Эволюционная стратегия с адаптацией матрицы ковариаций (CMA-ES)

Семинар по вычислительному интеллекту

Докладчик: Цой Ю.Р.

г. Томск, 06 апреля 2010 г.

http://qai.narod.ru/TomskWorkshop/

Введение

Алгоритм разработан Николасом Хансеном (Nikolaus Hansen)

http://www.lri.fr/~hansen/cmaesintro.html

Hansen and Ostermeier (1996). Adapting arbitrary normal mutation distributions in evolution strategies: The covariance matrix adaptation. In Proceedings of the 1996 IEEE International Conference on Evolutionary Computation, pp. 312-317.

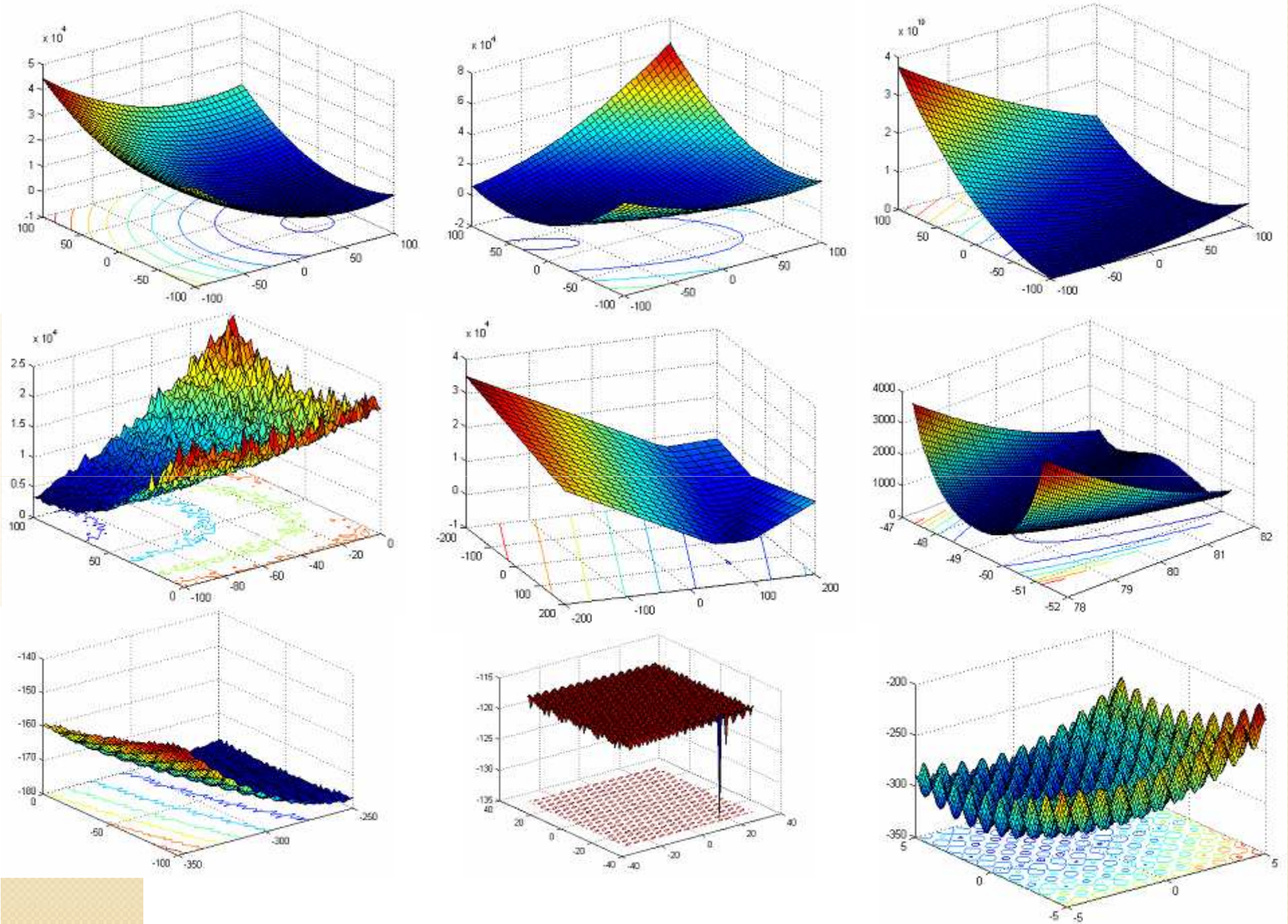
Hansen N. The CMA evolution strategy: a comparing review / In Lozano J.A., Larranaga P., Inza I., and Bengoetxea E., editors, Towards a new evolutionary computation. Advances on estimation of distribution algorithms, pages 75-102. Springer, 2006.

