МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ РФ

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Лабораторная работа № 3
Исследование алгоритма имитации отжига

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Цель работы

Изучение метода имитации отжига для поиска экстремума на примере унимодальной и мультимодальной функций одного переменного.

Постановка задачи

1. На интервале [-5; 2] задана унимодальная функция одного переменного f(x). Используя метод имитации отжига осуществить поиск минимума f(x).

2. При аналогичных исходных условиях осуществить поиск минимума f(x), модулированной сигналом sin(5x), т.е. мультимодальной функции f(x)*sin(5x).

Вариант 1:

№пп	Функция $f(x)$	a	b
1	$-0,5\cos 0,5x - 0,5$	–5	2

График функции

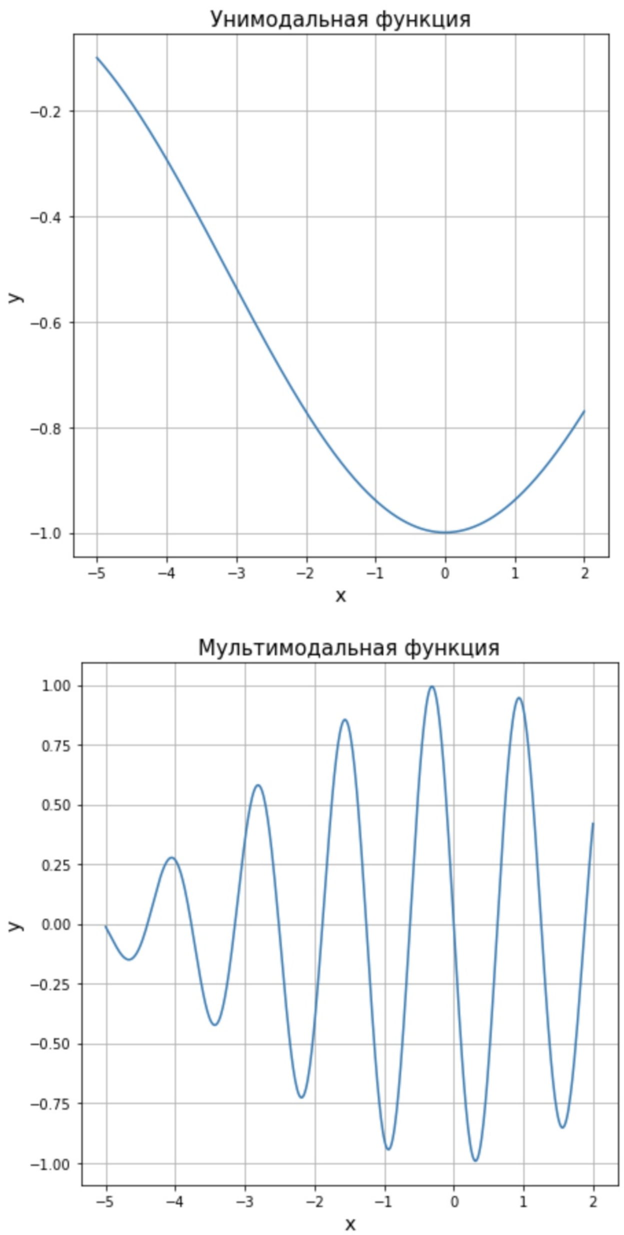

Рис.1. Графики функций

Скриншот консоли

```
/Users/kirillbrockij/TSISA/lab_03/cmake-build-debug/lab_03
Variant 1

 (-0.5)*cos(0.5*x)-0.5, interval: [-5 2]
```

