Population Reduction Differential Evolution with Multiple Mutation Strategies in Real World Industry Challenges

Symposium on Swarm Intelligence & Differential Evolution (SIDE 2012),

International Conference on Artificial Intelligence and Soft Computing (ICAISC 2012),

April 29 – May 3, 2012, Zakopane, Poland

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Motivation

- Work on an applied problem in computer animation and vision

A. Zamuda et al.
Differential Evolution for Parameterized Procedural Woody Plant Models Reconstruction.
Applied Soft Computing, 2011.

- Optimization algorithm
  - an extended version of differential evolution (DE),
- Optimization of Real World Industry Challenges (RWIC),
  - selected as CEC 2011 *Real World Optimization Problems*,
  - a benchmark set contains functions modelling the problems,
  - assessment on all 22 functions of CEC 2011 set,
  - functions with constraints are handled with additional care.

Selected challenges in CEC 2011 benchmark (1/2)

- Decomposition of radio FM signals,
- determination of ternary protein structure
  - Lennard-Jones inter-atom energy potential,
- parameterization of a chemical process,
  - methylcyclopentane $\rightarrow$ benzene,
- control parameterization for chemical reaction in a continuous stirred tank reactor,
- inter-atom potential in covalent Silicon systems
  - Tersoff energy potential,
- radar spectrum signal broadcast parameterization,
  - spread spectrum radar polly phase code design,
- electrical transmission network expansion planning,
  - new lines for transmission selection.

Selected challenges in CEC 2011 benchmark (2/2)

- Large scale transmission pricing,
- circular antenna array design,
- dynamic economic dispatch (with power generator control),
- static economic load dispatch (of power generated),
- hydrothermal scheduling (among hydro/thermal units),
- spacecraft trajectory optimization,
  - Mercury (*Messenger*),
  - Saturn (*Cassini*).

- The collection includes 22 functions, with constraints as:
  1. non-feasible evaluation is NaN when constraints are not met, or
  2. the constraints are included in the function evaluation value.

Differential evolution and set of jDE algorithms

- DE: population-based floating-point encoding EA for global optimization over continuos spaces
  - the **evolutionary process**, by **generations** improves **population of vectors**,
  - for each new population vector, **evolutionary operators** are executed.
- Basic jDE **algorithm**: *jDE/rand/1/bin*
  - **mutation**: $\mathbf{v}_{i,G+1} = \mathbf{x}_{r_1,G} + F \times (\mathbf{x}_{r_2,G} - \mathbf{x}_{r_3,G})$,
  - **crossover**:
    $$u_{i,j,G+1} = \begin{cases} v_{i,j,G+1} & \text{if } \mathrm{rand}(0,1) \leq CR \text{ ali } j = j_{rand} \\ x_{i,j,G} & \text{otherwise} \end{cases}$$ and
  - **selection**: $$\mathbf{x}_{i,G+1} = \begin{cases} \mathbf{u}_{i,G+1} & \text{if } f(\mathbf{u}_{i,G+1}) < f(\mathbf{x}_{i,G}) \\ \mathbf{x}_{i,G} & \text{otherwise} \end{cases},$$
  - includes mechanism of F and CR control parameters self-adaptation.

A jDE algorithm extension: population size reduction

- Reducing population size by half (dynNP-DE),

$$G_p > \frac{N_{max\_Feval}}{p_{max} NP_p},$$

  - when number of generations exceeds ratio between the number of function evaluations allowed and the population size.

- Other extensions (unused here) of the original jDE algorithm:
  - multi-objective optimization,
  - SQP local search,
  - ϵ-constraint handling,
  - three random strategies usage,
  - ageing of vectors, and
  - mutation rate F sign changing.

Population Reduction DE with Multiple Mutation Strategies Algorithm

- In the dynNP-DE algorithm, we include with population size reduction, two more mutation strategies:
  1. *rand/1/bin* and
  2. *best/1/bin*.

- The first strategy is executed, when population size is greater than 100, otherwise in half of trial vector computation cases.
- The second strategy is executed in the rest of cases.

- Initial population size (NP_{init}) is set to 200 and
- number of population reductions ($pmax$) to 4.

Experimental Setup

- The algorithm is tested on a recent benchmark collection:
  - framework from a competition at Congress on Evolutionary Computation (CEC) 2011.
- The Linux version of benchmark code is used
  - C++ wrappers with Matlab.
- Best, worst, median, average values and their standard deviation for 25 independent run results of our $\text{jDE}_{\text{NP,MM}}$ algorithm are recorded.
- Then, comparison of the average final best values for our and two other algorithms from CEC 2011 are shown:
  - C-0036, Korošec et. al. and
  - C-0362, Mallipeddi et. al.

