The Optimatics Letter

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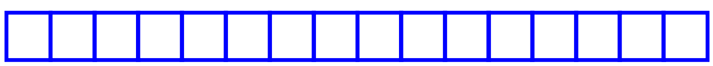
Advances in Optimization for Water Distribution System Design & Operations

How GA Optimization Works

Genetic algorithm (GA) optimization is a powerful search technique that can identify near-optimal solutions to complex engineering problems. The GA optimization search process mimics “natural selection” or “survival of the fittest”. Developed in the 1970’s by Professor John Holland at the University of Michigan, GA optimization was first used to optimize the design of water distribution systems by researchers at the University of Adelaide in South Australia in 1990.

Let’s look at how GA optimization is applied to a distribution system design problem. Starting with a calibrated hydraulic model, the choices to be considered (e.g., new pipes, tanks, pumps, and valves, pipe re-lining, regulator settings, etc.) are added to the model as decision variables. The GA creates trial solutions by assigning values to each choice and then evaluates every solution in a model run. Many thousands of trial solutions are evaluated as the GA search narrows in on a range of viable, near-optimal solution alternatives (see Figure 1 on back cover).

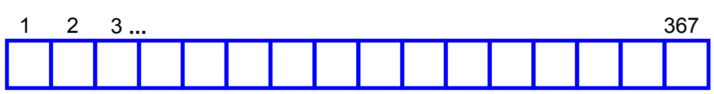
Step 1 – Prepare a chromosome format for the given distribution problem.



The length of the chromosome string corresponds to the total number of decision variables to be considered in the GA search.

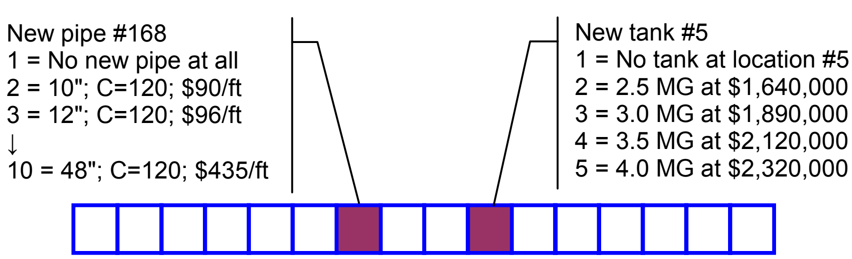
GA optimization can replace the simulation trial-and-error step in a traditional distribution system study to identify low-cost solution alternatives that satisfy the design and performance constraints.

Step 2 – Map the GA decision variables to the chromosome string cells.



Position	Decision Variable	Position	Decision Variable
1	New pipe #1	338	Existing PRV #1
2	New pipe #2	339	Existing PRV #2
3	New pipe #3	340	New PRV #1
↓		↓	
329	Existing pipe #1	366	Existing WTP #2
330	Existing pipe #2	367	New WTP #1

Step 3 – Define the allowable decision choices and assign each a unit cost.



Each decision variable choice is represented by an integer assigned to a given position in the chromosome string.

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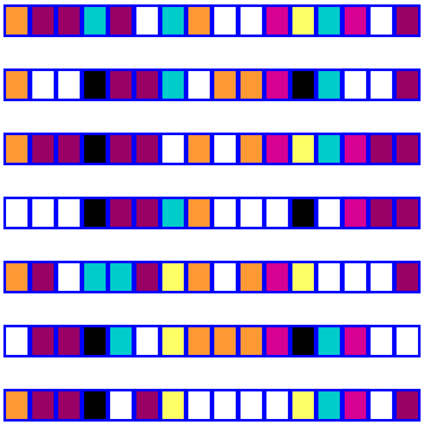
Step 4 – Create an initial population of say 100 trial solutions (i.e., 100 chromosomes).



Generation 0

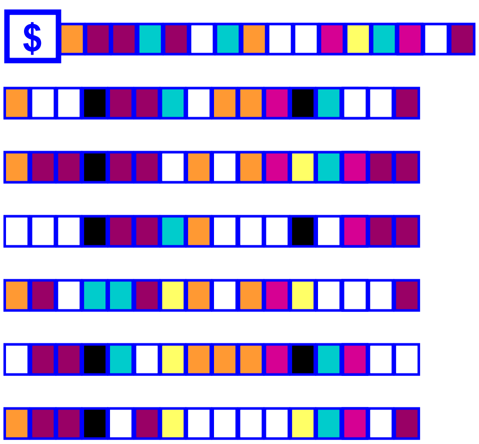
Each position in the 100 chromosomes is randomly filled with an integer that falls within the allowable range for the corresponding decision variable.