N	T	x	f(x)
1	10000	-4.57841	-0.170906
2	9500	-2.00333	-0.76945
3	9025	-4.96385	-0.104903
4	8573.75	0.645897	-0.974152
5	8145.06	0.591958	-0.978259
6	7737.81	-2.96368	-0.544419
7	7350.92	-0.902183	-0.949986
8	6983.37	1.00411	-0.938297
9	6634.2	1.07224	-0.929849
10	6302.49	0.775414	-0.962889
11	5987.37	0.380792	-0.990965
12	5688	-3.03016	-0.527843
13	5403.6	1.48092	-0.869079
14	5133.42	-0.135435	-0.998854
15	4876.75	0.74922	-0.965325
16	4632.91	-3.31729	-0.456131
17	4401.27	-2.52528	-0.651652
18	4181.2	0.67741	-0.971593
19	3972.14	-1.77325	-0.816016
20	3773.54	-4.01745	-0.287967
21	3584.86	-4.93749	-0.108974
22	3405.62	0.842498	-0.956289
23	3235.34	0.864476	-0.954015
24	3073.57	-0.847829	-0.955743
25	2919.89	-2.45395	-0.668544
26	2773.9	-1.25964	-0.904067
27	2635.2	-0.689345	-0.970593
28	2503.44	1.17914	-0.91559
29	2378.27	1.80469	-0.809885
30	2259.36	1.28447	-0.900379
31	2146.39	-4.8293	-0.126396
32	2039.07	-4.53908	-0.178372
33	1937.11	-0.344112	-0.992617
34	1840.26	0.517237	-0.983372
35	1748.25	-2.15972	-0.735726
36	1660.83	1.65473	-0.83841
37	1577.79	1.97808	-0.774746
38	1498.9	-4.29501	-0.227367
39	1423.96	1.62515	-0.843816
40	1352.76	1.85268	-0.800383
41	1285.12	-2.36985	-0.688184
42	1220.87	-4.965	-0.104726
43	1159.82	0.414004	-0.989326
44	1101.83	-4.83364	-0.125674
45	1046.74	-0.21382	-0.997145
46	994.403	-0.672619	-0.971989
47	944.682	-0.971374	-0.942177
48	897.448	1.79284	-0.812206
49	852.576	-4.73352	-0.142731
50	809.947	-1.03365	-0.934696
51	769.45	-3.54267	-0.400401
52	730.977	-4.44049	-0.197627
53	694.428	-0.707976	-0.968999
54	659.707	-3.95695	-0.301761
55	626.722	0.177594	-0.99803
56	595.386	-2.17622	-0.732081
57	565.616	-0.268367	-0.995505
58	537.335	-0.437533	-0.988083
59	510.469	-0.467233	-0.986418
60	484.945	-3.48693	-0.414095
61	460.698	-0.0117791	-0.999991
62	437.663	0.0293991	-0.999946
63	415.78	1.26971	-0.902578
64	394.991	-0.616296	-0.976448
65	375.241	-3.09366	-0.511982
66	356.479	-1.71741	-0.82671
67	338.655	-1.43275	-0.877096
68	321.723	1.81383	-0.80809
69	305.636	-0.0582781	-0.999788
70	290.355	-4.47944	-0.189929
71	275.837	-4.75425	-0.139124
72	262.045	-1.82068	-0.806739
73	248.943	-1.16831	-0.917089
74	236.496	1.20357	-0.912163
75	224.671	0.0882322	-0.999514
76	213.437	0.919073	-0.948129
77	202.765	-3.10862	-0.508243
78	192.627	-1.84247	-0.802419
79	182.996	-3.35209	-0.447472
80	173.846	1.57267	-0.853222
81	165.154	1.81944	-0.806984
82	156.896	-4.7014	-0.148395
83	149.051	-0.584989	-0.978764
84	141.599	-1.91369	-0.788051
85	134.519	-1.97808	-0.774746
86	127.793	0.299542	-0.994403
87	121.403	-3.6031	-0.385643
88	115.333	1.28607	-0.90014
89	109.566	0.961789	-0.943291
90	104.088	-3.2067	-0.483726
91	98.8836	-1.46821	-0.871215
92	93.9395	0.734536	-0.966656
93	89.2425	-0.655374	-0.973395
94	84.7804	-1.8763	-0.795641
95	80.5413	-1.11615	-0.924138
96	76.5143	-4.12501	-0.263934
97	72.6886	-3.51964	-0.40605
98	69.0541	-2.56826	-0.641378
99	65.6014	-0.748393	-0.965401
100	62.3214	-4.24055	-0.238879
101	59.2053	1.12104	-0.92349
102	56.245	-0.712109	-0.96864
103	53.4328	-3.41082	-0.432897
104	50.7611	-3.11298	-0.507153
105	48.2231	0.1534	-0.99853
106	45.8119	-2.80203	-0.584483
107	43.5213	-3.40403	-0.434578
108	41.3453	0.587299	-0.978597
109	39.278	-4.26844	-0.232958
110	37.3141	-4.78526	-0.133802
111	35.4484	-1.66851	-0.835865
112	33.676	1.33011	-0.893442
113	31.9922	-0.873707	-0.953044
114	30.3926	-3.39644	-0.436461
115	28.8729	-4.3232	-0.221487
116	27.4293	-3.61746	-0.382152
117	26.0578	-1.67173	-0.835268
118	24.7549	-3.75592	-0.348822
119	23.5172	-0.587561	-0.978578
120	22.3413	-3.13445	-0.501784
121	21.2243	0.387941	-0.990623
122	20.1631	-1.86965	-0.796979
123	19.1549	-1.63748	-0.841571
124	18.1972	-2.11013	-0.746586
125	17.2873	1.80819	-0.809198
126	16.4229	-1.72866	-0.824575
127	15.6018	-1.58288	-0.851411
128	14.8217	-1.48981	-0.867577
129	14.0806	1.83504	-0.803896
130	13.3766	-2.2966	-0.70502
131	12.7078	-4.71684	-0.14566
132	12.0724	0.702582	-0.969465
133	11.4687	1.29841	-0.898283
134	10.8953	-1.46086	-0.872444
135	10.3505	-0.634653	-0.975037
136	9.83302	-3.60812	-0.384423
137	9.34136	-4.28964	-0.228492
138	8.8743	-3.42522	-0.429331
139	8.43058	-4.64965	-0.157709
140	8.00905	-1.36598	-0.887845
141	7.6086	-2.98871	-0.538184
142	7.22817	-0.760557	-0.964281
143	6.86676	1.31653	-0.895527
144	6.52342	-3.89904	-0.315132
145	6.19725	0.327985	-0.993292
146	5.88739	-1.55183	-0.85689
147	5.59302	-1.21734	-0.910204
148	5.31337	-3.89015	-0.3172
149	5.0477	-1.39289	-0.883564
150	4.79532	-0.292979	-0.994645
151	4.55555	-1.09276	-0.927206
152	4.32777	-1.63514	-0.841999
153	4.11138	-3.83103	-0.331034
154	3.90581	0.00808046	-0.999996
155	3.71052	-2.19168	-0.728649
156	3.525	-3.50536	-0.409558
157	3.34875	-2.80281	-0.58429
158	3.18131	-1.90473	-0.789879
159	3.02224	0.182956	-0.997909
160	2.87113	-3.06105	-0.52013
161	2.72758	1.09298	-0.927176
162	2.5912	-3.22353	-0.479522
163	2.46164	-0.708095	-0.968989
164	2.33856	1.04489	-0.9333
165	2.22163	-1.17282	-0.916466
166	2.11055	-2.99976	-0.535429
167	2.00502	0.554457	-0.980909
168	1.90477	-3.24795	-0.473423
169	1.80953	-4.15754	-0.256796
170	1.71905	-3.49191	-0.412867
171	1.6331	1.39474	-0.883267
172	1.55145	0.389288	-0.990558
173	1.47387	-0.233594	-0.996593
174	1.40018	-0.233594	-0.996593
175	1.33017	0.952084	-0.944408
176	1.26366	-3.69742	-0.362826
177	1.20048	0.939287	-0.945865
178	1.14045	-3.40184	-0.435123
179	1.08343	-1.77326	-0.816013
180	1.02926	-2.19258	-0.728451
181	0.977798	-0.458436	-0.986922
182	0.928908	-0.458436	-0.986922
183	0.882462	-2.08986	-0.75098
184	0.838339	-2.65908	-0.619462
185	0.796422	0.117038	-0.999144
186	0.756601	-4.94084	-0.108454
187	0.718771	-0.494234	-0.984811
188	0.682833	-2.58841	-0.63654
189	0.648691	-2.34345	-0.694282
190	0.616256	-2.32346	-0.698877
191	0.585444	-2.33015	-0.697342
192	0.556171	-2.33015	-0.697342
193	0.528363	-2.33015	-0.697342
194	0.501945	-0.249813	-0.996105
195	0.476847	-3.61047	-0.383852
196	0.453005	-1.87511	-0.79588
197	0.430355	0.968458	-0.942517
198	0.408837	0.968458	-0.942517
199	0.388395	0.841944	-0.956346
200	0.368975	-1.44627	-0.874867
201	0.350527	1.70215	-0.829588
202	0.333	1.70215	-0.829588
203	0.31635	1.70215	-0.829588
204	0.300533	-2.70927	-0.607241
205	0.285506	-4.13992	-0.260654
206	0.271231	0.613186	-0.976684
207	0.257669	0.613186	-0.976684
208	0.244786	0.613186	-0.976684
209	0.232547	-1.05575	-0.93194
210	0.220919	-1.24099	-0.906795
211	0.209873	-0.793998	-0.961113
212	0.19938	-0.720717	-0.967885
213	0.189411	-0.720717	-0.967885
214	0.17994	-0.720717	-0.967885
215	0.170943	-0.720717	-0.967885