Optimization results for 25 independent runs (1/3)

Fun.	FES	Best	Worst	Median	Average	Std. dev.
F1	50000	3.5067e-27	1.7616e+01	1.0167e+01	7.9306e+00	6.9176e+00
F1	100000	0.0000e+00	1.7325e+01	0.0000e+00	1.5262e+00	4.3884e+00
F1	150000	0.0000e+00	1.6460e+01	0.0000e+00	1.1067e+00	3.9046e+00
F2	50000	-2.4458e+01	-1.4863e+01	-2.0507e+01	-2.0288e+01	2.1585e+00
F2	100000	-2.5423e+01	-1.9449e+01	-2.3028e+01	-2.2839e+01	1.5306e+00
F2	150000	-2.6033e+01	-2.1875e+01	-2.4207e+01	-2.4284e+01	1.0418e+00
F3	50000	1.1515e-05	1.1515e-05	1.1515e-05	1.1515e-05	1.6120e-19
F3	100000	1.1515e-05	1.1515e-05	1.1515e-05	1.1515e-05	1.7033e-19
F3	150000	1.1515e-05	1.1515e-05	1.1515e-05	1.1515e-05	1.3730e-19
F4	50000	1.3771e+01	2.0820e+01	1.4329e+01	1.5316e+01	2.4938e+00
F4	100000	1.3771e+01	2.0820e+01	1.4329e+01	1.5158e+01	2.3877e+00
F4	150000	1.3771e+01	2.0820e+01	1.4329e+01	1.5158e+01	2.3877e+00
F5	50000	-3.6291e+01	-3.1447e+01	-3.3875e+01	-3.3386e+01	1.2044e+00
F5	100000	-3.6124e+01	-3.3942e+01	-3.4106e+01	-3.4374e+01	6.6266e-01
F5	150000	-3.6450e+01	-3.4086e+01	-3.4441e+01	-3.4779e+01	7.7855e-01
F6	50000	-2.9131e+01	-2.1268e+01	-2.7427e+01	-2.7050e+01	2.1680e+00
F6	100000	-2.9166e+01	-2.3006e+01	-2.8734e+01	-2.8021e+01	1.6751e+00
F6	150000	-2.9166e+01	-2.7429e+01	-2.9147e+01	-2.8651e+01	7.8281e-01
F7	50000	8.9644e-01	1.6204e+00	1.3414e+00	1.3231e+00	1.6425e-01
F7	100000	8.5265e-01	1.4976e+00	1.1417e+00	1.1477e+00	1.7377e-01
F7	150000	8.0404e-01	1.4326e+00	1.1421e+00	1.1677e+00	1.5041e-01

Optimization results for 25 independent runs (2/3)

Fun.	FES	Best	Worst	Median	Average	Std. dev.
F8	50000	2.2000e+02	2.2000e+02	2.2000e+02	2.2000e+02	0.0000e+00
F8	100000	2.2000e+02	2.2000e+02	2.2000e+02	2.2000e+02	0.0000e+00
F8	150000	2.2000e+02	2.2000e+02	2.2000e+02	2.2000e+02	0.0000e+00
F9	50000	1.4667e+03	7.6387e+03	2.8741e+03	3.2413e+03	1.6096e+03
F9	100000	1.7671e+03	4.0275e+03	2.3870e+03	2.5200e+03	5.3784e+02
F9	150000	1.2819e+03	3.4166e+03	2.1349e+03	2.2419e+03	5.2331e+02
F10	50000	-2.1217e+01	-1.7052e+01	-2.0392e+01	-1.9870e+01	1.3676e+00
F10	100000	-2.1361e+01	-1.7881e+01	-2.1217e+01	-2.0743e+01	1.0375e+00
F10	150000	-2.1421e+01	-2.0780e+01	-2.1321e+01	-2.1300e+01	1.2491e-01
F11	50000	7.4678e+04	5.2735e+05	2.0435e+05	2.2755e+05	1.1962e+05
F11	100000	5.1197e+04	2.4823e+05	5.9560e+04	8.3780e+04	5.6018e+04
F11	150000	5.1030e+04	6.8184e+04	5.2497e+04	5.3040e+04	3.2412e+03
F12	50000	1.0757e+06	1.2337e+06	1.1354e+06	1.1424e+06	4.4843e+04
F12	100000	1.0725e+06	1.1323e+06	1.0749e+06	1.0803e+06	1.3601e+04
F12	150000	1.0713e+06	1.0780e+06	1.0743e+06	1.0745e+06	1.6768e+03
F13	50000	1.5444e+04	1.5479e+04	1.5448e+04	1.5452e+04	9.4020e+00
F13	100000	1.5444e+04	1.5459e+04	1.5445e+04	1.5446e+04	3.4605e+00
F13	150000	1.5444e+04	1.5445e+04	1.5444e+04	1.5444e+04	4.4370e-01
F14	50000	1.8427e+04	1.9139e+04	1.8653e+04	1.8666e+04	1.3434e+02
F14	100000	1.8339e+04	1.8744e+04	1.8532e+04	1.8560e+04	1.2390e+02
F14	150000	1.8338e+04	1.8783e+04	1.8508e+04	1.8529e+04	8.7554e+01

