

ОФП

Program for two phase relative permeability computation
based on unsteady-state experimental data.

Company: Ufa branch of the Ugansk Research and Planning Oil Institute
of the YUKOS Oil Company (2000-2001)

Languages/Compilers/API: Borland Delphi and Microsoft Fortran 90

Group leader: Dr. Karavaev A.D.

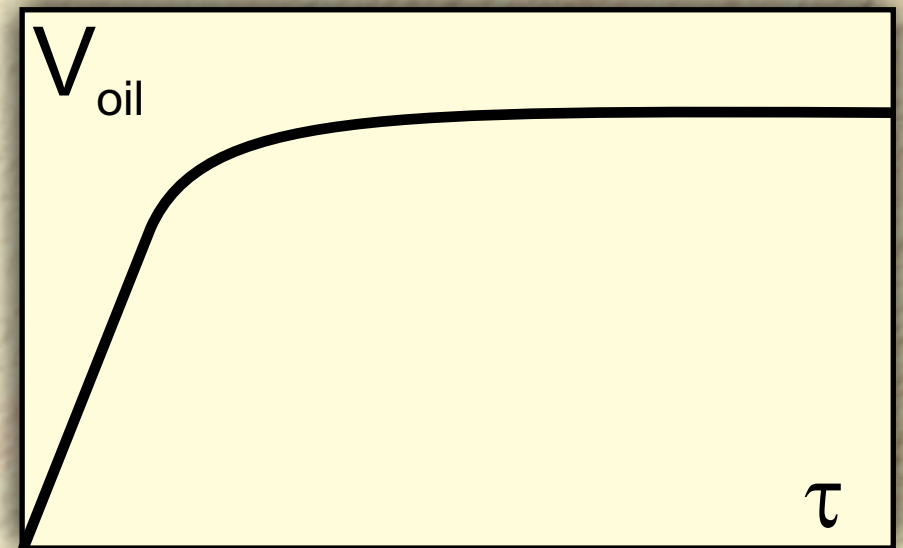
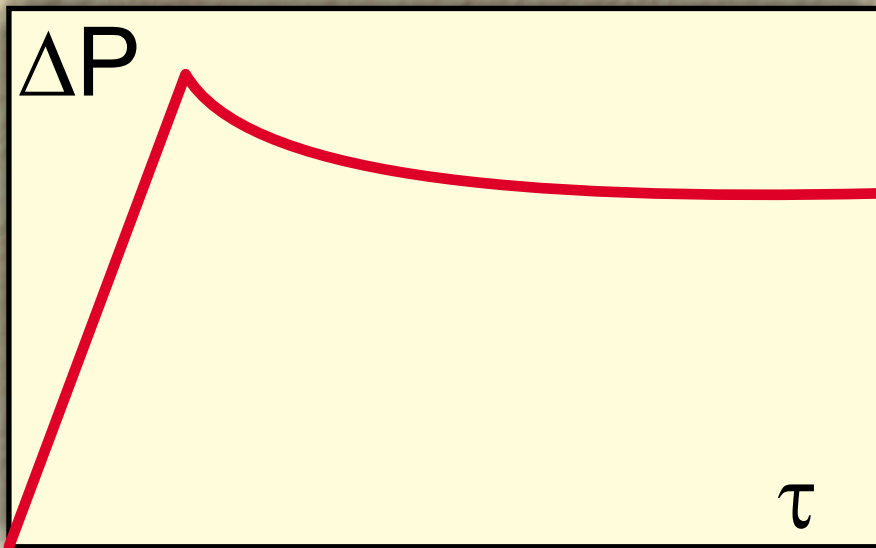
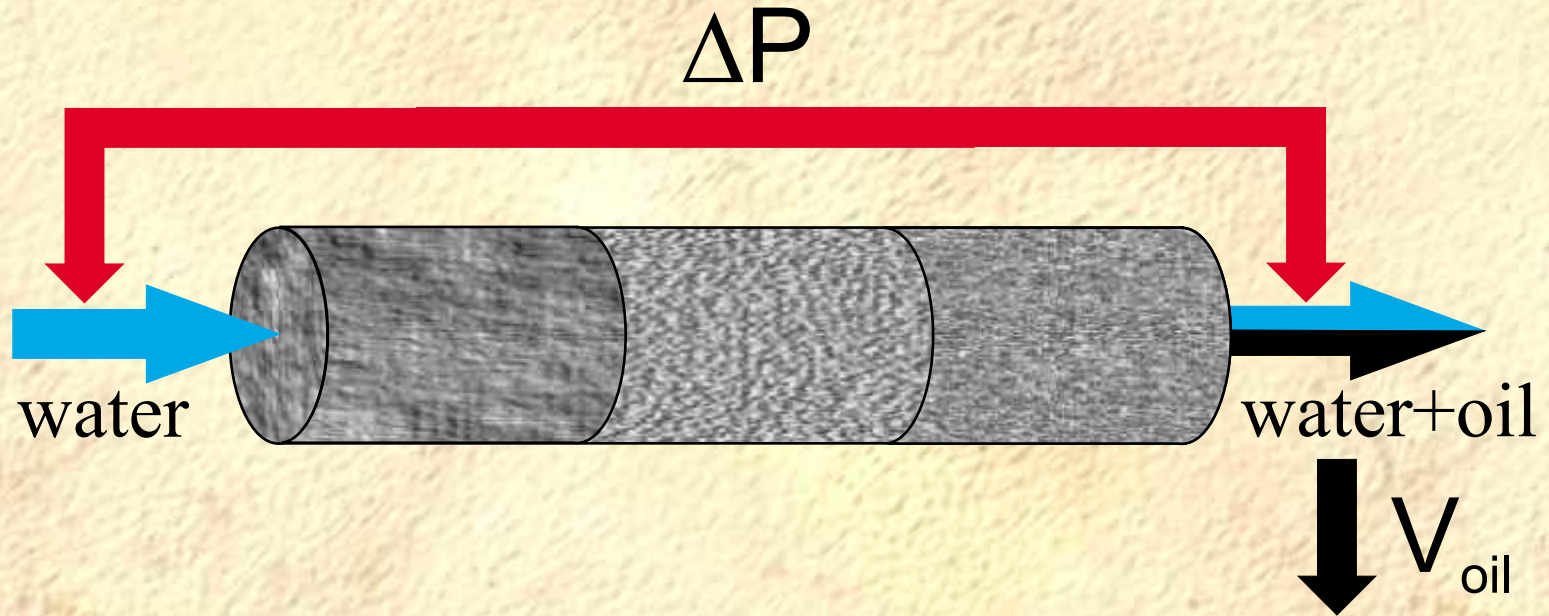
Mathematicians: Prof. Mukhametshin R.K.,
Dr. Urazakov T.K. and Dr. Bulgakova G.T.