Each chromosome string can then be "decoded" into a trial solution for the water distribution system design—consisting of all of the decision variable choices represented in the chromosome string plus the existing pipe network elements in the hydraulic model that will remain unchanged.

Please visit us at one of these AWWA conferences:

- *Texas Water 2003 in Corpus Christi, April 1-4*
- *IMTech 2003 in Santa Clara, CA, April 27-30*
- *Annual Conference in Anaheim, June 15-19*
- *Cal.-Nev. Section Conf. in San Diego, Oct. 6-9*

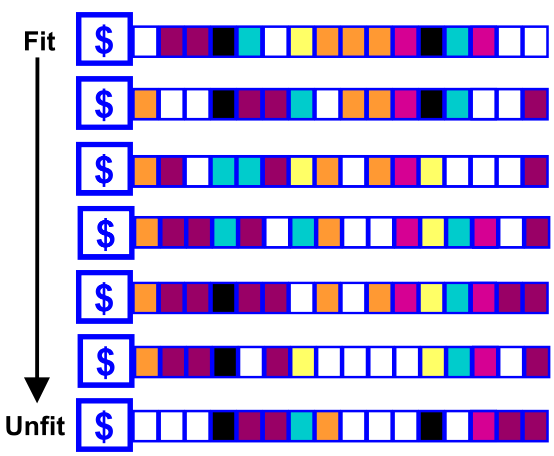
Step 5 – Compute the total cost or "fitness" of the trial solutions one at a time.



Each solution is simulated in the hydraulic model to see if it meets the design constraints, such as minimum pressures at supply nodes. Its fitness is then computed based on the sum of its estimated capital cost plus a pseudo-penalty cost corresponding to how badly the solution fails to meet the specified design and performance criteria. Fitness is often taken as the inverse of total cost.

The GA search will attempt to drive the penalty cost to zero and to minimize capital costs as the solutions evolve. A zero penalty cost means that a solution is fully feasible.

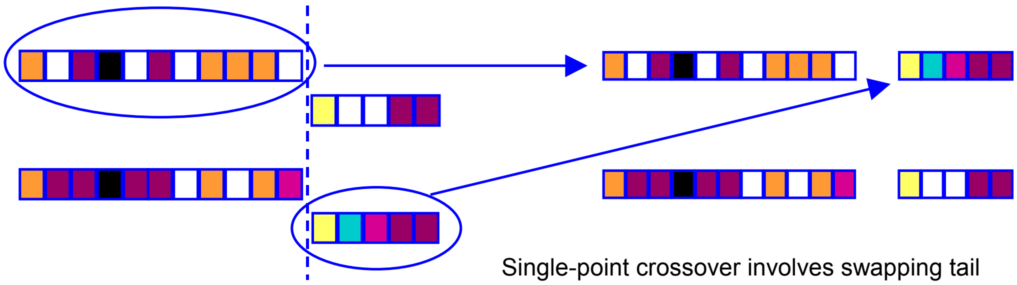
Step 6 – Select the parent strings for the next generation considering fitness.



As in natural selection, the "fittest" solutions have the highest probability of being selected as parents from the mating pool used to create the next generation.

The fittest solutions are those that exhibit low capital cost and good hydraulic performance relative to all other solutions in a given population.

Step 7 – Pair up the parents, then use "crossover" and "mutation" to create offspring solutions (i.e., new individual trial solutions) to populate the next generation.



Single-point crossover involves swapping tail ends between pairs of chromosome strings.

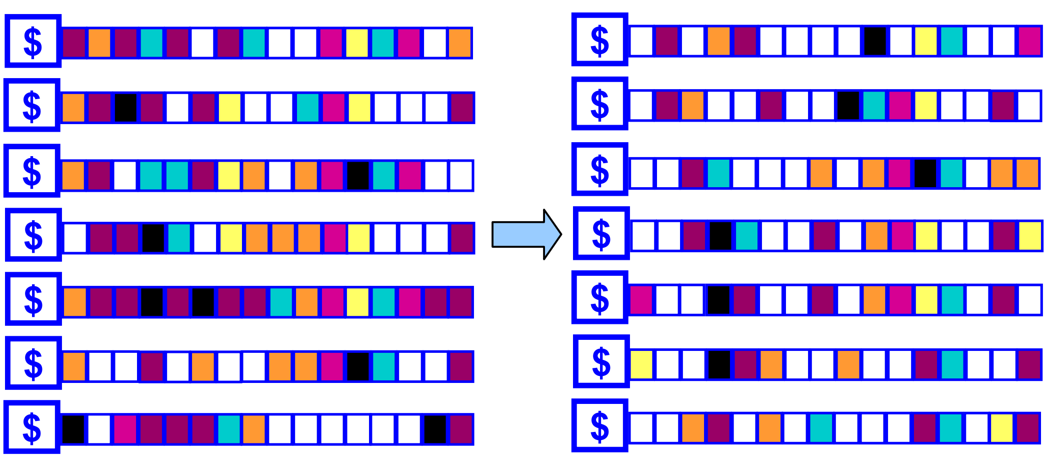
Mutation is applied sparingly and is accomplished by randomly changing an integer value in some cell on the chromosome string.

