The Ohio State University

CCAPP

Evolving Antennas for Ultra-High Energy Neutrino Detection

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Genetically Evolving NEuTrino teleScopes (GENETIS) Collaboration

APS Meeting April 19, 2020

NSF

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Northwestern University

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Ohio Supercomputer Center
An OH·TECH Consortium Member

Generously supported by:

- CCAPP
- The National Science Foundation
- The Ohio Supercomputer Center

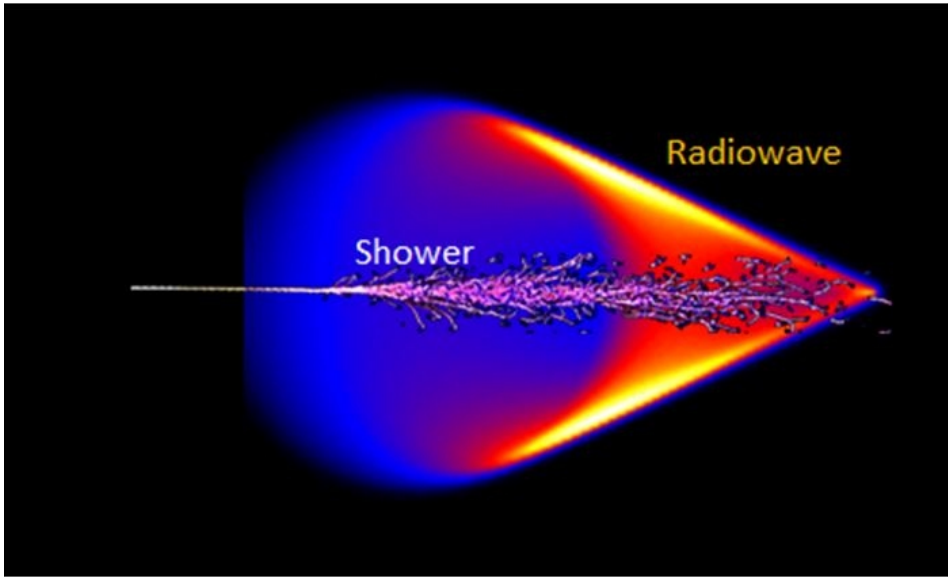
GENETIS

- Using genetic algorithms to evolve detector designs
- Members
  - 3 Professors
    - Amy Connolly, The Ohio State University
    - Carl Pfendner, Denison University
    - Stephanie Wissel, Pennsylvania State University
  - 1 Research Scientist
    - Kai Staats, North Western University
  - 1 Grad Student
  - 7 Undergrads
  - Numerous former undergrad members

Neutrino Radio Detection

- Ultra-High Energy (UHE) neutrinos interacting with ice create particle cascades
- These cascades emit Askaryan radiation

- Experiments need to cover large areas to be able to detect events
- Antennas are placed in holes drilled in the ice



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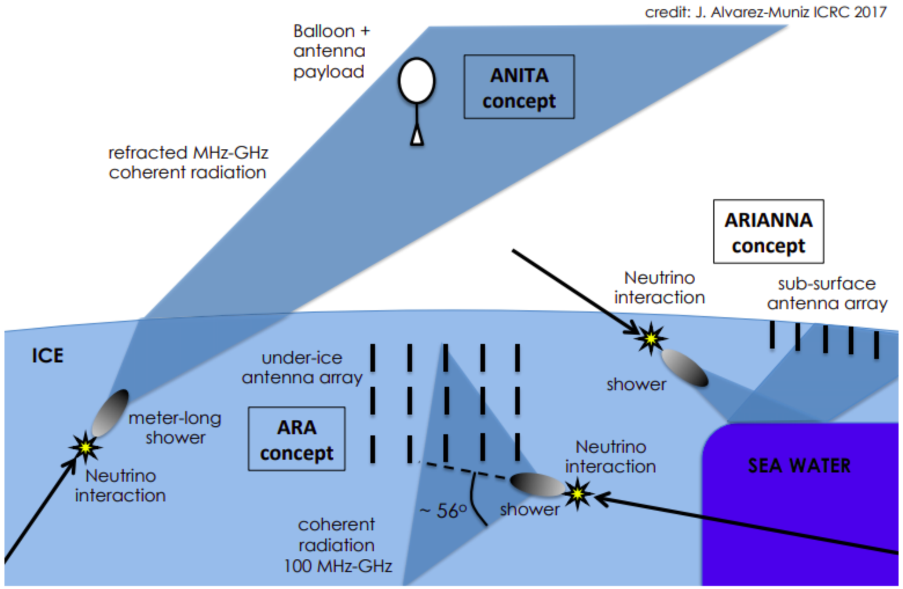