Optimization results for 25 independent runs (3/3)

Fun.	FES	Best	Worst	Median	Average	Std. dev.
F15	50000	3.2769e+04	3.3033e+04	3.2889e+04	3.2882e+04	5.5334e+01
F15	100000	3.2757e+04	3.2929e+04	3.2842e+04	3.2843e+04	4.4323e+01
F15	150000	3.2719e+04	3.2898e+04	3.2812e+04	3.2815e+04	4.2736e+01
F16	50000	1.3214e+05	1.4639e+05	1.3529e+05	1.3652e+05	3.5227e+03
F16	100000	1.3101e+05	1.4055e+05	1.3309e+05	1.3359e+05	2.3260e+03
F16	150000	1.2958e+05	1.3529e+05	1.3260e+05	1.3266e+05	1.5770e+03
F17	50000	1.9246e+06	2.2007e+06	1.9499e+06	1.9650e+06	5.5502e+04
F17	100000	1.9211e+06	2.1883e+06	1.9474e+06	1.9629e+06	5.7849e+04
F17	150000	1.9028e+06	1.9876e+06	1.9421e+06	1.9462e+06	2.1343e+04
F18	50000	9.3784e+05	1.1032e+06	9.4637e+05	9.5964e+05	4.0189e+04
F18	100000	9.3942e+05	9.4961e+05	9.4396e+05	9.4397e+05	2.6203e+03
F18	150000	9.3899e+05	9.4986e+05	9.4419e+05	9.4397e+05	2.7674e+03
F19	50000	1.1204e+06	1.6541e+06	1.2904e+06	1.3137e+06	1.5365e+05
F19	100000	1.0366e+06	1.5295e+06	1.2547e+06	1.2818e+06	1.3172e+05
F19	150000	1.0013e+06	1.4053e+06	1.2602e+06	1.2464e+06	1.2539e+05
F20	50000	9.3784e+05	1.1032e+06	9.4637e+05	9.5964e+05	4.0189e+04
F20	100000	9.3942e+05	9.4961e+05	9.4396e+05	9.4397e+05	2.6203e+03
F20	150000	9.3899e+05	9.4986e+05	9.4419e+05	9.4397e+05	2.7674e+03
F21	50000	1.3416e+01	2.2495e+01	1.7869e+01	1.7961e+01	2.2384e+00
F21	100000	1.4534e+01	2.0373e+01	1.7188e+01	1.6921e+01	1.6142e+00
F21	150000	1.1470e+01	1.9076e+01	1.6734e+01	1.6599e+01	1.7991e+00
F22	50000	1.1162e+01	2.0083e+01	1.4415e+01	1.4754e+01	2.2620e+00
F22	100000	1.0376e+01	1.7406e+01	1.3290e+01	1.3154e+01	1.7894e+00
F22	150000	9.1802e+00	1.5959e+01	1.1707e+01	1.2404e+01	1.7697e+00

- The algorithm is successfully run on all benchmark functions.

Comparison of average final best evaluation values (1/3)