Run: lab_03

```
| 216 | 0.162396  | -0.720717 | -0.967885    |
| 217 | 0.154276  | 1.66737   | -0.836075    |
| 218 | 0.146562  | 1.66737   | -0.836075    |
| 219 | 0.139234  | -0.656215 | -0.973327    |
| 220 | 0.132272  | -0.656215 | -0.973327    |
| 221 | 0.125659  | 0.528402  | -0.982651    |
| 222 | 0.119376  | -0.154012 | -0.998518    |
| 223 | 0.113407  | -0.154012 | -0.998518    |
| 224 | 0.107737  | -0.154012 | -0.998518    |
| 225 | 0.10235   | -0.227365 | -0.996773    |
| 226 | 0.0972324 | -0.227365 | -0.996773    |
| 227 | 0.0923708 | 0.488805  | -0.985141    |
| 228 | 0.0877523 | 0.488805  | -0.985141    |
| 229 | 0.0833647 | 0.488805  | -0.985141    |
| 230 | 0.0791964 | 0.488805  | -0.985141    |
| 231 | 0.0752366 | 0.488805  | -0.985141    |
| 232 | 0.0714748 | 1.38573   | -0.884709    |
| 233 | 0.067901  | -0.703368 | -0.969397    |
| 234 | 0.064506  | -0.703368 | -0.969397    |
| 235 | 0.0612807 | -0.703368 | -0.969397    |
| 236 | 0.0582167 | -0.703368 | -0.969397    |
| 237 | 0.0553058 | -0.703368 | -0.969397    |
| 238 | 0.0525405 | -0.703368 | -0.969397    |
| 239 | 0.0499135 | 0.482869  | -0.985498    |
| 240 | 0.0474178 | 0.482869  | -0.985498    |
| 241 | 0.0450469 | 0.482869  | -0.985498    |
| 242 | 0.0427946 | 0.482869  | -0.985498    |
| 243 | 0.0406549 | 0.482869  | -0.985498    |
| 244 | 0.0386221 | 0.482869  | -0.985498    |
| 245 | 0.036691  | 0.482869  | -0.985498    |
| 246 | 0.0348565 | 0.482869  | -0.985498    |
| 247 | 0.0331136 | 0.482869  | -0.985498    |
| 248 | 0.031458  | 0.482869  | -0.985498    |
| 249 | 0.0298851 | -0.150383 | -0.998587    |
| 250 | 0.0283908 | -0.150383 | -0.998587    |
| 251 | 0.0269713 | -0.969135 | -0.942438    |
| 252 | 0.0256227 | -0.153403 | -0.99853     |
```