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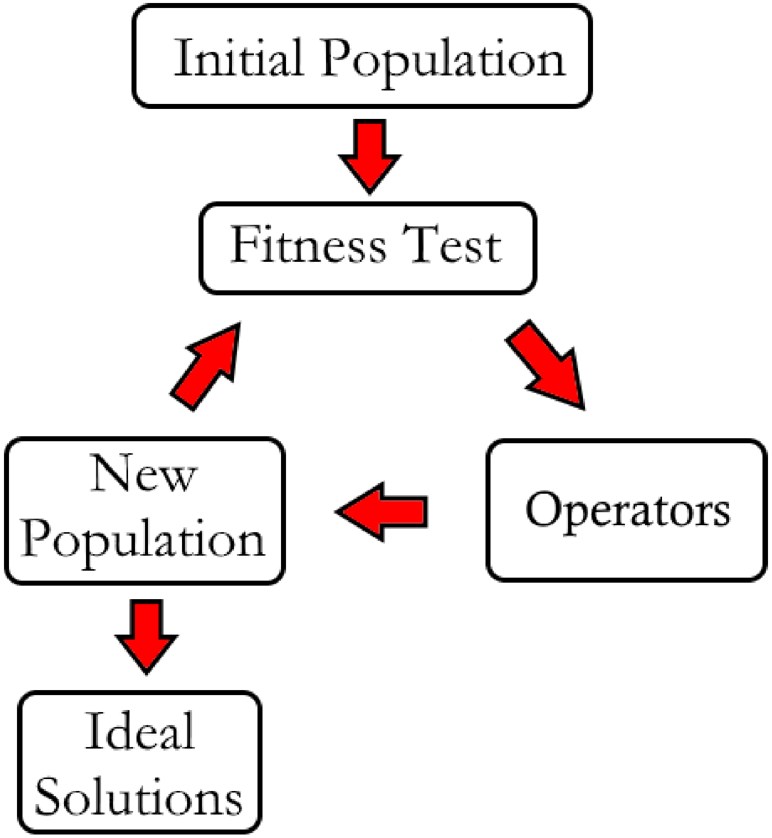
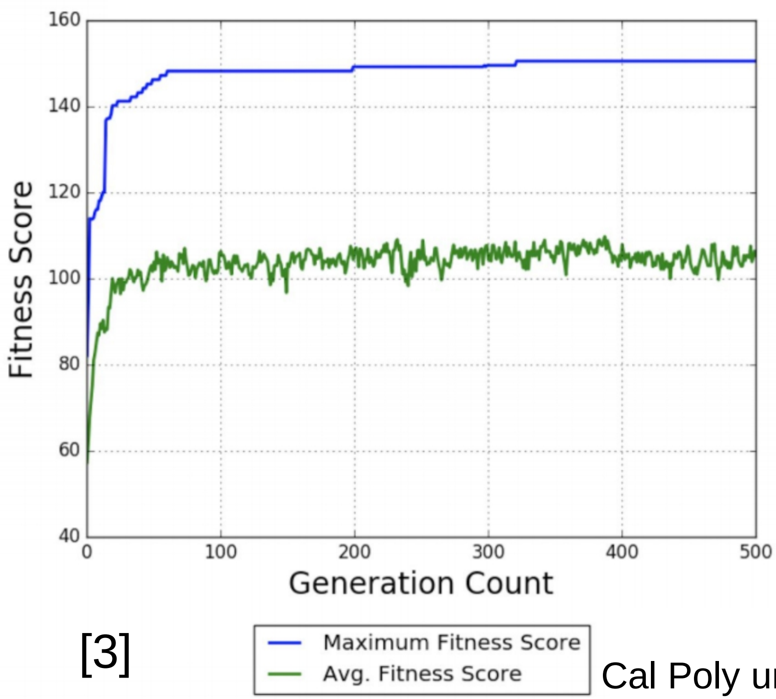
Genetic Algorithms

