NCSeX Coil Evolution

Buff Miner and Prashant Valanju
Fusion Research Center

Steve Hirshman
Oak Ridge National Laboratory

Art Brooks and Neil Pomphrey
Princeton Plasma Physics Laboratory

- We are seeking a global minimum in $\int (B \cdot n)^2 ds$
- Current sheet solution yields 0.11% error
- 5 independent contours, constant currents yields 1.0% error
- Neil's optimizer (currents and contours) 0.5% error
  caveat: on the order of 8000 cpu seconds
- Steve's optimizer uses the simplex method
  caveat: may get stuck in local minima
- Need a robust, global optimizer that's fast

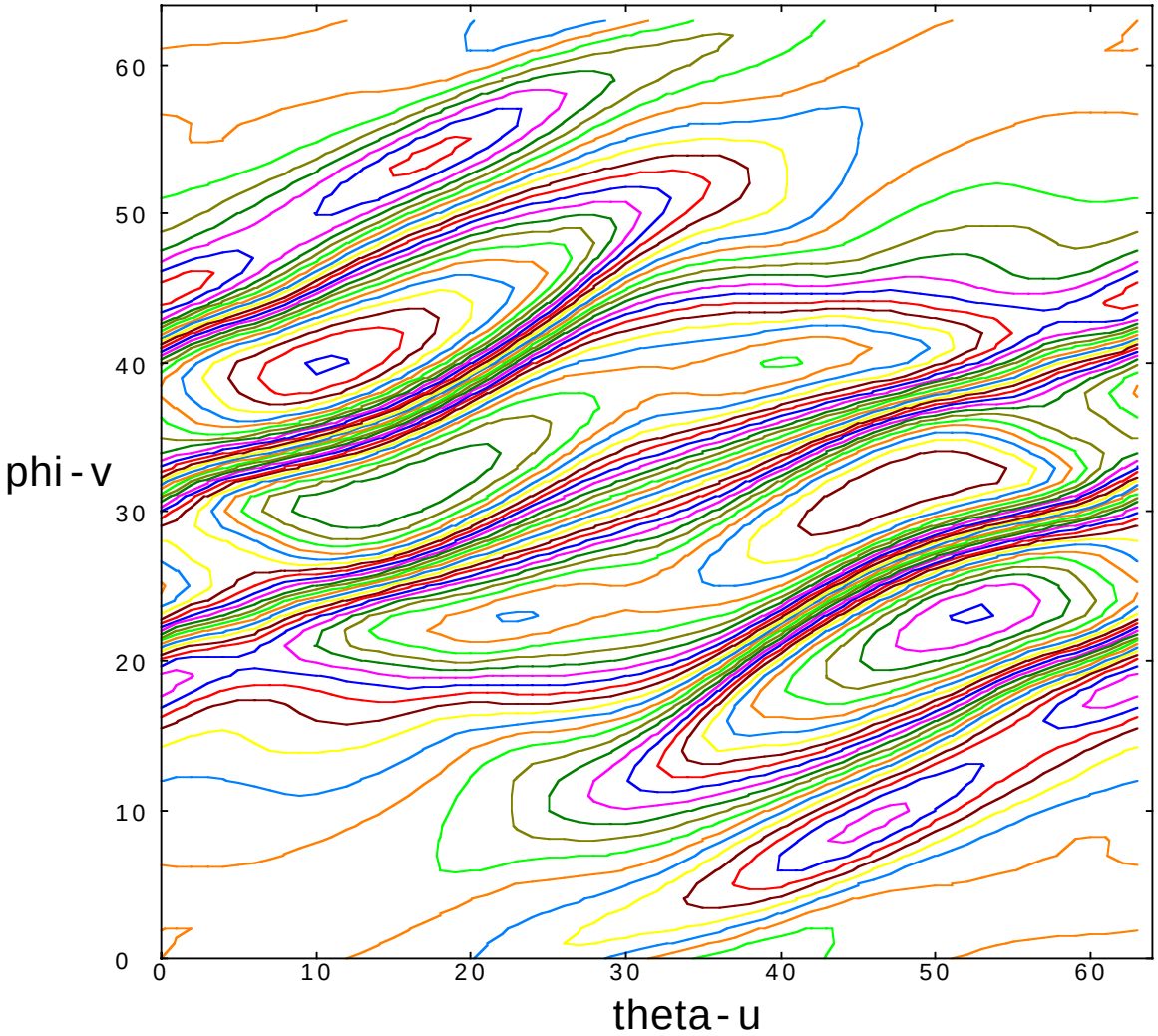
Optimization Algorithm

- Compute the inductance matrix G where

$$G_{ij} I_j = B_i \qquad (1)$$

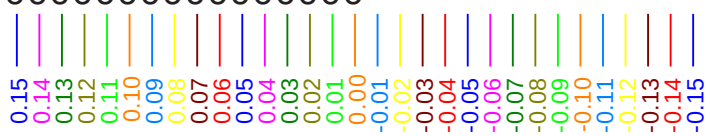
- Done by putting unit currents in each contour
- Use the genetic algorithm to choose which contours to energize
- Use SVD to determine optimal current values by solving (1)