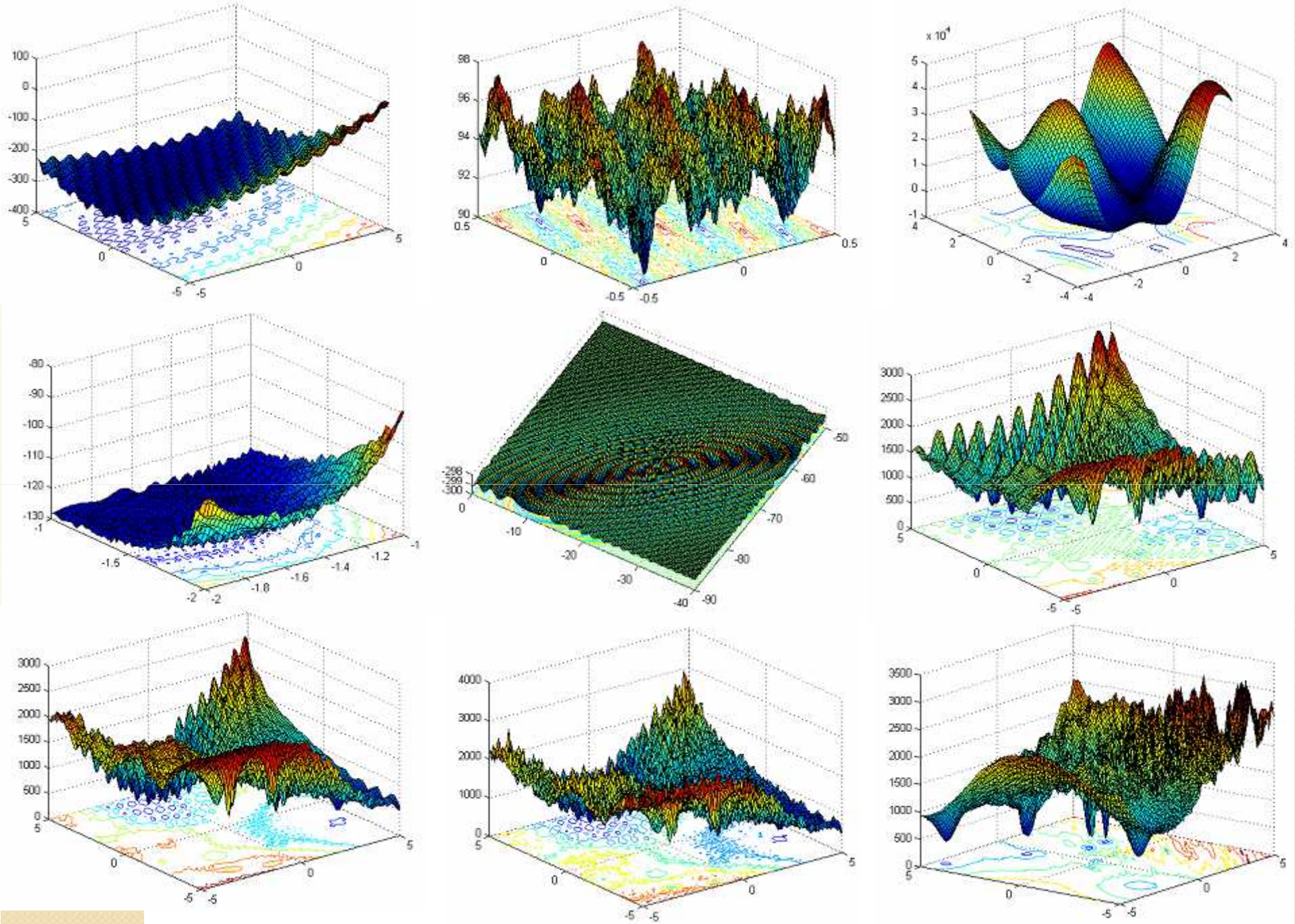
Основные моменты

- Адаптация длины шага
- Адаптация матрицы ковариаций
- Накопление информации об «эволюционном пути»

