Optimization of Digital Modulation Schemes using Evolutionary Algorithms

Derek Kozel

Introduction

- Derek Kozel
  - Masters in ECE from Carnegie Mellon
  - SpaceX, Range Networks, currently Ettus Research
  - Past research includes SDR and SDN based cellular systems, low power system on chip architecture, and evolutionary algorithms

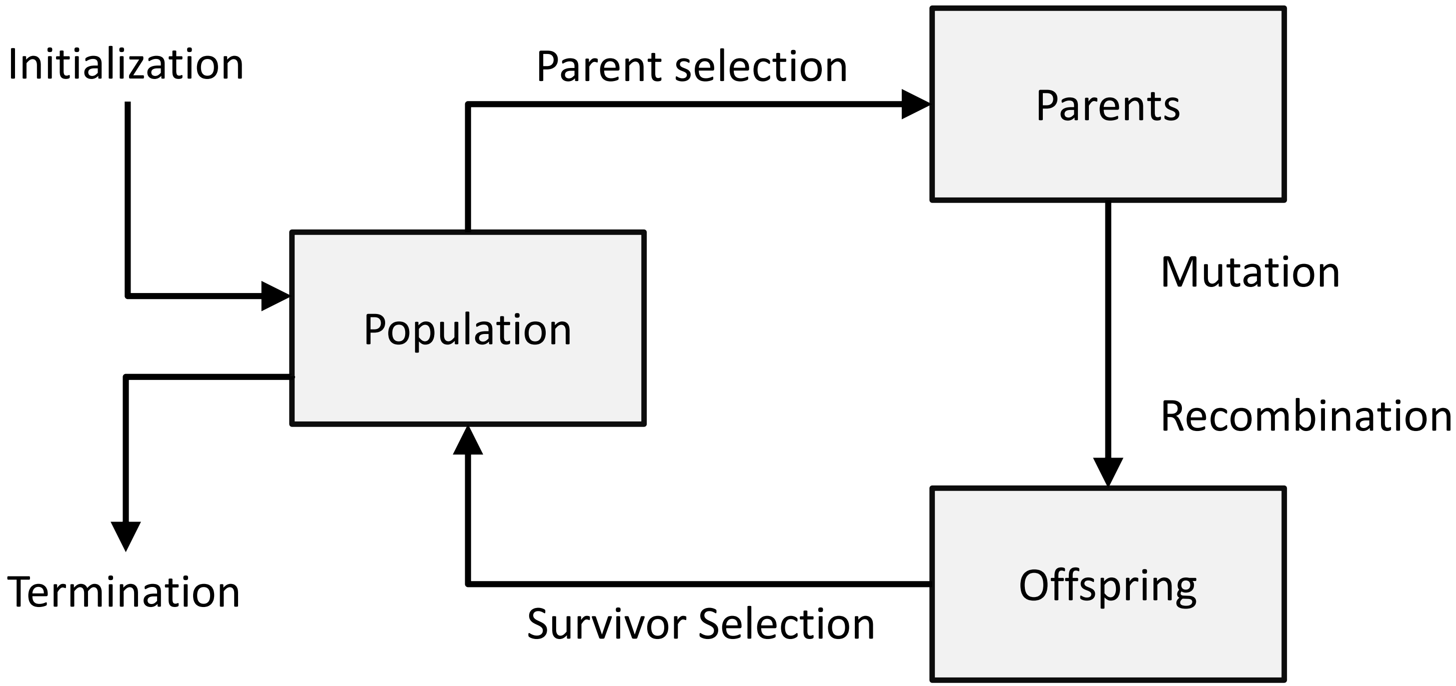
Recognition and Thanks

- Original work done during my masters
- “Evolution of digital modulation schemes for radio systems” at GECCO 2014
- Co-Authors
  - Ervin Teng, Bob Iannucci, and Jason Lohn

What is Evolutionary Computing?

- Subfield of artificial intelligence
- Continuous and combinatorial optimization
- Stochastic, optimal result not guaranteed
- Good for large, complex, search spaces

Basic Flow


Initialization
Parent selection
Parents
Mutation
Population
Recombination
Termination
Offspring
Survivor Selection

Basic Flow

BEGIN

INITIALIZE population with random candidate solutions

EVALUATE each candidate

REPEAT UNTIL (TERMINATION CONDITION is satisfied)