You can view the OGA optimization search in action by visiting us online at:

www.frey-water.com

or www.optimatics.com

Step 8 – Repeat steps 5, 6 and 7 on the new population of offspring solutions, and then continue repeating these steps over many, many generations.



Generation 1 **Generation 2,000**

The GA optimization process efficiently promotes the most desirable features of the decision variables into the population to ensure both low capital cost (and/or operating cost) and satisfactory hydraulic performance. The GA search thus identifies a range of near-optimal solution alternatives with low cost that fully satisfy the utility's design and performance criteria.

Steps 1-8 illustrate the basic GA optimization search process used to optimize a water master plan or system rehabilitation and replacement plan. The GA can be applied to a set of distinct steady-state demand cases (e.g., peak hour, max day plus fire flow, emergency main break, etc.) or to an extended period simulation model. The GA search aims to minimize capital costs or system life cycle costs (i.e., capital and operating costs). No matter what the application, GA optimization should be viewed as a powerful tool that the water utility and its consultants can call on to help them develop customized, low-cost design and operating solutions.

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Please pass this newsletter on to key staff involved in distribution system planning and operations.

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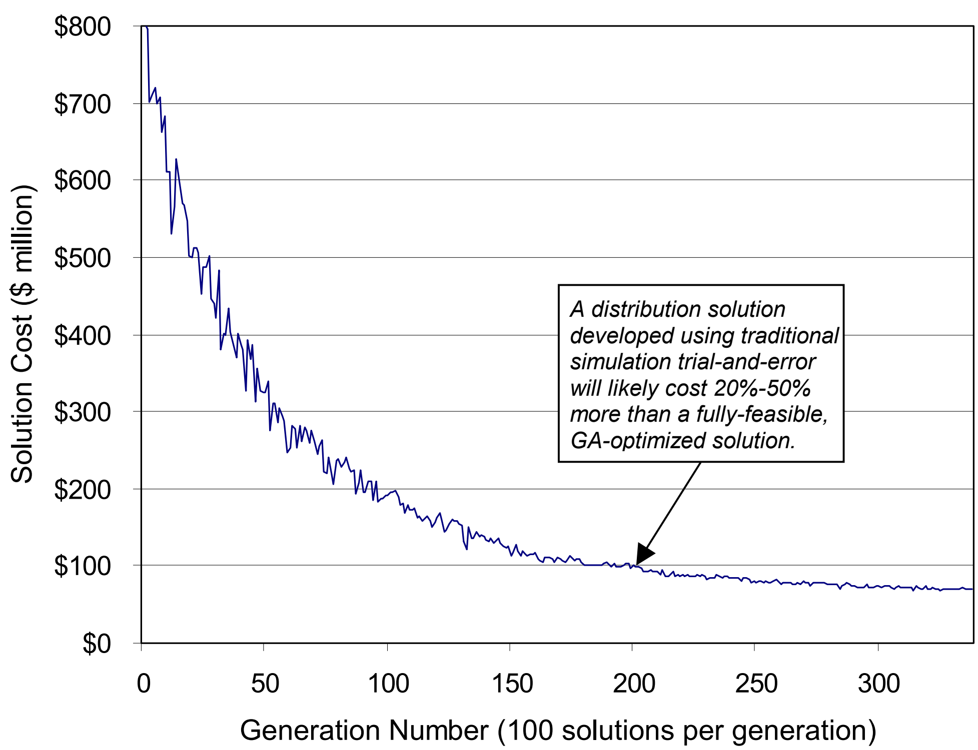

Figure 1. A typical GA optimization search plot. The GA "evolves" low cost solutions over many generations.

Hundreds of thousands of trial solutions are simulated in the hydraulic model. Each solution is costed out and evaluated to see if it satisfies the utility's specified design and performance criteria.

The curve plots the lowest solution cost in each generation. Although solution costs fall or rise from one generation to the next, the GA search is relentless as it narrows in on the least-cost solution.

Water utilities are using GA optimization to save millions of dollars in capital improvement and rehabilitation and replacement costs.