- Can we use GAs to design better antennas?
- Designed to mimic evolution
  - Generate an initial population of possible solutions, or individuals
  - Determine the fitness of individuals
  - Select some individuals to be used to make the next generation
  - Repeat until an ideal solution is approached!



Past Work

- Antenna Response Targeted Evolution (AREA)
  - Evolved ideal beam patterns for in ice neutrino detection
  - Fitness function was the number of neutrino events that trigger the detector



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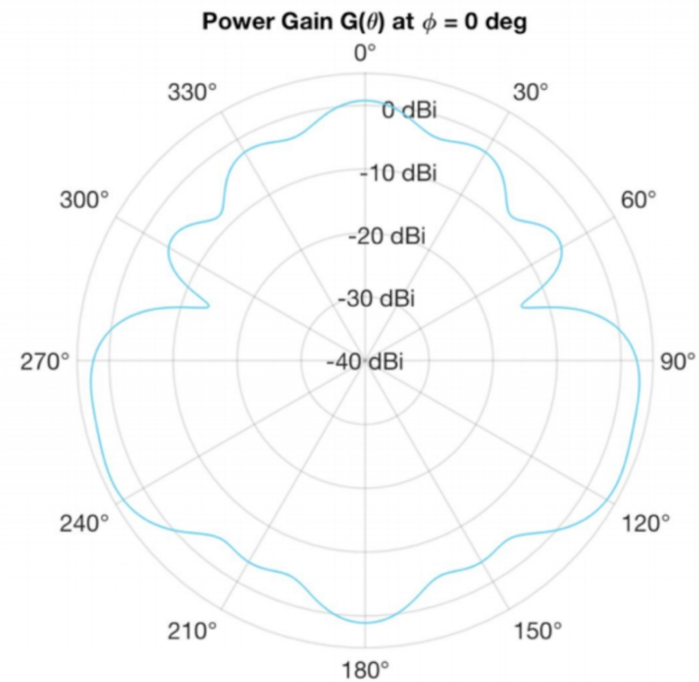
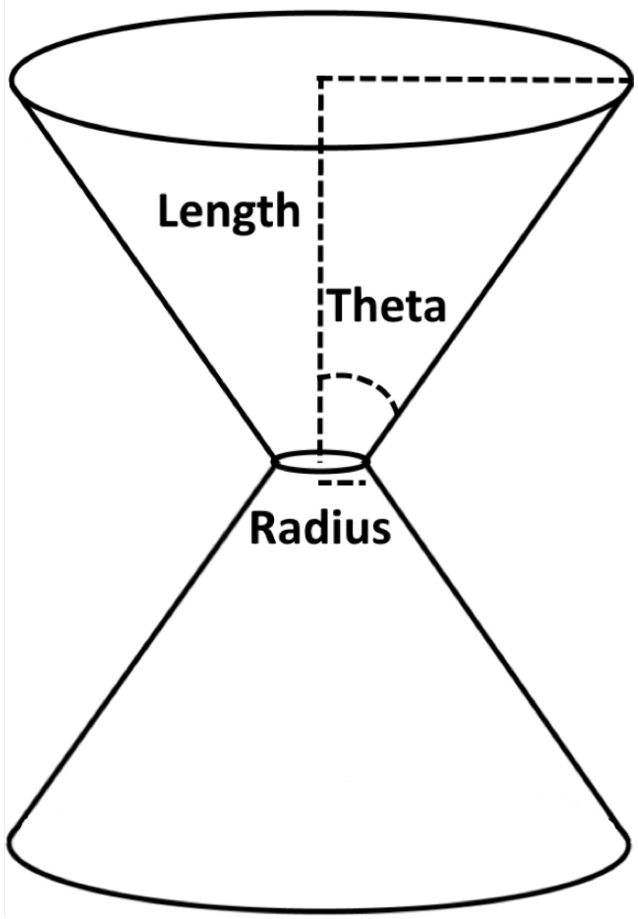