Programmer: Ryzhkov A.B.

Experiment: Hakimov A.M., Mikhal'chuk T. and Reshetnikov A.

Experiment

Displacement of oil by water in the core sample



Theory

Buckley-Leverett equation

$$\frac{ds}{d\tau} + f'(s) \frac{ds}{d\xi} = 0$$

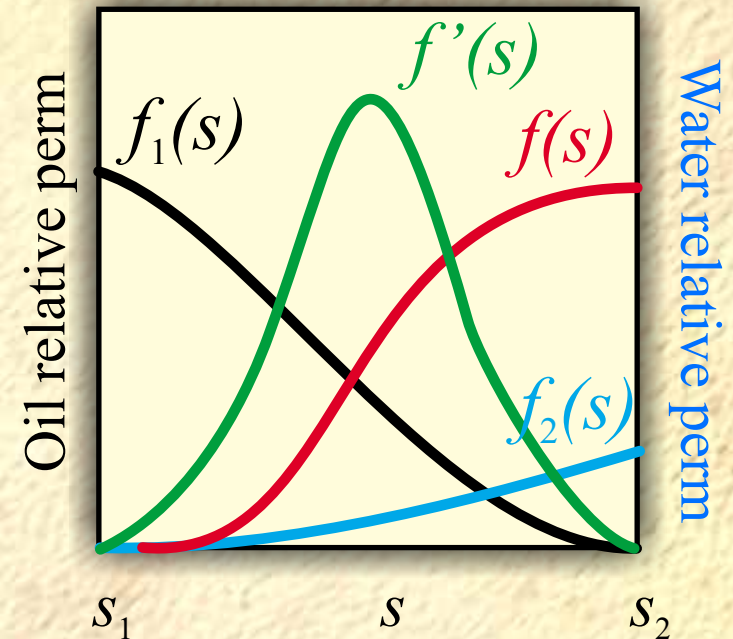
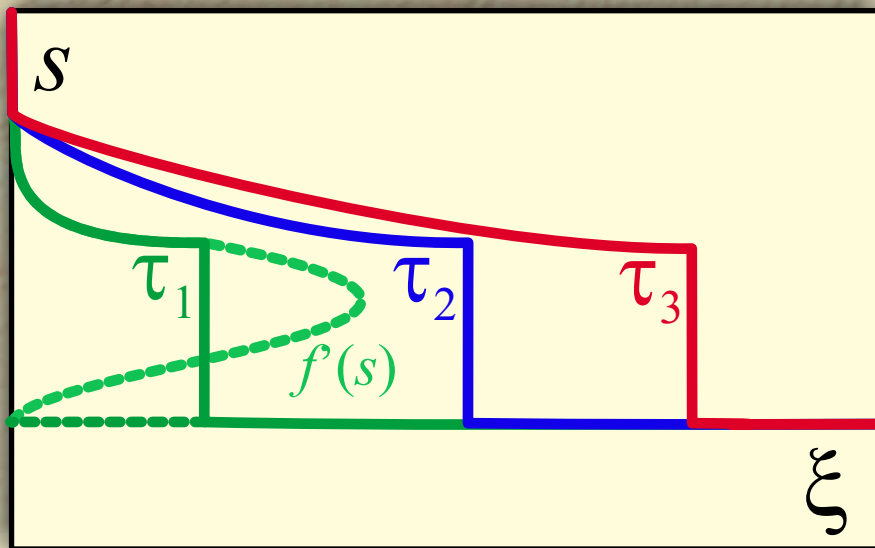
s - water saturation,
 τ and ξ - dimensionless
time and length,
 $\mu_0 = \mu_1 / \mu_2$ - water and oil
viscosities ratio

Buckley-Leverett function

$$f(s) = \frac{f_1(s)}{\varphi(s)}$$

$$\varphi(s) = f_1(s) + \mu_0 f_2(s)$$

Solution:



Direct problem

$$\Delta P^{\tau < \tau_c} = -\mu_1 L v \tau \int_{s_c}^{s_2} \frac{f''(s)}{k(s) \cdot \varphi(s)} ds + \mu_2 L v \int_{x_c}^1 \frac{dx}{k(x)}$$

$$\Delta P^{\tau \geq \tau_c} = -\mu_1 L v \tau \int_{\bar{s}}^{s_2} \frac{f''(s)}{k(s) \cdot \varphi(s)} ds$$

$$V^{\tau \leq \tau_c} = \tau \cdot V_n$$

$$V^{\tau > \tau_c} = \left[\bar{s} - s_1 + \tau \cdot (1 - f(\bar{s})) \right] \cdot V_n$$

