Advanced Algorithms for Hydropower Dispatch

CSU Meeting 4/25/2011 version

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About This Project

- **Title: *Advanced Optimization Algorithms for Hydropower Dispatch* (S&T Project ID# 486)**
- **FY2011 support graciously provided by Reclamation's Science and Technology Research Program.**
- **David A. Harpman, Principal Investigator**
- **Collaborators: Argonne National Laboratory and Colorado State University.**
- **Further details can be found at: http://www.usbr.gov/research/science-and-tech/projects/**

Research Objectives

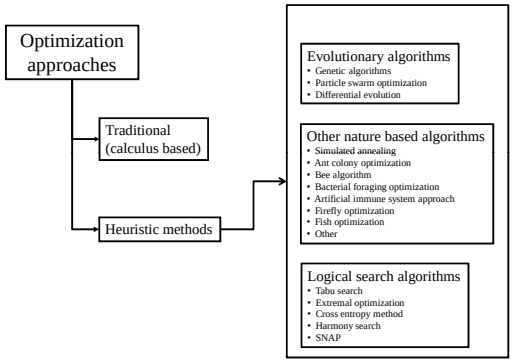
- **Investigate practical application of these approaches.**
- **Explore performance characteristics of these algorithms on hydropower problems of specific interest to Reclamation, and others.**
- **Potentially, develop solvers for installation at Reclamation powerplants.**
- **Scholarly products.**

Progress in Optimization Techniques

- **Traditional optimization methods, based on calculus, date back to Sir Isaac Newton (circa 1670).**
- **Research on heuristic optimization algorithms not practical until microcomputers became widely available (circa 1980).**
- **The approaches investigated here were not described until 1980, and later.**

$$b_{t+1} = b_t - \left[\frac{\partial^2 \ell}{\partial b_t \partial b_t}\right]^{-1} \times \frac{\partial \ell}{\partial b_t}$$

Taxonomy of Optimization Algorithms

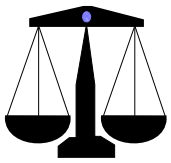


Traditional vs Evolutionary Algorithms

	Traditional Algorithms	Evolutionary Algorithms
Problem formulation	Linear or nonlinear	Linear or nonlinear
Mathematical requirements	Smooth, continuous and twice differentiable	Can be piecewise, discontinuous and non-differentiable
Allowable constraints	Equality, inequality, linear or non-linear.	Equality, inequality, linear or non-linear.
Mathematical construction	Calculus, linear and matrix algebra operations	Primitive mathematical operators only (add, subtract, multiply, divide)
Function return	Single solution	Multiple solutions
Optimal point	Extremal point closest to starting position usually identified. This may or may not be the global optima.	Extremal point within search range usually identified. This is more likely to be the global optima.
Memory requirements	Extensive	Modest
Convergence characteristics	Slow large-scale search Fast local convergence	Fast large-scale search Slow local convergence
Solution time	Short	Often lengthy
Code implementation	Complex (very)	Unsophisticated

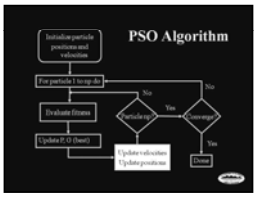
Algorithm Selection Criteria

- **Designed for continuous *R* domain.**
- **Multiple cites in "mainstream" literature.**
- **Suitability for constrained optimization.**
- **Power system applications.**



Algorithms Selected

- Differential evolution (DE)
- Particle swarm optimization (PSO)
- Real coded genetic algorithm (RCGA)



Hydropower Dispatch Problem

$$Maximize \quad \sum_{1}^{T} R_t \, p_t(q_t)$$

subject to:

$$\sum_{1}^{T} q_t \le Q$$

$$p_t \ge 0$$

$$q_{\max} \le q_t \le q_{\max}$$

$$p_{\min} \le p_t \le p_{\max}$$

$$abs(\Delta q) \le rrate$$

Where:

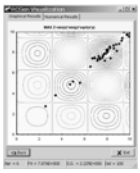
R_t = price ($/MWh) at time (t)
p_t = generation (MW) at time (t)
q_t = release (cfs or af) at time (t)
Q = total release (af).
q_{min} = minimum release.
q_{max} = maximum release
p_{min} = minimum generation level.
p_{max} = maximum generation level
Δq = change in q from t to t+1.
rrate = maximum ramp rate.

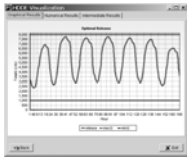
Hydropower Dispatch Problem (2)

Problem Feature	Details
Generation p(q, elev)	nonlinear in q
Dimensions	t={24, 168}
Head h(q, elev)	varies with q
Total release (Q)	user selectable
Prices (R)	summer, winter
Reservoir elevation	variable (set)
qmax, qmin	user selectable
Ramp rate	user selectable

Phases of Development

- **Initial development on unconstrained test problems.**
- **Application to constrained hydropower dispatch problem.**
- **Construction of testing environment.**





Testing Environment

- **Evolutionary algorithms stochastic.**
- **Replicated independent experiments.**
- **Outputs for each trial and iteration.**
- **Facilitates subsequent analysis.**

Progress To-Date

Algorithm	Test Program	Unit Dispatch	Economic Dispatch	Testing Environment
PSO	Complete	Working prototype	Complete	Complete
DE	Complete	Working prototype	Complete	Complete
RCGA	Complete	TBD	Complete	Complete
Bees	TBD	TBD	TBD	TBD
Lambda Search	NA	TBD	Complete	NA

Progress To-Date (2)

- **Meetings with collaborators.**
- **Concurrent report writing.**
- **Planned briefing for Reclamation.**
- **Ongoing experiments.**
- **Other.**

Planned Experiments

- **N-trials with statistical analysis.**
- **Initialization approaches.**
- **Starting and stopping criteria.**
- **Parameter settings, variants.**
- **Problem specifications.**
- **Compare algorithm performance.**
- **Other.**

Some Outstanding Questions

- Reformulation as unconstrained problem?
- Homomorphous mapping?
- Other.

Suggestions, Comments & Guidance

For information about this research, please contact:

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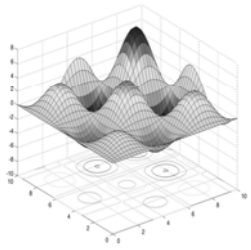
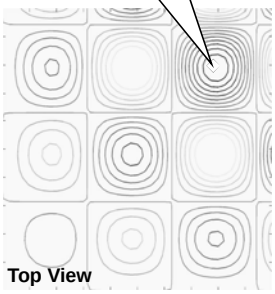
Test Function 4

$$Z = \sin(x)\sin(y)sqrt(x+y)$$





Top View

$$x, y \in \{0..10\}$$

Live Demo (1)

Real coded genetic algorithm (RCGA)

Live Demo (2)

Hydropower dispatch with RCGA