(далее смотрим:

- July 2009, Montreal, Tutorial at GECCO, *Evolution Strategies and Covariance Matrix Adaptation* http://www.lri.fr/~hansen/gecco2009handout.pdf
- *The CMA Evolution Strategy: A Tutorial* http://www.lri.fr/~hansen/cmatutorial.pdf)

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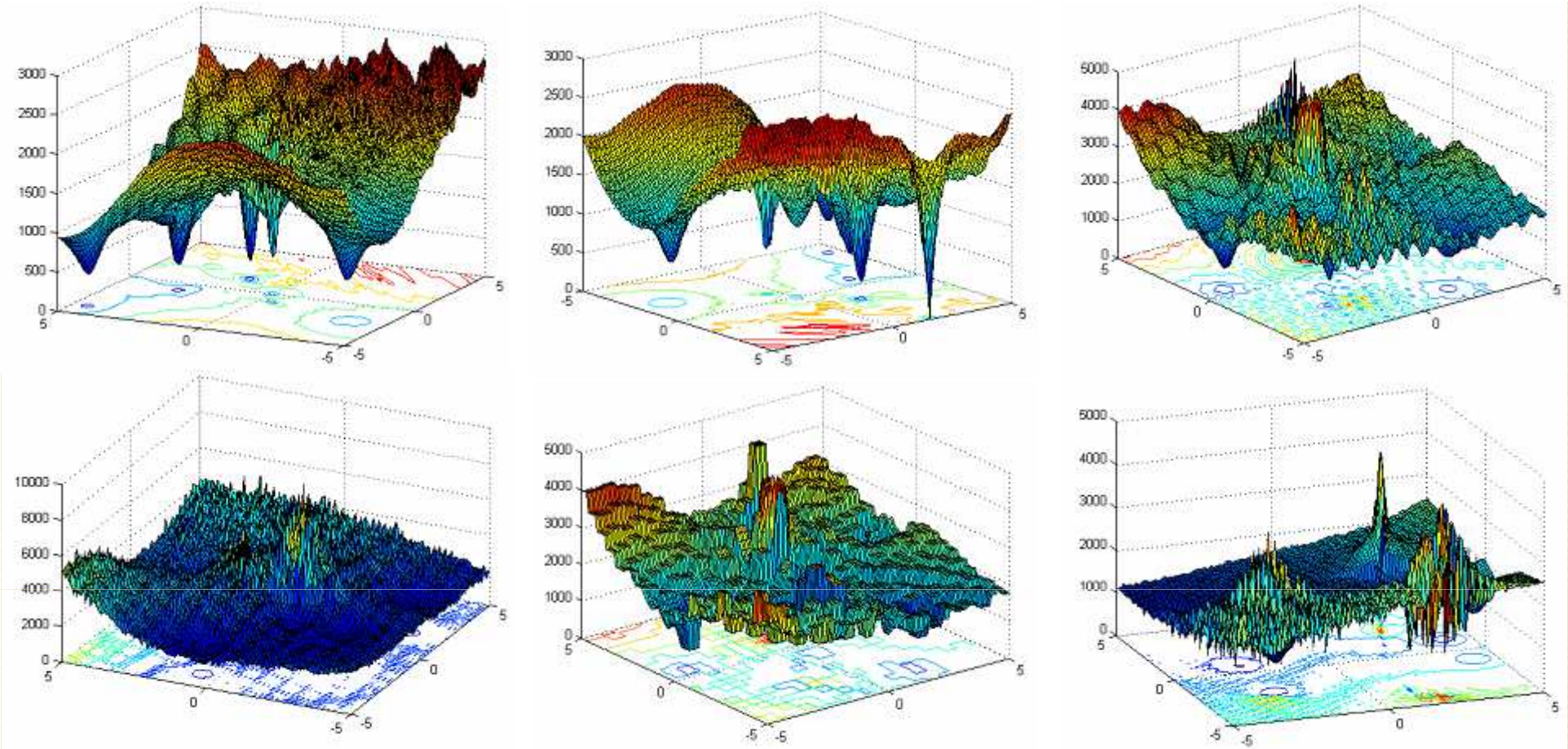