Run: lab_03

```
| 253 | 0.0243416 | 0.348611   | -0.992424    |
| 254 | 0.0231245 | 0.348611   | -0.992424    |
| 255 | 0.0219683 | 0.348611   | -0.992424    |
| 256 | 0.0208699 | 0.348611   | -0.992424    |
| 257 | 0.0198264 | 0.348611   | -0.992424    |
| 258 | 0.018835  | 0.348611   | -0.992424    |
| 259 | 0.0178933 | 0.348611   | -0.992424    |
| 260 | 0.0169986 | 0.00239574 | -1           |
| 261 | 0.0161487 | 0.265206   | -0.995611    |
| 262 | 0.0153413 | 0.265206   | -0.995611    |
| 263 | 0.0145742 | 0.265206   | -0.995611    |
| 264 | 0.0138455 | 0.265206   | -0.995611    |
| 265 | 0.0131532 | 0.265206   | -0.995611    |
| 266 | 0.0124956 | 0.265206   | -0.995611    |
| 267 | 0.0118708 | 0.265206   | -0.995611    |
| 268 | 0.0112772 | 0.265206   | -0.995611    |
| 269 | 0.0107134 | 0.265206   | -0.995611    |
| 270 | 0.0101777 | 0.265206   | -0.995611    |
---------------------------------------------
Result: Xmin = 0.265206, Fmin = -0.995611


 (-0.5)*cos(0.5*x)-0.5)*sin(5x), interval: [-5 2]
---------------------------------------------
| N   | T          | x          | f(x)         |
---------------------------------------------
| 1   | 10000      | -3.8214    | 0.0848657    |
| 2   | 9500       | 1.77375    | -0.430655    |
| 3   | 9025       | 0.418458   | -0.857621    |
| 4   | 8573.75    | 0.0249994  | -0.124667    |
| 5   | 8145.06    | -2.22182   | -0.717277    |
| 6   | 7737.81    | -2.10088   | -0.660098    |
| 7   | 7350.92    | -2.55713   | 0.140084     |
| 8   | 6983.37    | 1.57369    | -0.852952    |
| 9   | 6634.2     | -1.95284   | -0.259687    |
| 10  | 6302.49    | 1.71364    | -0.625208    |
| 11  | 5987.37    | -1.87163   | 0.0530322    |
| 12  | 5688       | -4.97542   | -0.0260804   |
| 13  | 5403.6     | -4.85745   | -0.0911101   |
| 14  | 5133.42    | -3.12986   | 0.0294932    |
| 15  | 4876.75    | -4.3755    | 0.0238919    |
```

