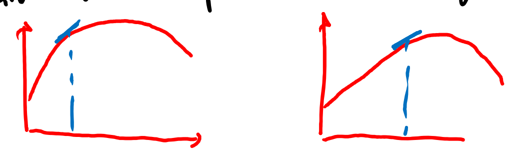
2 possible solutions: ① $\lambda = 0$ $\sum_{i=1}^{N} q^i_{ginj} < q_{g\,total}$, there is enough gas for all wells to be at their maximum

$$\frac{\partial f_i(q^i_{ginj})}{\partial q^i_{ginj}} = 0$$

② $\lambda > 0$ all gas is used $\sum_{i=1}^{N} q^i_{ginj} = q_{g\,total}$

$$\frac{\partial f_i(q^i_{ginj})}{\partial q^i_{ginj}} = \lambda$$

all wells must operate at the same gradient!



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Handling constraints

- Lagrange multipliers
- **Barrier functions**

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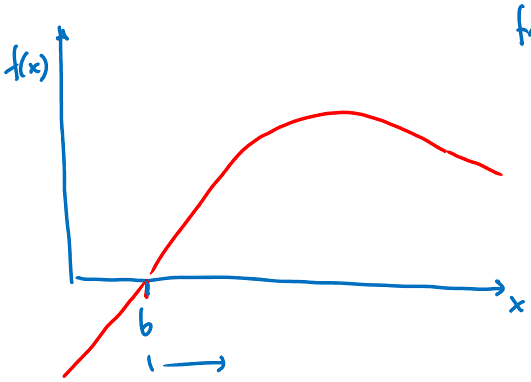
Handling constraints: barrier functions



fin minimum of f(x)
x>b

f(x) + c(x)

c(x) { high! x ≤ b ; 0 x > b

a possible $c(x) = \mu \log(x-b)$

↖ very small number