Fun.	FES	$jDE_{NP,MM}$	C-0036	C-0362	diff(C-0036)	diff(C-0362)
F1	50000	7.9306e+00	1.3995e+01	7.06E+00	**-6.0644e+00**	*8.7060e-01*
F1	100000	1.5262e+00	1.0872e+01	2.29E+00	**-9.3458e+00**	**-7.6380e-01**
F1	150000	1.1067e+00	1.0128e+01	1.78E+00	**-9.0213e+00**	**-6.7330e-01**
F2	50000	-2.0288e+01	-1.5775e+01	-1.26E+01	**-4.5130e+00**	**-7.6880e+00**
F2	100000	-2.2839e+01	-1.6766e+01	-1.64E+01	**-6.0730e+00**	**-6.4390e+00**
F2	150000	-2.4284e+01	-1.7566e+01	-1.83E+01	**-6.7180e+00**	**-5.9840e+00**
F3	50000	1.1515e-05	1.1515e-05	1.15E-05	0.0000e+00	*1.5000e-08*
F3	100000	1.1515e-05	1.1515e-05	1.15E-05	0.0000e+00	*1.5000e-08*
F3	150000	1.1515e-05	1.1515e-05	1.15E-05	0.0000e+00	*1.5000e-08*
F4	50000	1.5316e+01	1.4173e+01	1.67E+01	*1.1430e+00*	**-1.3840e+00**
F4	100000	1.5158e+01	1.4039e+01	1.67E+01	*1.1190e+00*	**-1.5420e+00**
F4	150000	1.5158e+01	1.3936e+01	1.67E+01	*1.2220e+00*	**-1.5420e+00**
F5	50000	-3.3386e+01	-3.3533e+01	-2.38E+01	*1.4700e-01*	**-9.5860e+00**
F5	100000	-3.4374e+01	-3.3834e+01	-2.75E+01	**-5.4000e-01**	**-6.8740e+00**
F5	150000	-3.4779e+01	-3.3909e+01	-2.90E+01	**-8.7000e-01**	**-5.7790e+00**
F6	50000	-2.7050e+01	-2.3150e+01	-1.28E+01	**-3.9000e+00**	**-1.4250e+01**
F6	100000	-2.8021e+01	-2.5581e+01	-1.55E+01	**-2.4400e+00**	**-1.2521e+01**
F6	150000	-2.8651e+01	-2.6748e+01	-1.70E+01	**-1.9030e+00**	**-1.1651e+01**
F7	50000	1.3231e+00	1.0262e+00	1.61E+00	*2.9690e-01*	**-2.8690e-01**
F7	100000	1.1477e+00	9.6956e-01	1.49E+00	*1.7814e-01*	**-3.4230e-01**
F7	150000	1.1677e+00	9.3895e-01	1.42E+00	*2.2875e-01*	**-2.5230e-01**
F8	50000	2.2000e+02	2.2000e+02	2.20E+02	0.0000e+00	0.0000e+00
F8	100000	2.2000e+02	2.2000e+02	2.20E+02	0.0000e+00	0.0000e+00
F8	150000	2.2000e+02	2.2000e+02	2.20E+02	0.0000e+00	0.0000e+00

Comparison of average final best evaluation values (2/3)

Fun.	FES	$jDE_{NP,MM}$	C-0036	C-0362	diff(C-0036)	diff(C-0362)
F9	50000	3.2413e+03	1.6940e+03	2.875E+03	*1.5473e+03*	*3.6630e+02*
F9	100000	2.5200e+03	1.2338e+03	2.529E+03	*1.2862e+03*	**-9.0000e+00**
F9	150000	2.2419e+03	1.0692e+03	2.529E+03	*1.1727e+03*	**-2.8710e+02**
F10	50000	-1.9870e+01	-1.2655e+01	-1.52E+01	**-7.2150e+00**	**-4.6700e+00**
F10	100000	-2.0743e+01	-1.3213e+01	-1.55E+01	**-7.5300e+00**	**-5.2430e+00**
F10	150000	-2.1300e+01	-1.3540e+01	-1.56E+01	**-7.7600e+00**	**-5.7000e+00**
F11	50000	2.2755e+05	5.2607e+04	5.26E+04	*1.7494e+05*	*1.7495e+05*
F11	100000	8.3780e+04	5.2160e+04	5.24E+04	*3.1620e+04*	*3.1380e+04*
F11	150000	5.3040e+04	5.2017e+04	5.22E+04	*1.0230e+03*	*8.4000e+02*
F12	50000	1.1424e+06	1.2750e+06	1.08E+06	**-1.3260e+05**	*6.2400e+04*
F12	100000	1.0803e+06	1.2733e+06	1.07E+06	**-1.9300e+05**	*1.0300e+04*
F12	150000	1.0745e+06	1.2717e+06	1.07E+06	**-1.9720e+05**	*4.5000e+03*
F13	50000	1.5452e+04	1.5516e+04	1.55E+04	**-6.4000e+01**	**-4.8000e+01**
F13	100000	1.5446e+04	1.5512e+04	1.55E+04	**-6.6000e+01**	**-5.4000e+01**
F13	150000	1.5444e+04	1.5511e+04	1.55E+04	**-6.7000e+01**	**-5.6000e+01**
F14	50000	1.8666e+04	1.9341e+04	1.82E+04	**-6.7500e+02**	*4.6600e+02*
F14	100000	1.8560e+04	1.9332e+04	1.82E+04	**-7.7200e+02**	*3.6000e+02*
F14	150000	1.8529e+04	1.9323e+04	1.81E+04	**-7.9400e+02**	*4.2900e+02*
F15	50000	3.2882e+04	3.3185e+04	3.28E+04	**-3.0300e+02**	*8.2000e+01*
F15	100000	3.2843e+04	3.3183e+04	3.28E+04	**-3.4000e+02**	*4.3000e+01*
F15	150000	3.2815e+04	3.3181e+04	3.27E+04	**-3.6600e+02**	*1.1500e+02*
F16	50000	1.3652e+05	1.4715e+05	1.32E+05	**-1.0630e+04**	*4.5200e+03*
F16	100000	1.3359e+05	1.4669e+05	1.31E+05	**-1.3100e+04**	*2.5900e+03*
F16	150000	1.3266e+05	1.4666e+05	1.31E+05	**-1.4000e+04**	*1.6600e+03*