Cal Poly undegrads Corey Harris, Luke Letwin, and Jacob Trevithick

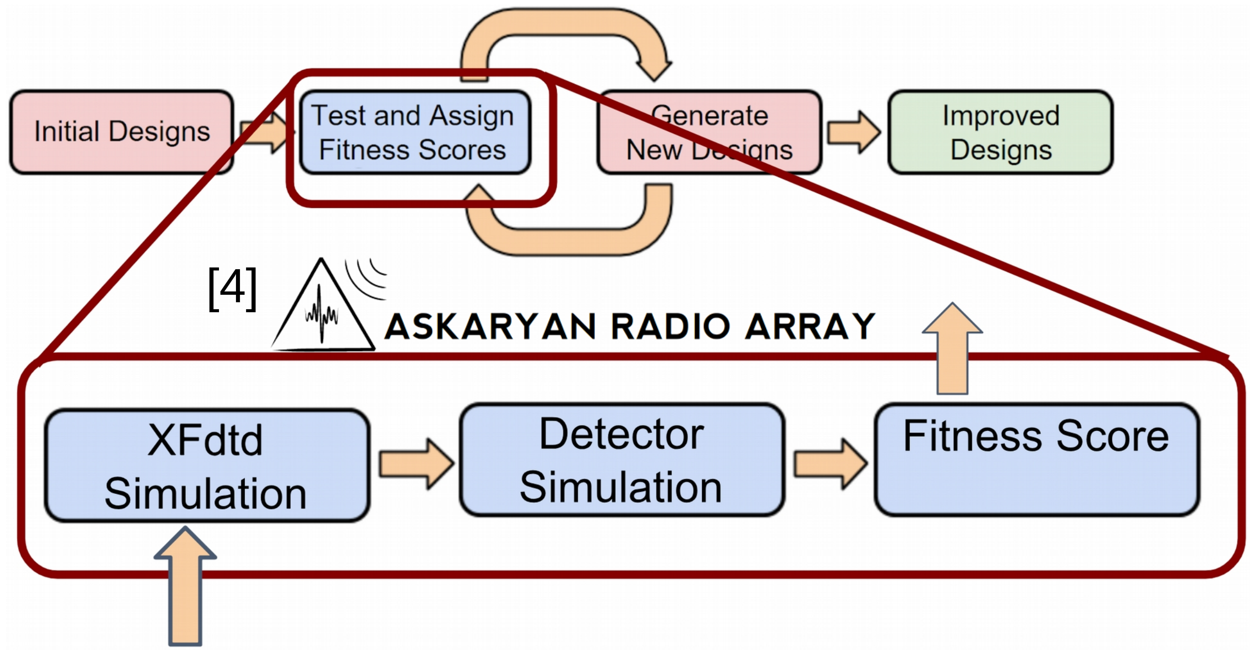
Evolving Antennas

- Currently evolve bicone antennas with 3 genes
  - Length, inner radius, and opening angle
    - Genes for initial generation are generated from gaussian distributions
  - Antenna beam patterns determined using an industry standard modeling software (XFdtd)
  - Pass these beam patterns to neutrino detection simulation software (AraSim)



"The Loop"

1. Generate new population
2. Model individuals in XF to create beam patterns
3. Send beam patterns through AraSim
4. Calculate Fitness Score
5. Select individuals to create next generation