τ_c - water break time, s_1 and s_2 - initial and final water saturation, L - core length, v - displacement rate, k - permeability of the core, $\varphi(s) = f_1(s) + \mu_0 f_2(s)$, V_n - porosity

displacement front saturation $s_c \rightarrow f(s_c) = f'(s_c) \cdot (s_c - s_1)$

saturation at the core end $\bar{s} \rightarrow \tau = 1 / f'(\bar{s})$

parametrization of relative permeability functions

$$f_1(s) = F_1 x^{r_1 + r_2 x} \quad x = (s - s_1) / (s_2 - s_1)$$

$$f_2(s) = F_2 (1 - x)^{q_1 + q_2 x}$$

Analytical vs. Numerical solution

fast

applicable to any equation

Inverse problem

minimization functional

$$\Phi(r, q) = \sum_{i=1}^n \left(\alpha \left(\frac{V_{c,i} - V_{e,i}}{V_{e,i}} \right)^2 + \left(\frac{\Delta p_{c,i} - \Delta p_{e,i}}{\Delta p_{e,i}} \right)^2 \right) \rightarrow \min$$

α - scale factor

Optimization methods:

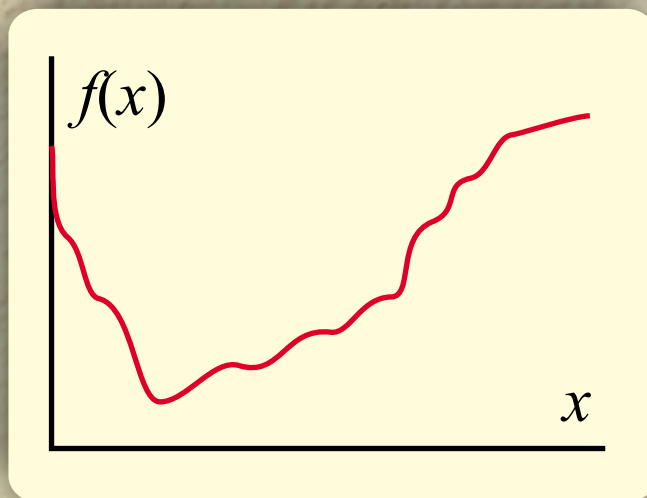
Newton

Gradient and Quasi-Newton: DFP, BFGS

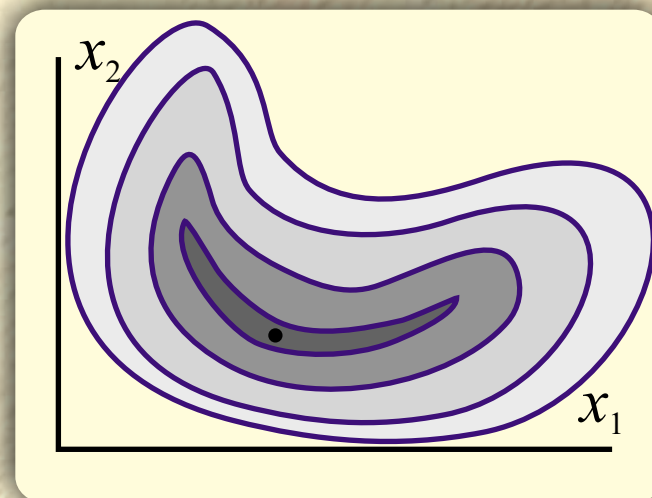
Direct methods: Simplex, Powell

Monte-Carlo

Genetic algorithm

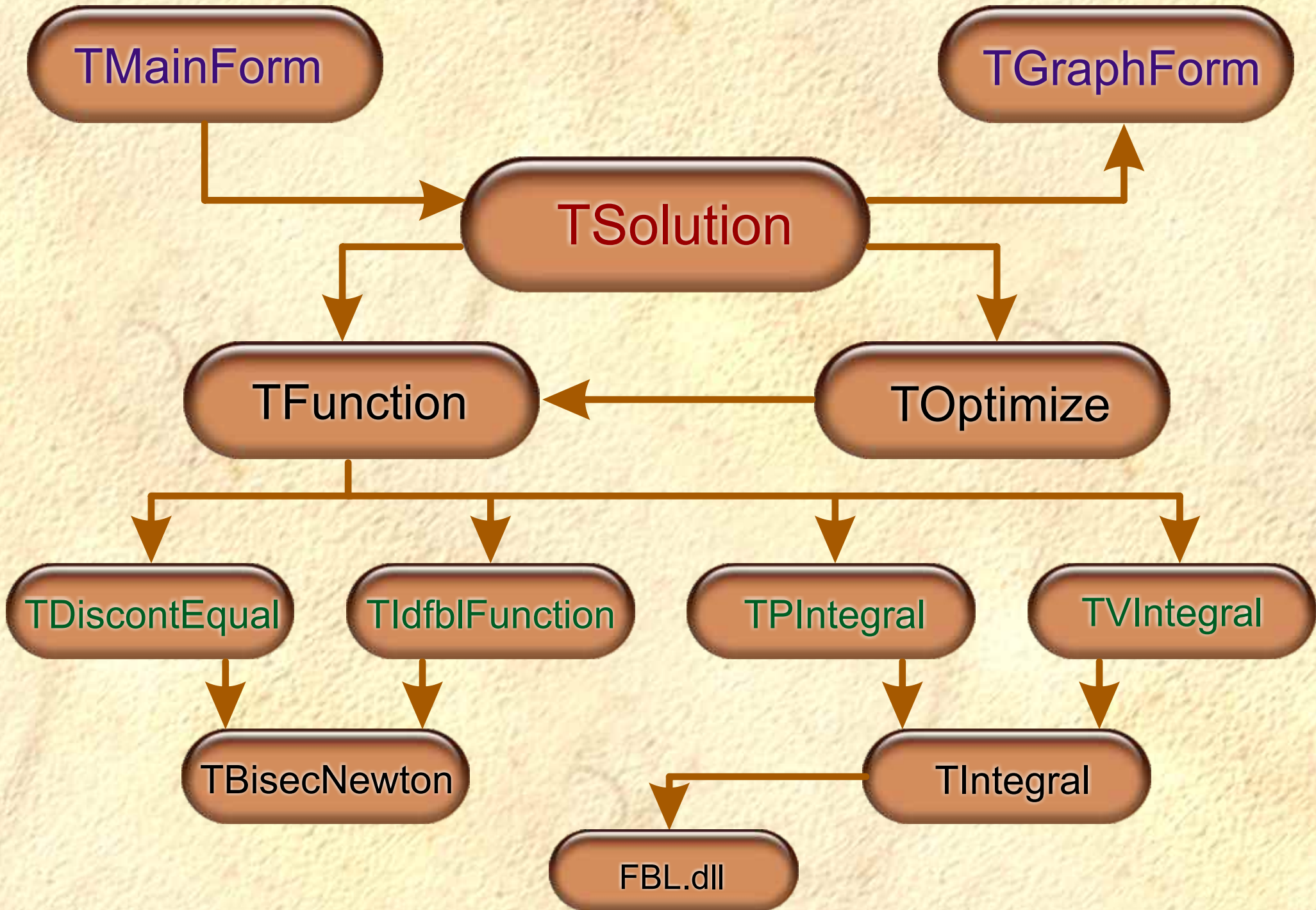


nonsmooth

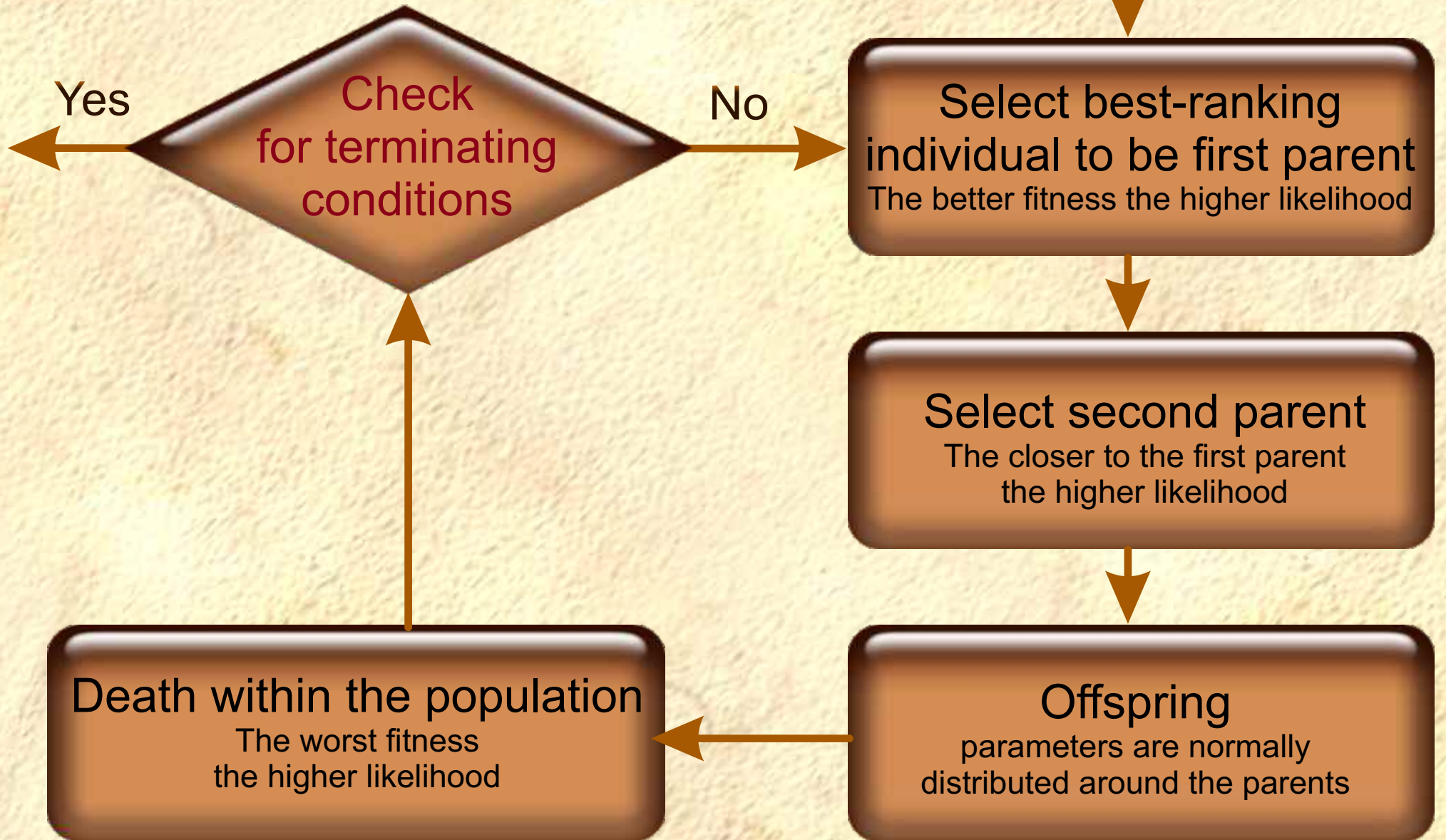


ravine surface

Program structure



Genetic optimization



ОФП interface

ОФП C:\My Documents\OFP\ZMB-1.7-GaussGen-s002-0-SourceExp.dat

Files Calculation Windows Help

ЗМБ-1 N0

	tau	V2, cm3	dp, МПа
1	0.00100	0.02000	0.03012
2	0.00324	0.06480	0.03132
3	0.00548	0.10959	0.03252
4	0.00772	0.15439	0.03372
5	0.00996	0.19918	0.03491
6	0.01220	0.24398	0.03611
7	0.01444	0.28877	0.03731
8	0.01668	0.33357	0.03851
9	0.01892	0.37836	0.03971
10	0.02116	0.42315	0.04091
11	0.02340	0.46794	0.04211
12	0.02564	0.51273	0.04331
13	0.02788	0.55752	0.04451
14	0.03012	0.60231	0.04571
15	0.03236	0.64710	0.04691