Potential Contour plot

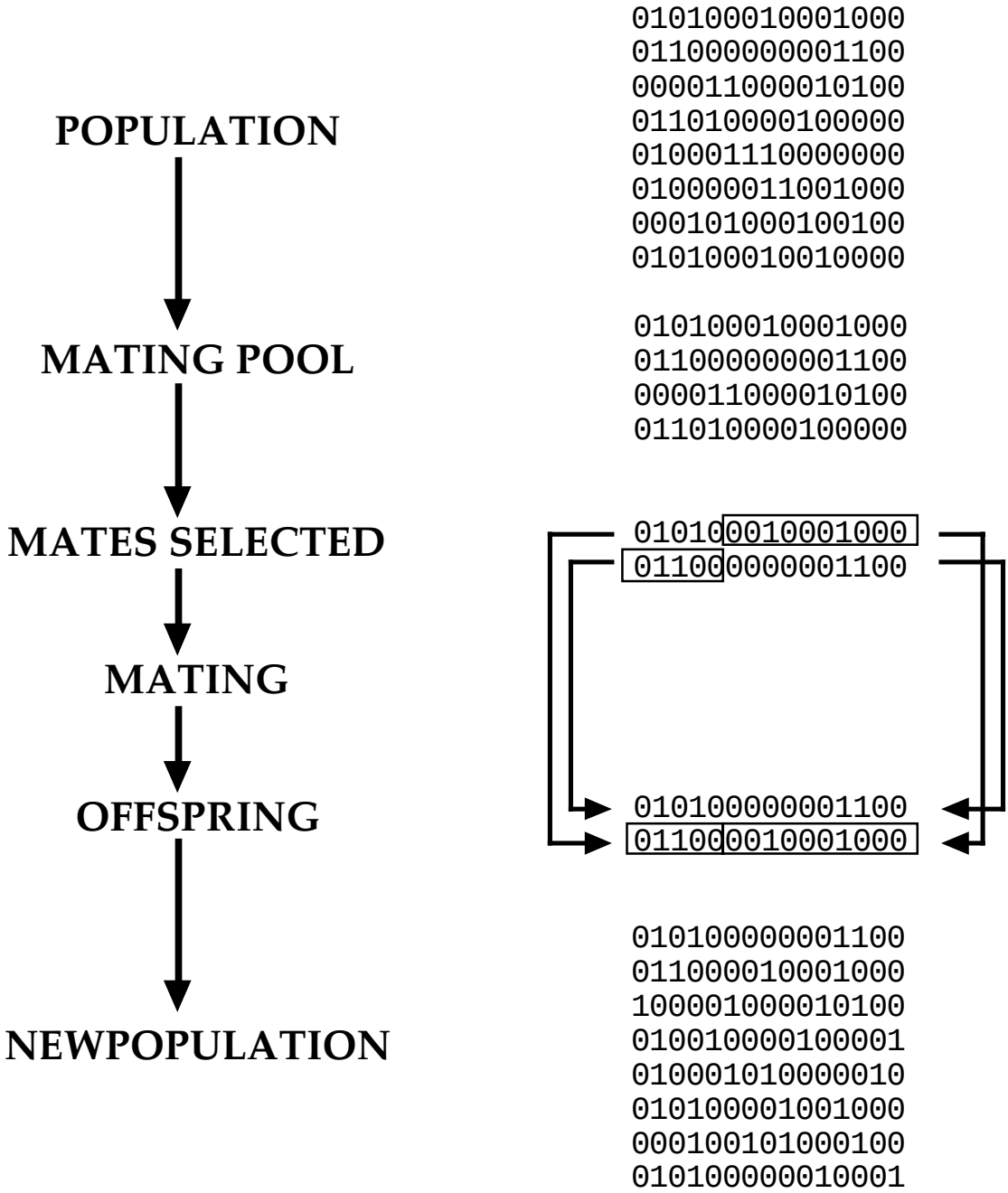


Chromosome

000000000000000000



GENETIC ALGORITHM



R.L. Haupt and S.E. Haupt, **Practical Genetic Algorithms**, John Wiley and Sons, Inc., New York (1998).
GA code : David L. Carroll, University of Illinois
http://www.staff.uiuc.edu/~carroll/

Initial Population

Chromosome	Cost
010100010001000	-0.0188
000000011001100	-0.0298
000011000010100	-0.0221
011010000100000	-0.0322
010001110000000	-0.0459
010000011001000	-0.0206
000100000000100	-0.0261
010100010010000	-0.0229
010100010010000	-0.0288
000111000000010	-0.0429
000100010001100	-0.0167
000000010000100	-0.0355
010100010001000	-0.0188
100001001000010	-0.0306
010100010000001	-0.0388
001100010001000	-0.0199
001100010000100	-0.0142
000100010001100	-0.0167
000100010000100	-0.0159
001100011000000	-0.0342
011100000001000	-0.0487
001100000001100	-0.0450
000000011001100	-0.0298
011010000100000	-0.0322