Run: lab_03

```
| 16  | 4632.91    | -2.10655   | -0.668736    |
| 17  | 4401.27    | -3.76687   | -0.00527046  |
| 18  | 4181.2     | -1.49106   | 0.799342     |
| 19  | 3972.14    | 0.782238   | 0.669572     |
| 20  | 3773.54    | -3.92686   | 0.218131     |
| 21  | 3584.86    | -0.702351  | -0.350725    |
| 22  | 3405.62    | -0.404891  | 0.889672     |
| 23  | 3235.34    | 1.28578    | -0.130715    |
| 24  | 3073.57    | -3.86402   | 0.146573     |
| 25  | 2919.89    | -0.0431527 | 0.214068     |
| 26  | 2773.9     | 1.66104    | -0.753447    |
| 27  | 2635.2     | -3.8603    | 0.141564     |
| 28  | 2503.44    | 0.947677   | 0.944592     |
| 29  | 2378.27    | 0.823119   | 0.792608     |
| 30  | 2259.36    | -2.83574   | 0.575668     |
| 31  | 2146.39    | -2.3294    | -0.554669    |
| 32  | 2039.07    | -4.27936   | 0.129158     |
| 33  | 1937.11    | 0.834129   | 0.820088     |
| 34  | 1840.26    | -2.62953   | 0.34407      |
| 35  | 1748.25    | -1.48301   | 0.786377     |
| 36  | 1660.83    | -0.144864  | 0.661756     |
| 37  | 1577.79    | -3.7222    | -0.0843232   |
| 38  | 1498.9     | 1.918      | 0.129484     |
| 39  | 1423.96    | 1.7305     | -0.575125    |
| 40  | 1352.76    | 1.47578    | -0.773595    |
| 41  | 1285.12    | -2.6352    | 0.357993     |
| 42  | 1220.87    | -2.58587   | 0.226215     |
| 43  | 1159.82    | -2.64421   | 0.379386     |
| 44  | 1101.83    | -3.86933   | 0.15358      |
| 45  | 1046.74    | 0.160436   | -0.717718    |
| 46  | 994.403    | -3.54786   | -0.357543    |
| 47  | 944.682    | 1.88879    | 0.0152007    |
| 48  | 897.448    | 1.0421     | 0.820203     |
| 49  | 852.576    | -0.188718  | 0.807869     |
| 50  | 809.947    | 1.21585    | 0.184368     |
| 51  | 769.45     | -3.15613   | -0.0360467   |
| 52  | 730.977    | -4.07179   | 0.275226     |
| 53  | 694.428    | -2.12251   | -0.689983    |
| 54  | 659.707    | 1.00337    | 0.895231     |
| 55  | 626.722    | -0.521547  | 0.500256     |
| 56  | 595.386    | 0.360382   | -0.965532    |
```