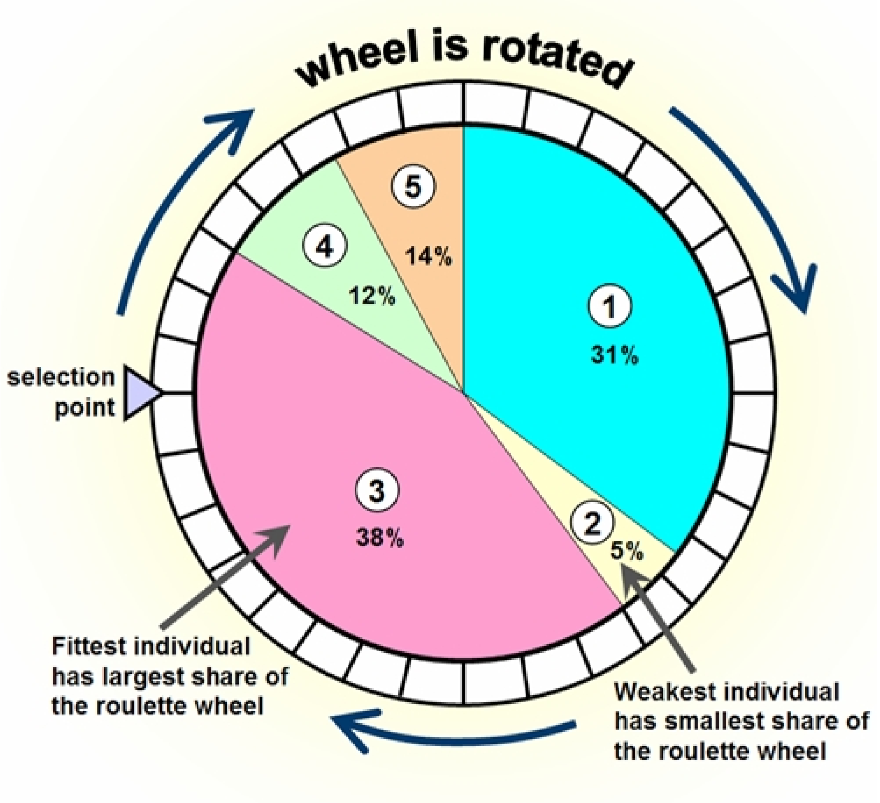


Total **run** time is ~3 hours per generation (for 10 individuals and 10^5 neutrinos)

XF	AraSim	Rest of Code	Total
2-3 hours	1 hour	Negligible	3 hours

Fitness Function

- Uses sensitivity of antenna to neutrino events as described by $(V\Omega)_{eff}$
  - Neutrino energies are set to 10^{18} eV
- Antennas are penalized for being too big
  - Holes in ice are drilled with a 15 cm diameter
  - Antennas bigger than are penalized to encourage the algorithm to make smaller antennas
- Roulette Selection
  - Higher fitness scores are more likely to be selected



[5]