Initial Population Sorted

		Chromosome	Cost	
N_{ipop}	N_{good}	001100010000100	-0.0142	N_{pop}
		010100010000100	-0.0159	
		000100010001100	-0.0167	
		000100010001100	-0.0167	
		010100010001000	-0.0188	
		010100010000100	-0.0195	
	N_{bad}	001100010001000	-0.0199	
		010000011001000	-0.0206	
		000011000010100	-0.0221	
		010100010010000	-0.0229	
		000100000000100	-0.0261	
		010100010010000	-0.0288	
		000000011001100	-0.0298	
		000000011001100	-0.0298	
		100001001000010	-0.0306	
		011010000100000	-0.0322	
		011010000100000	-0.0322	
		001100011000000	-0.0342	
		000000010000100	-0.0355	
		010100010000001	-0.0388	
		000111000000010	-0.0429	
		001100000001100	-0.0450	
		010001110000000	-0.0459	
		011100000001000	-0.0487	

Pairing and Mating Process for Single Point Crossover

Chromosome	Family	Binary String	Cost
1	$parent_1$	001100010000100	-0.0142
2	$parent_2$	010100010000100	-0.0159
7	$offspring_1$	001100010000100	-0.0142
8	$offspring_2$	010100010000100	-0.0159
3	$parent_1$	000100010001100	-0.0167
4	$parent_2$	000100010001100	-0.0167
9	$offspring_1$	000100010001100	-0.0167
10	$offspring_2$	000100010001100	-0.0167
5	$parent_1$	010010010001000	-0.0188
6	$parent_2$	010100001000100	-0.0195
11	$offspring_1$	010010001000100	-0.0122
12	$offspring_2$	010100010001000	-0.0172

Mutations

Original Chromosome	Mutated Chromosome	Cost
010100010001000	010100010001000	-0.0188
0000000 11001100	0000001 01001100	-0.0298
000011000010100	000011000010100	-0.0221
01 1010000100000	01 0010000100001	-0.0322
010001110000000	010001110000000	-0.0459
0100000 1001000	0100000 0101000	-0.0206
000100000000100	000100000000100	-0.0261
010100010010000	010100010010000	-0.0229
010100010010000	010100010010000	-0.0288
0001 1000000010	0001 0000010010	-0.0429
000100010001100	000100010001100	-0.0167
000000010000100	000000010000100	-0.0355

Jump mutation
Creep mutation

Output from the genetic algorithm

```
###############   SVD Currents   ################
#########    4 coils per half period  ###########
###############  Generation    1  ###############
#   Binary Code     Fitness
 1 010100010001000  -0.0188
 2 000000011001100  -0.0298
 3 000011000010100  -0.0221
 4 011010000100000  -0.0322
 5 010001110000000  -0.0459

Average Function Value of Generation=-0.02977
Maximum Function Value              =-0.01883


 Number of Crossovers      =   34

 Number of Jump Mutations  =    5
 Number of Creep Mutations =    0
 Elitist Reproduction on Individual    1
###############   SVD Currents   ################
#########    4 coils per half period  ###########
###############  Generation    2  ###############
#   Binary Code     Fitness
 1 010100010001000  -0.0188
 2 000100000000110  -0.0264
 3 010111000011100  -0.5144
 4 000011001011000  -0.5231
 5 000111000100000  -0.0329

Average Function Value of Generation=-0.22313
Maximum Function Value              =-0.01883
```

Note: In the second generation, the number of energized coils is not preserved.

Output from the genetic algorithm

```
###############   SVD Currents   ################
#########    4 coils per half period  ###########
###############  Generation    1  ###############
#   Binary Code    Fitness
 1 000010000000001 -0.0477
 2 000011010100000 -0.0331
 3 100000000010101 -0.1378
 4 000100001001010 -0.0116
 5 010010001100000 -0.0317
Average Function Value of Generation=-0.05237
Maximum Function Value              =-0.01164


 Number of Crossovers      =   39

 Number of Jump Mutations  =    8
 Number of Creep Mutations =    0
###############   SVD Currents   ################
#########    4 coils per half period  ###########
###############  Generation    2  ###############
#   Binary Code    Fitness
 1 000101001100000 -0.0322
 2 000100001001010 -0.0116
 3 000101011000000 -0.0396
 4 100000001001010 -0.0169
 5 000000010101010 -0.0300
Average Function Value of Generation=-0.02606
Maximum Function Value              =-0.01164
```

Preliminary Results

Total # Contours	# Independent	Currents	Error	Final Chromosome
30	3	SVD	0.01146	001000000100010
30	4	SVD	0.00883	010010000100010
30	5	SVD	0.00592	010010000100101
60	3	SVD	0.01099	000001000000000000010000000100
60	4	SVD	0.00682	000010000000001000000001000010
60	5	SVD	0.00480	000100000010000000100000100010