	Length, m	k, mkm2
1	0.15130	0.02780

Water viscosity, mPa*s: 0.4

Oil viscosity, mPa*s: 2

F1, water RPP. Optimization 0.03

F2, oil RPP. Optimization 0.7

Water saturation: 0.3

Residual water saturation: 0.6

Interstice volume, cm3: 20

Displacement speed, m/year: 60

Nonequilibrium factor: 0

r1 5 q1 2

r2 3 q2 -1

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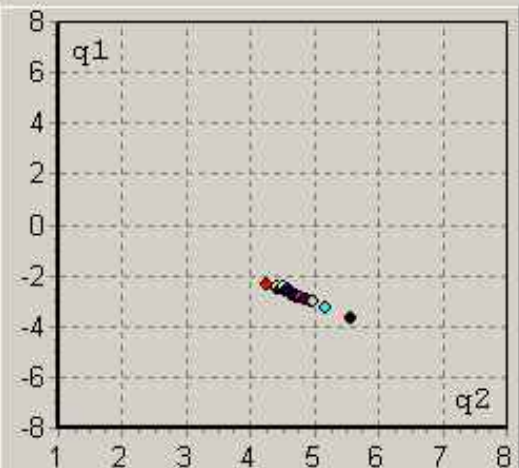
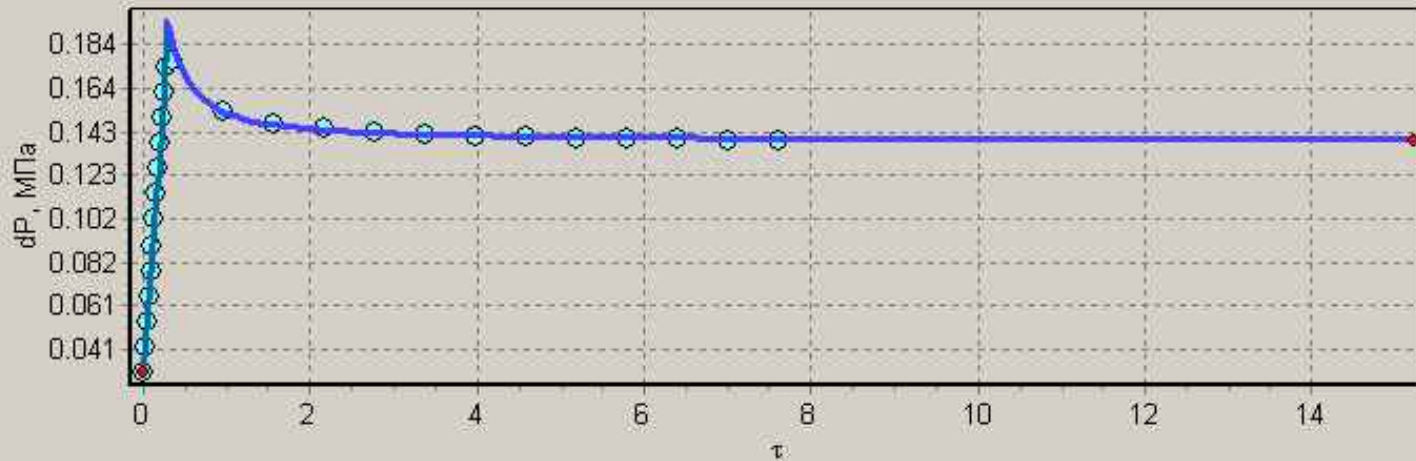
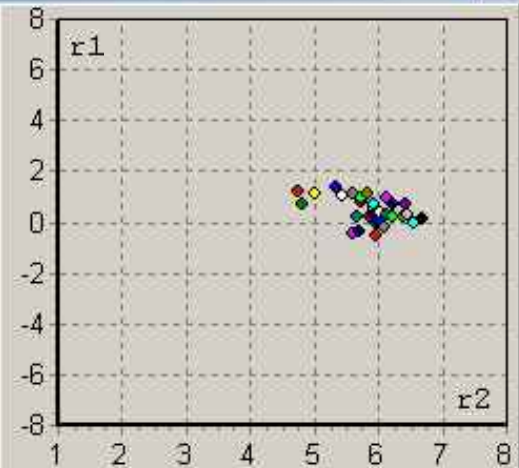
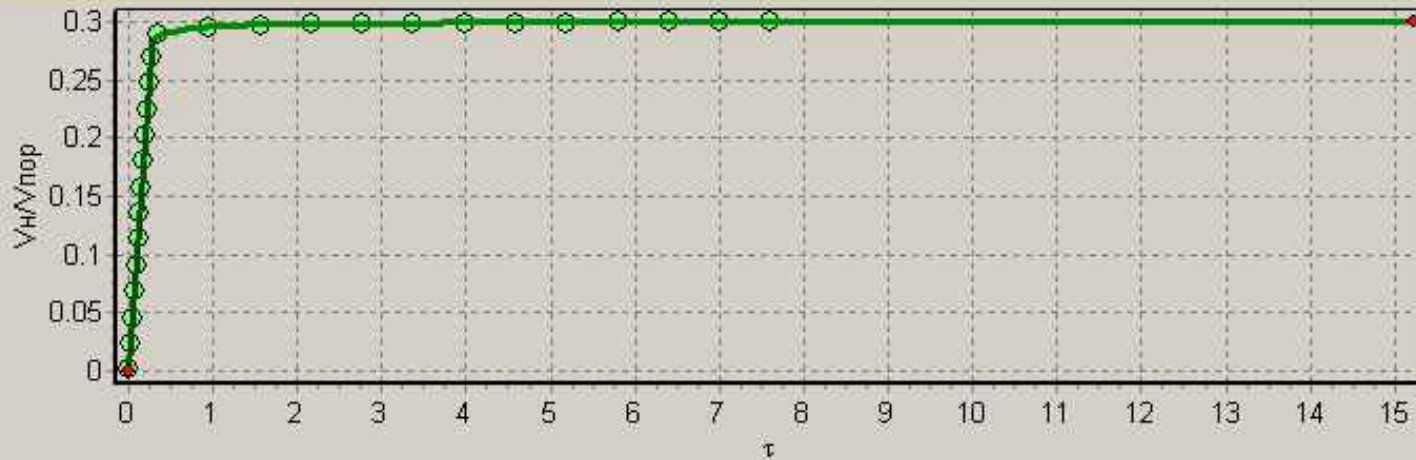
Integral method Difference scheme