Run: lab_03

```
| 57  | 565.616    | -3.05738   | 0.212979     |
| 58  | 537.335    | -2.46355   | -0.163948    |
| 59  | 510.469    | -4.8977    | -0.069221    |
| 60  | 484.945    | 0.385226   | -0.928862    |
| 61  | 460.698    | 1.49057    | -0.798588    |
| 62  | 437.663    | -4.54247   | -0.117347    |
| 63  | 415.78     | -1.80795   | 0.303938     |
| 64  | 394.991    | -0.242854  | 0.933666     |
| 65  | 375.241    | -2.973     | 0.404737     |
| 66  | 356.479    | 0.759334   | 0.58753      |
| 67  | 338.655    | -1.12755   | -0.555       |
| 68  | 321.723    | 0.266893   | -0.967882    |
| 69  | 305.636    | 0.672302   | 0.212046     |
| 70  | 290.355    | 0.366841   | -0.957411    |
| 71  | 275.837    | 0.490336   | -0.626955    |
| 72  | 262.045    | 0.218553   | -0.885255    |
| 73  | 248.943    | 0.227264   | -0.904165    |
| 74  | 236.496    | -0.376656  | 0.94316      |
| 75  | 224.671    | -4.91051   | -0.0620603   |
| 76  | 213.437    | 1.00433    | 0.893759     |
| 77  | 202.765    | 1.85807    | -0.107144    |
| 78  | 192.627    | -3.49674   | -0.403066    |
| 79  | 182.996    | -2.64514   | 0.381541     |
| 80  | 173.846    | -1.28664   | 0.134534     |
| 81  | 165.154    | 0.372324   | -0.949732    |
| 82  | 156.896    | 1.64529    | -0.78253     |
| 83  | 149.051    | -2.24937   | -0.693257    |
| 84  | 141.599    | -4.91707   | -0.0583851   |
| 85  | 134.519    | -2.80067   | 0.57959      |
| 86  | 127.793    | -2.92389   | 0.491095     |
| 87  | 121.403    | 0.213959   | -0.874594    |
| 88  | 115.333    | 0.00406356 | -0.0203164   |
| 89  | 109.566    | -3.22556   | -0.195262    |
| 90  | 104.088    | -2.07066   | -0.60465     |
| 91  | 98.8836    | -2.56388   | 0.160824     |
| 92  | 93.9395    | 1.13651    | 0.520747     |
| 93  | 89.2425    | -2.28424   | -0.644685    |
| 94  | 84.7804    | -1.1824    | -0.331935    |
| 95  | 80.5413    | -2.49994   | -0.0438202   |
| 96  | 76.5143    | -3.39859   | -0.418242    |
| 97  | 72.6886    | 1.96418    | 0.300054     |
```