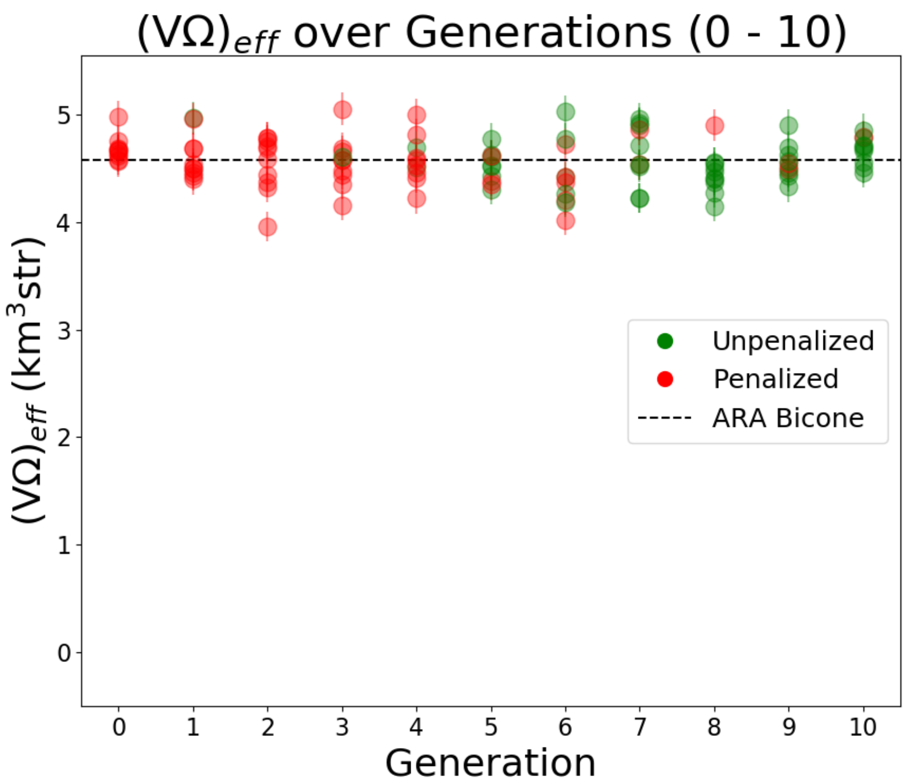
$$P_i = \frac{F_i}{\sum F}$$

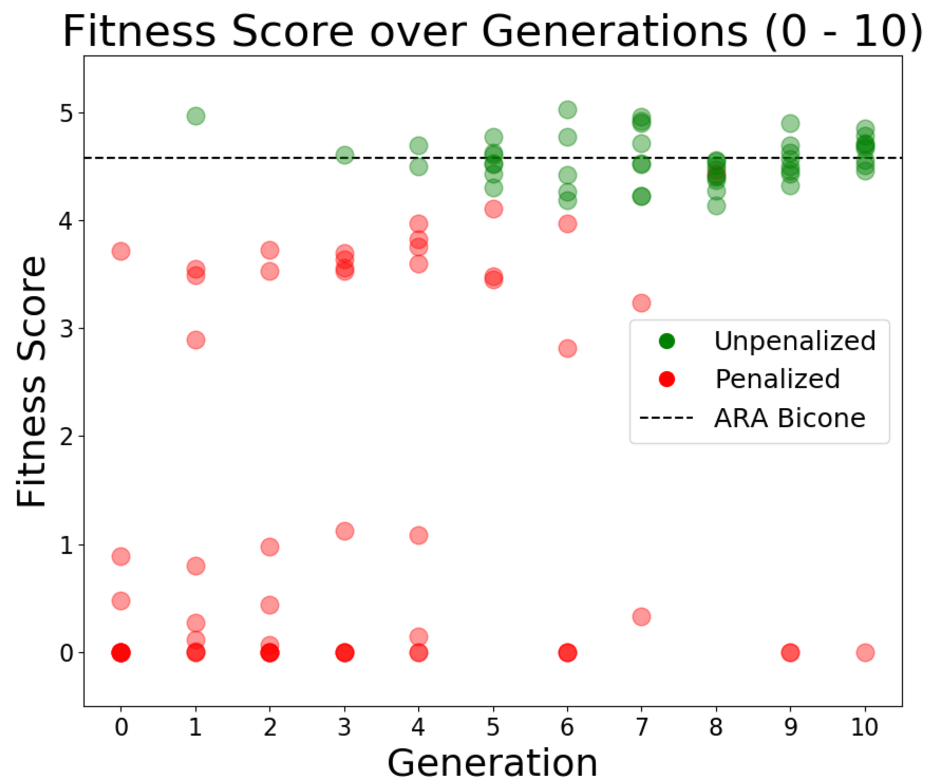
Efforts to Automate and improve speed

- Only human interaction with the loop is at the start
- Detector simulation
  - Sped up by a factor of 2 since last year
  - Parallelized in the loop (by a factor of 100)
    - (OSU undergrad Alex Patton)
- Developing a database of simulated antennas
  - Eliminates the need to simulate the same antennas repeatedly

Results

- Evolved 10 individuals for 10 generations using 10^5 neutrinos at $E_\nu = 10^{18}$ eV
- Algorithm learns to create “fitter” antennas





Next Steps

- Keep evolving!
  - Goal is hundreds of individuals and hundreds of generations
  - Explore other types of algorithms
  - Increase number of parameters
    - Design asymmetric antennas
- Build and test designs
  - Center for Design and Manufacturing Excellence at OSU can help machine candidate antennas
  - Deploy a prototype with Radio Neutrino Observatory in Greenland
- Expand into other areas
  - Use GAs to improve other aspects of experiments

Bibliography

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