Comparison of average final best evaluation values (3/3)

Fun.	FES	$jDE_{NP,MM}$	C-0036	C-0362	diff(C-0036)	diff(C-0362)
F17	50000	1.9650e+06	2.4168e+06	1.92E+06	**-4.5180e+05**	*4.5000e+04*
F17	100000	1.9629e+06	2.1476e+06	1.92E+06	**-1.8470e+05**	*4.2900e+04*
F17	150000	1.9462e+06	2.0375e+06	1.92E+06	**-9.1300e+04**	*2.6200e+04*
F18	50000	9.5964e+05	1.0127e+06	9.44E+05	**-5.3060e+04**	*1.5640e+04*
F18	100000	9.4397e+05	9.4803e+05	9.43E+05	**-4.0600e+03**	*9.7000e+02*
F18	150000	9.4397e+05	9.4569e+05	9.43E+05	**-1.7200e+03**	*9.7000e+02*
F19	50000	1.3137e+06	1.5823e+06	9.94E+05	**-2.6860e+05**	*3.1970e+05*
F19	100000	1.2818e+06	1.4433e+06	9.91E+05	**-1.6150e+05**	*2.9080e+05*
F19	150000	1.2464e+06	1.4012e+06	9.90E+05	**-1.5480e+05**	*2.5640e+05*
F20	50000	9.5964e+05	1.0567e+06	9.44E+05	**-9.7060e+04**	*1.5640e+04*
F20	100000	9.4397e+05	9.8217e+05	9.43E+05	**-3.8200e+04**	*9.7000e+02*
F20	150000	9.4397e+05	9.4887e+05	9.43E+05	**-4.9000e+03**	*9.7000e+02*
F21	50000	1.7961e+01	2.8815e+01	2.26E+01	**-1.0854e+01**	**-4.6390e+00**
F21	100000	1.6921e+01	2.7518e+01	1.98E+01	**-1.0597e+01**	**-2.8790e+00**
F21	150000	1.6599e+01	2.6419e+01	1.88E+01	**-9.8200e+00**	**-2.2010e+00**
F22	50000	1.4754e+01	3.3463e+01	1.99E+01	**-1.8709e+01**	**-5.1460e+00**
F22	100000	1.3154e+01	3.0902e+01	1.57E+01	**-1.7748e+01**	**-2.5460e+00**
F22	150000	1.2404e+01	2.9620e+01	1.39E+01	**-1.7216e+01**	**-1.4960e+00**
B/W					47 / 13	31 / 32

- Our algorithm is, compared to the first (C-0036), **better on 47**, *worse on 13*, and shows no difference for 6 function instances.
- Our algorithm is, compared to the second (C-0362), **better on 31**, *worse on 32*, and shows no difference for 3 function instances.

Conclusion

- We presented an algorithm for optimization of 22 real world industry challenges,
- the set of challenges is as composed for Congress on Evolutionary Computation (CEC) 2011.
- The presented algorithm is based on the jDE (dynNP-DE) algorithm and
- the dynNP-DE algorithm is here extended with multiple mutation strategies,

- The algorithm is successfully assessed on all benchmark functions (constraint and unconstraint),
- the algorithm shows competitive results with the related algorithms.

Future Work

- Improve performance for some functions,
  - population size adjustment,
  - analysis of including other DE enhancements.
- Other:
  - DE parallelization,
  - multiobjective reconstruction of tree geometry.

Thank you for your attention.

Questions?