Рисунки:

P. N. Suganthan, N. Hansen, J. J. Liang, K. Deb, Y.-P. Chen, A. Auger and S. Tiwari, "Problem Definitions and Evaluation Criteria for the CEC 2005 Special Session on Real-Parameter Optimization", Technical Report, Nanyang Technological University, Singapore, May 2005 AND KanGAL Report #2005005, IIT Kanpur, India.

http://www.bionik.tu-berlin.de/user/niko/Tech-Report-May-30-05.pdf

Фрагменты презентации
http://www.bionik.tu-berlin.de/user/niko/cec2005compareresults.pdf

Compilation of Results on the 2005 CEC Benchmark Function Set

Nikolaus Hansen

Computational Laboratory (CoLab)
Institute of Computational Science
ETH Zurich

May 4, 2006

Unimodal Functions

Normalized Success Performance, Tabulated

$n = 10$, $\mathtt{FE}_{\max} = 100000$

	solved functions	success rate	1 Sphere	2 Schwefel 1.2	3 Ellipsoid Condition 10^6	4 Schwefel 1.2 with Noise	5 Schwefel 2.6 on Bounds	6 Rosenbrock
G-CMA-ES	6	100%	1.6(25)	1.0(25)	1.0(25)	1.0(25)	1.0(25)	1.5(25)
EDA	6	97%	10.0(25)	4.6(25)	2.5(23)	4.1(25)	4.2(25)	9.6(22)
DE	6	96%	29.0(25)	19.2(25)	18.5(20)	17.9(25)	6.9(25)	6.6(24)
L-CMA-ES	6	88%	1.7(25)	1.1(25)	1.0(25)	65.5(7)	1.0(25)	1.3(25)
BLX-GL50	5	83%	19.0(25)	17.1(25)	[9]	14.5(25)	4.7(25)	7.3(25)
DMS-L-PSO	5	80%	12.0(25)	5.0(25)	1.8(25)	[11]	18.6(20)	7.7(25)
L-SaDE	5	77%	10.0(25)	4.2(25)	8.0(16)	15.9(24)	[9]	6.9(25)
SPC-PNX	4	67%	6.7(25)	12.9(25)	[11]	10.7(25)	6.8(25)	[10]
CoEVO	4	67%	23.0(25)	11.3(25)	6.8(25)	16.2(25)	[10]	[11]
K-PCX	4	62%	1.0(25)	1.0(25)	[8]	19.7(21)	[11]	1.0(22)
BLX-MA	3	49%	12.0(25)	15.4(25)	[10]	25.9(24)	[8]	[9]

- **First row**: Success Performance $\mathtt{FEs} = \mathtt{mean}(\#\mathit{fevals}) \times \frac{\#\text{all runs (25)}}{\#\text{successful runs}}$ of the best algorithm, where $\#\mathit{fevals}$ includes only successful runs
- **Table entries**: Success Performance $\mathtt{FEs}$ divided by $\mathtt{FEs}$ of the best algorithm (first row), (number of successful runs in round brackets), [rank of median final function value, where $\mathtt{FEs}$ is not available, in square brackets]