2 parameter RPP $f1 = F1 * x^{(r1 + q1 * x)}$

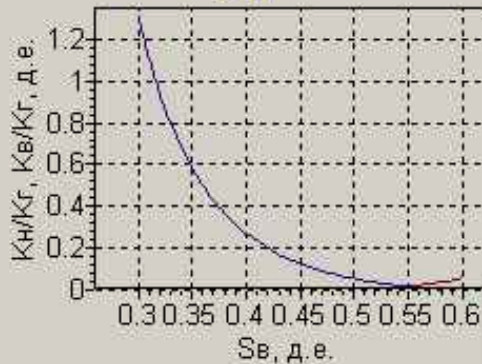
4 parameter RPP $f2 = F2 * (1 - x)^{(r2 + q2 * x)}$

ОФП interface

Graphs



ОФП



Genetic optimization

$r1=6.00$ [0.00..0.00]
 $q1=0.05$ [0.00..0.00]
 $r2=4.89$ [0.00..0.00]
 $q2=-2.97$ [0.00..0.00]
 $F1=0.0565$
 $F2=1.3080$
 $Lambda=0.0000$

$I = 0.00122$
 $I_v = 0.00007$ $I_p = 0.01143$

Стоп

$\tau_{[cr]}=0.286$ $s_{[cr]}=0.574$