Run: lab_03

```
| 98  | 69.0541    | 1.53932    | -0.848459    |
| 99  | 65.6014    | 1.4351     | -0.68253     |
| 100 | 62.3214    | -3.69645   | -0.130383    |
| 101 | 59.2053    | -2.53786   | 0.0795251    |
| 102 | 56.245     | -4.91038   | -0.0621341   |
| 103 | 53.4328    | -3.78106   | 0.0190986    |
| 104 | 50.7611    | -1.01512   | -0.875833    |
| 105 | 48.2231    | -0.186206  | 0.800498     |
| 106 | 45.8119    | -3.39639   | -0.417389    |
| 107 | 43.5213    | -3.16568   | -0.059357    |
| 108 | 41.3453    | 0.79066    | 0.697487     |
| 109 | 39.278     | -4.4335    | -0.0349197   |
| 110 | 37.3141    | -3.90423   | 0.195332     |
| 111 | 35.4484    | -0.352583  | 0.973995     |
| 112 | 33.676     | -3.5919    | -0.301801    |
| 113 | 31.9922    | 0.875026   | 0.899222     |
| 114 | 30.3926    | 1.36393    | -0.453929    |
| 115 | 28.8729    | 0.510498   | -0.546613    |
| 116 | 27.4293    | -0.0543446 | 0.268342     |
| 117 | 26.0578    | -4.0212    | 0.27305      |
| 118 | 24.7549    | -2.71081   | 0.506587     |
| 119 | 23.5172    | 1.83697    | -0.19094     |
| 120 | 22.3413    | -1.04148   | -0.821651    |
| 121 | 21.2243    | -2.10484   | -0.666187    |
| 122 | 20.1631    | -1.8012    | 0.329619     |
| 123 | 19.1549    | -2.23711   | -0.705567    |
| 124 | 18.1972    | -0.0594301 | 0.292732     |
| 125 | 17.2873    | -1.7824    | 0.399448     |
| 126 | 16.4229    | -2.73406   | 0.536839     |
| 127 | 15.6018    | 0.615122   | -0.0643886   |
| 128 | 14.8217    | 1.35261    | -0.410866    |
| 129 | 14.0806    | 1.35261    | -0.410866    |
| 130 | 13.3766    | -2.65241   | 0.398061     |
| 131 | 12.7078    | 1.59272    | -0.844557    |
| 132 | 12.0724    | -4.15259   | 0.242891     |
| 133 | 11.4687    | -2.97181   | 0.407106     |
| 134 | 10.8953    | -0.715034  | -0.406836    |
| 135 | 10.3505    | -3.57023   | -0.330912    |
| 136 | 9.83302    | 1.93456    | 0.192412     |
| 137 | 9.34136    | -1.1431    | -0.494968    |
| 138 | 8.8743     | -2.01788   | -0.472687    |
```

Run: lab_03

```
| 139 | 8.43058    | -0.326869  | 0.991332     |
| 140 | 8.00905    | -0.759841  | -0.589438    |
| 141 | 7.6086     | -0.655022  | -0.129582    |
| 142 | 7.22817    | -4.25649   | 0.153264     |
| 143 | 6.86676    | -0.778862  | -0.658031    |
| 144 | 6.52342    | 1.66811    | -0.738932    |
| 145 | 6.19725    | -4.14977   | 0.244672     |
| 146 | 5.88739    | 0.586838   | -0.20152     |
| 147 | 5.59302    | 1.98036    | 0.3555       |
| 148 | 5.31337    | -3.51833   | -0.386637    |
| 149 | 5.0477     | -3.51833   | -0.386637    |
| 150 | 4.79532    | -1.75324   | 0.501774     |
| 151 | 4.55555    | -4.6177    | -0.145583    |
| 152 | 4.32777    | 1.29033    | -0.1508      |
| 153 | 4.11138    | -4.49387   | -0.0861042   |
| 154 | 3.90581    | -0.995276  | -0.906814    |
| 155 | 3.71052    | -0.995276  | -0.906814    |
| 156 | 3.525      | -0.995276  | -0.906814    |
| 157 | 3.34875    | -0.995276  | -0.906814    |
| 158 | 3.18131    | -3.55549   | -0.348882    |
| 159 | 3.02224    | 1.71655    | -0.616834    |
| 160 | 2.87113    | -1.89794   | -0.0513236   |
| 161 | 2.72758    | 0.462745   | -0.726679    |
| 162 | 2.5912     | 0.462745   | -0.726679    |
| 163 | 2.46164    | 0.462745   | -0.726679    |
| 164 | 2.33856    | 0.462745   | -0.726679    |
| 165 | 2.22163    | -0.49551   | 0.606896     |
| 166 | 2.11055    | 1.1505     | 0.465414     |
| 167 | 2.00502    | -2.6213    | 0.32325      |
| 168 | 1.90477    | -3.1155    | 0.0658909    |
| 169 | 1.80953    | -0.23798   | 0.92505      |
| 170 | 1.71905    | 0.375907   | -0.944328    |
| 171 | 1.6331     | -1.12925   | -0.548597    |
| 172 | 1.55145    | 1.31478    | -0.256756    |
| 173 | 1.47387    | -1.53727   | 0.847382     |
| 174 | 1.40018    | -4.16406   | 0.235218     |
| 175 | 1.33017    | -4.3847    | 0.0141222    |
| 176 | 1.26366    | -2.58029   | 0.209955     |
| 177 | 1.20048    | 1.42376    | -0.65164     |
| 178 | 1.14045    | -1.87626   | 0.0345694    |
| 179 | 1.08343    | -4.83487   | -0.102668    |
```

```
| 264 | 0.0138455 | 0.357003   | -0.969379    |
| 265 | 0.0131532 | 0.357003   | -0.969379    |
| 266 | 0.0124956 | 0.357003   | -0.969379    |
| 267 | 0.0118708 | 0.357003   | -0.969379    |
| 268 | 0.0112772 | 0.357003   | -0.969379    |
| 269 | 0.0107134 | 0.357003   | -0.969379    |
| 270 | 0.0101777 | 0.357003   | -0.969379    |
---------------------------------------------
Result: Xmin = 0.357003, Fmin = -0.969379

Process finished with exit code 0
```