Unimodal Functions

Normalized Success Performance, Tabulated

$n = 30$, $\mathtt{FE}_{\max} = 300000$

	solved functions	success rate	1 Sphere 2700	2 Schwefel 1.2 12000	3 Ellipsoid Condition 10^6 43000	4 Schwefel 1.2 with Noise 59000	5 Schwefel 2.6 on Bounds 66000	6 Rosenbrock 60000
G-CMA-ES	6	90%	1.7(25)	1.1(25)	1.0(25)	1.0(10)	1.0(25)	1.0(25)
L-CMA-ES	5	83%	1.8(25)	1.2(25)	1.0(25)	[11]	1.1(25)	1.1(25)
EDA	4	67%	55.6(25)	13.3(25)	5.1(25)	3.4(25)	[3]	[10]
DMS-L-PSO	4	63%	1.9(25)	10.8(25)	7.9(21)	[9]	[9]	5.5(24)
BLX-GL50	3	50%	21.5(25)	13.3(25)	[7]	[6]	[6]	3.7(25)
SPC-PNX	4	45%	11.1(25)	26.7(22)	[11]	6.1(19)	[10]	86.7(1)
K-PCX	3	43%	1.0(25)	1.0(25)	[6]	[8]	[7]	1.1(14)
L-SaDE	3	41%	7.4(25)	12.5(24)	[8]	9.2(13)	[4]	[8]
BLX-MA	1	17%	11.9(25)	[10]	[10]	[7]	[7]	[8]
DE	1	17%	51.9(25)	[11]	[9]	[5]	[5]	[7]
CoEVO	2	7%	519 (3)	70.0(8)	[5]	[10]	[11]	[11]

- **First row**: Success Performance $\mathtt{FEs} = \mathtt{mean}(\#fevals) \times \frac{\#\text{all runs (25)}}{\#\text{successful runs}}$ of the best algorithm, where $\#fevals$ includes only successful runs
- **Table entries**: Success Performance $\mathtt{FEs}$ divided by $\mathtt{FEs}$ of the best algorithm (first row), (number of successful runs in round brackets), [rank of median final function value, where $\mathtt{FEs}$ is not available, in square brackets]

Solved Multimodal Functions

Normalized Success Performance, Tabulated

$n = 10$, $\mathtt{FE}_{\max} = 100000$

	solved functions	success rate	7 Griewank out Bounds		9 Rastrigin Separable		10 Rastrigin Rotated		11 Weierstrass		12 Schwefel 2.13		15 Hybrid Separable
			4700	17000	55000	190000	8200	33000
G-CMA-ES	5	63%	1.0(25)	4.5(19)	1.2(23)	1.4(6)	4.0(22)	[6]
L-SaDE	4	53%	36.2(6)	1.0(25)	[5]	[8]	3.9(25)	1.0(23)
DMS-L-PSO	4	47%	126 (4)	2.1(25)	[3]	[7]	6.6(19)	1.7(22)
K-PCX	3	40%	[10]	2.9(24)	1.0(22)	[10]	1.0(14)	[11]
DE	5	30%	255 (2)	10.6(11)	[9]	1.0(12)	8.8(19)	75.8(1)
L-CMA-ES	2	25%	1.2(25)	[11]	[10]	[6]	11.6(12)	[6]
BLX-GL50	3	17%	12.3(9)	10.0(3)	[5]	[5]	12.1(13)	[9]
BLX-MA	2	15%	[11]	5.7(18)	[7]	[9]	[9]	8.5(5)
EDA	3	9%	404 (1)	[9]	[4]	2.9(3)	4.3(10)	[9]
SPC-PNX	2	1%	383 (1)	[8]	[8]	5.8(1)	[10]	[6]
CoEVO	0	0%	[9]	[10]	[11]	[11]	[11]	[8]

- **First row**: Success Performance $\mathtt{FEs} = \frac{\#fevals}{p_{\mathrm{succ}}}$ of the best algorithm
- **Table entries**: Success Performance $\mathtt{FEs}$ normalized (divided) by the first row, (number of successful runs in round brackets), [rank of median final function value, where $\mathtt{FEs}$ is not available, in square brackets]

Solved Multimodal Functions

Normalized Success Performance, Tabulated

$n = 30$, $\mathtt{FE}_{\max} = 300000$

	solved functions	success rate	7 Griewank out Bounds	9 Rastrigin Separable	10 Rastrigin Rotated	11 Weierstrass	12 Schwefel 2.13	15 Hybrid Separable
			6100	99000	450000	5000000	180000	
K-PCX	4	38%	2.5(10)	3.3(18)	1.0(14)	[7]	1.0(5)	[11]
G-CMA-ES	5	37%	1.0(25)	8.0(9)	5.3(3)	1.0(1)	1.3(8)	[1]
L-SaDE	2	36%	21.3(20)	1.0(25)	[4]	[5]	[4]	[2]
DMS-L-PSO	2	22%	9.8(24)	[6]	[5]	[5]	8.3(4)	[4]
EDA	1	20%	21.3(25)	[10]	[9]	[10]	[7]	[4]
BLX-GL50	1	20%	10.2(25)	[5]	[3]	[4]	[8]	[4]
DE	1	20%	32.8(22)	[6]	[6]	[10]	[5]	[8]
L-CMA-ES	1	20%	1.1(25)	[11]	[11]	[3]	[9]	[8]
SPC-PNX	1	13%	60.7(16)	[8]	[7]	[2]	[10]	[8]
CoEVO	1	9%	93.4(11)	[9]	[10]	[9]	[11]	[10]
BLX-MA	1	7%	[11]	6.7(9)	[8]	[8]	[6]	[4]

- **First row**: Success Performance $\mathtt{FEs} = \mathtt{mean}(\#fevals) \times \frac{\#\text{all runs (25)}}{\#\text{successful runs}}$ of the best algorithm, where $\#fevals$ includes only successful runs
- **Table entries**: Success Performance $\mathtt{FEs}$ divided by $\mathtt{FEs}$ of the best algorithm (first row), (number of successful runs in round brackets), [rank of median final function value, where $\mathtt{FEs}$ is not available, in square brackets]

Never Solved Multimodal Functions

Rank of Final Function Value

$n = 10$, $\mathrm{FE}_{\max} = 10^5$

	mean	8 Ackley Condition 10^2	13 Expanded 6&7	14 Expanded Schaffer F6	16 Hybrid Rotated	17 Hybrid with Noise	18 Hybrid F18	19 Hybrid Narrow	20 Hybrid on Bounds	21 Hybrid F21	22 Hybrid High Condition	23 Hybrid Non-Continuous	24 Hybrid F24	25 Hybrid out B
G-CMA-ES	3.8	5.5	4	7	1	5.5	3	2.5	2.5	5.5	1.5	4	5	2.5
BLX-GL50	4.2	5.5	6	1.5	2.5	3	3	2.5	2.5	5.5	5.5	4	5	8.5
L-SaDE	5.3	5.5	1	6	5.5	3	8	7.5	7.5	5.5	5.5	4	5	4.5
DMS-L-PSO	5.7	5.5	2	3.5	4	3	8	7.5	7.5	5.5	5.5	8	5	8.5
L-CMA-ES	6.0	5.5	3	11	7.5	11	6	5	5	1	3	4	11	4.5
SPC-PNX	6.2	11	8	8	7.5	5.5	3	2.5	2.5	5.5	9	4	5	8.5
EDA	6.2	5.5	10	5	9	8	3	7.5	7.5	5.5	8	4	5	2.5
BLX-MA	6.6	5.5	7	1.5	5.5	7	8	7.5	7.5	10	5.5	10	5	6
K-PCX	7.0	5.5	5	3.5	2.5	1	10	11	10	11	1.5	11	10	8.5
DE	7.0	5.5	11	10	11	10	3	2.5	2.5	5.5	10	4	5	11
CoEVO	8.2	5.5	9	9	10	9	11	10	11	5.5	11	9	5	1

- **Table entries**: Rank of the median of the final best function values from 25 runs measured with two digits of precision

BBOB'09

http://coco.gforge.inria.fr/doku.php?id=bbob-2009

- Функции 2, 3, 5, 10, 20 и 40 переменных с шумом и без.
- 24 функции без шума
- 30 функций с шумом (гауссовский шум, равномерный шум, шум по распределению Коши)