Листинг программы с реализацией алгоритмов на C++

```
#include <iostream>
#include <cmath>
#include <ctime>
#include <iomanip>


const double a = -5.;
const double b = 2.;

void printZagolovok() {
   std::cout << std::left << std::string(47, '-') << '\n'
       << "| " << std::setw(4) << "N"
       << "| " << std::setw(10) << "T"
       << "| " << std::setw(11) << "x"
       << "| " << std::setw(13) << "f(x)" << "|\n"
       << std::string(47, '-') << '\n';
}

void printLine(const int iteration, const double T,
             const double value, const double functionValue) {
   std::cout << "| " << std::setw(4) << iteration
       << "| " << std::setw(10) << T
       << "| " << std::setw(11) << value
       << "| " << std::setw(13) << functionValue << "|\n";
}

double random(const double lower, const double upper) {
   return lower + rand() * 1./RAND_MAX * (upper - lower);
}

template<class Function>
auto Method(const double A, const double B,
          Function func) {
   printZagolovok();
   const double T_min = .01;
   double T_i = 10000.;
   double x_i = random(A, B);
   int i = 0;
   while (T_i > T_min) {
      ++i;
      double x_new = random(A, B);
      double delta_f = func(x_new) - func(x_i);
      if (delta_f <= 0) {
```

```
            x_i = x_new;
        } else {
            double rand_Prob = random(0, 1);
            double proba = exp(-delta_f / T_i);
            if (rand_Prob < proba){
                x_i = x_new;
            }
        }
        printLine(i, T_i, x_i, func(x_i));
        T_i *= .95;
    }

    std::cout << std::string(47, '-') << '\n';
    return std::pair{x_i, func(x_i)};
}

double MyFunction(const double x) {
    return (-0.5)*std::cos(0.5*x)-0.5;
}

double MyFunctionWithSin(const double x) {
    return MyFunction(x) * sin(5*x);
}


int main() {
    std::cout << "Variant 1\nFunction 1: (-0.5)*cos(0.5*x)-0.5, interval: ["
              << a << " " << b << "]\n";
    srand(time(nullptr));
    auto result_1 = Method(a, b, MyFunction);
    std::cout << "Result: Xmin = " << result_1.first
         << ", Fmin = " << result_1.second << '\n';

    std::cout << "\nFunction 2: cos(x)*th(x)*sin(5*x), interval: ["
              << a << " " << b << "]\n";
    auto result_2 = Method(a, b, MyFunctionWithSin);
    std::cout << "Result: Xmin = " << result_2.first
         << ", Fmin = " << result_2.second << '\n';

    return 0;
}
```

Контрольный вопрос

В чем состоит сущность метода имитации отжига? Какова область применимости данного метода?

Основная идея алгоритма случайного заключается в том, точка, в которой может быть минимум и сравнивается значение функции в нём со точку. Если же оно больше, то осуществляется переход в новую точку с некоторой что итеративно выбирается значением в предыдущей точке. Если значение меньше, то выполняется переход в новую вероятностью, которая зависит от значения параметра-температуры (чем меньше температура, тем меньше вероятность перехода). За счёт этого можно выходить из локальных минимумов.

В настоящее время метод имитации отжига применяется для решения многих оптимизационных задач – финансовых, компьютерной графики, комбинаторных, в телекоммуникационных сетях и многих других. Зачастую метод отжига используют для обучения нейронных сетей.