Итоги пока не подвели (очень много данных, 324 таблицы), но BIPOP-CMA-ES выглядит очень убедительно и, скорее всего, будет «на коне». Небольшое обсуждение есть здесь:

http://groups.google.com/group/ecetc/browse_thread/thread/fc7a6c518a8825c9?hl=ru

Распространение

Ссылки на статьи, в которых CMA-ES используется для решения практических задач:

http://www.lri.fr/~hansen/cmaapplications.pdf

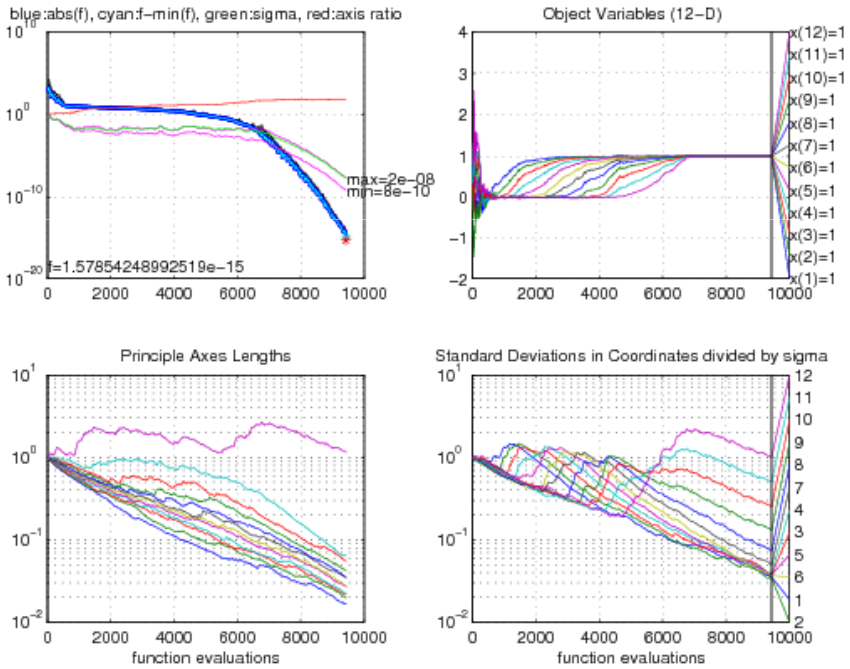
Тематика (примеры, начиная с 1998 г.):

- Промышленное проектирование.
- Робототехника.
- Синтез лекарств.
- Нейроинформатика
- Биоинформатика.
- Оптика.
- Медицинская информатика.
- Химия
- и др.

Программная реализация

http://www.lri.fr/~hansen/cmaes_inmatlab.html

- C (ANSI)
- C++
- Fortran
- Java
- Matlab and Octave
- Python
- Scilab



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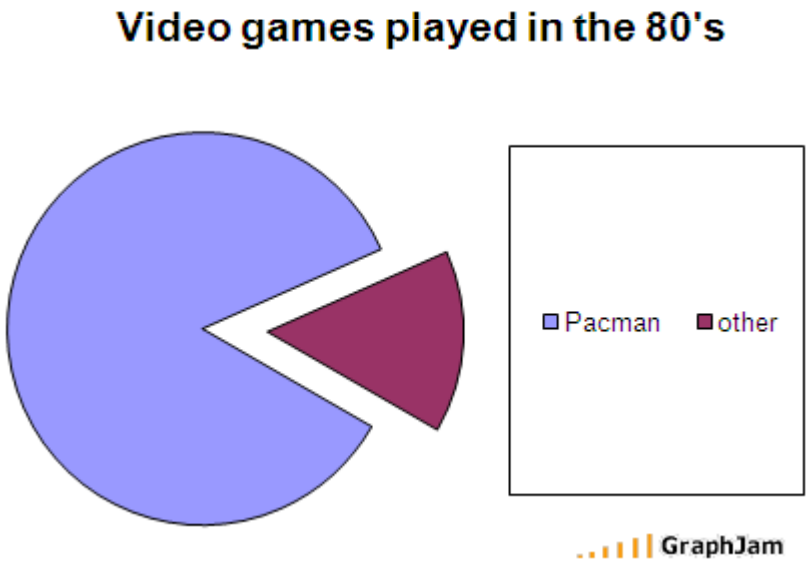
Эта презентация:
http://qai.narod.ru/TomskWorkshop/cmaes_02_2010.pdf