1 SELECT parents

2 RECOMBINE pairs of parents

3 MUTATE the resulting offspring

4 EVALUATE new candidates

5 SELECT individuals for the next generation

Components

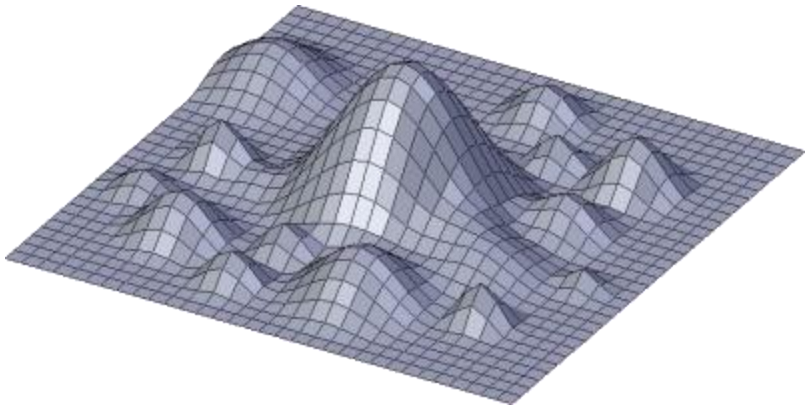
- Representation
- Fitness Function
- Population
- Parent selection mechanism
- Variation operators
  - Mutation, Recombination, others
- Survivor selection mechanism

Representation

- Genotype
  - Physical representation
    - i.e. bit strings
- Phenotype
  - Logical meaning
    - i.e. ints, floats, coordinates on a chess board

Fitness Functions

- Defining how good a solution is
  - AKA Objective Function in optimization
- Can be a simple formula or a statistic from a complex simulation



Example 2D fitness landscape

Population

- A pool of individual potential solutions (inputs)
  - Collection of phenotypes
- Can be divided up in different ways
  - Island
  - Age
  - Fitness
- Total of μ individuals

Parent Selection

- Parenthood not guaranteed
- Selection can be random, fitness based, deterministic, etc
- λ offspring are created for each generation

Fitness Proportional Selection

- Individuals are chosen to be parents with a probability proportional to their absolute fitness

$$p(individual\ i\ chosen) = \frac{f_i}{\sum_{j=1}^{\mu} f_j}$$

- This means that individuals with high fitness dominate the population quickly
  - Premature convergence

Ranking Selection

- Individuals chosen as parents with a probability proportional to their relative fitnesses

$$P_{lin-rank}(i) = \frac{(2-s)}{\mu} + \frac{2i(s-1)}{\mu(\mu-1)}$$

	Fitness	Rank	P_{selFP}	P_{selLR} (s=2)	P_{selLR} (s=1.5)
A	1	1	0.1	0	0.167
B	5	3	0.5	0.67	0.5
C	4	2	0.4	0.33	0.33
Sum	10		1.0	1.0	1.0

Variation Operators

- Used to create children different but related to the parents
- Operators apply to a certain number of parents (Arity)
  - Mutation is done to one individual at a time
  - Recombination takes two or more parents to make an child

Mutation

- Changes a single individual
- Bit flipping for bitstrings
  - For each bit, flip with a probability p_m

1	0	1	0	0	0	1	0	→	1	0	0	1	0	0	1	1

- For numbers
  - For each value, add a random value with probability p_m
  - Reset to a random value with probability p_m

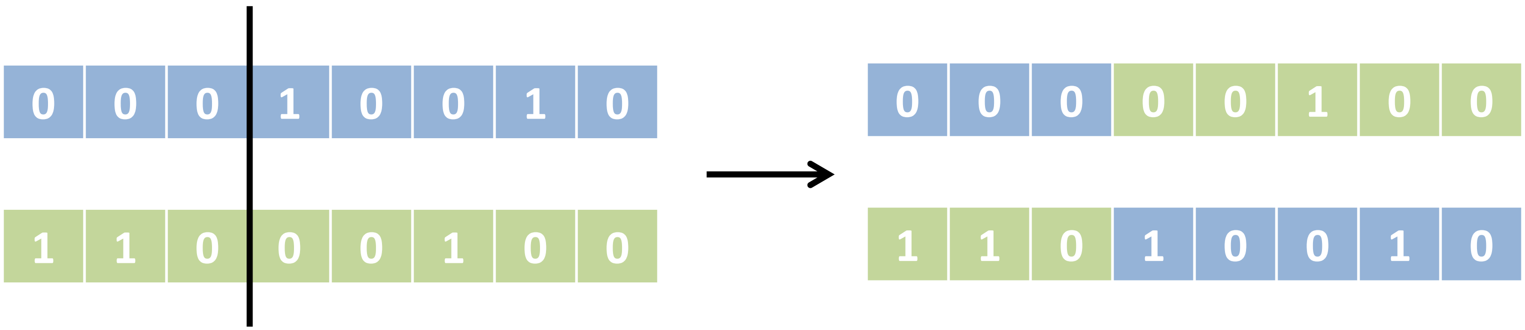
Mutation continued

- Swapping

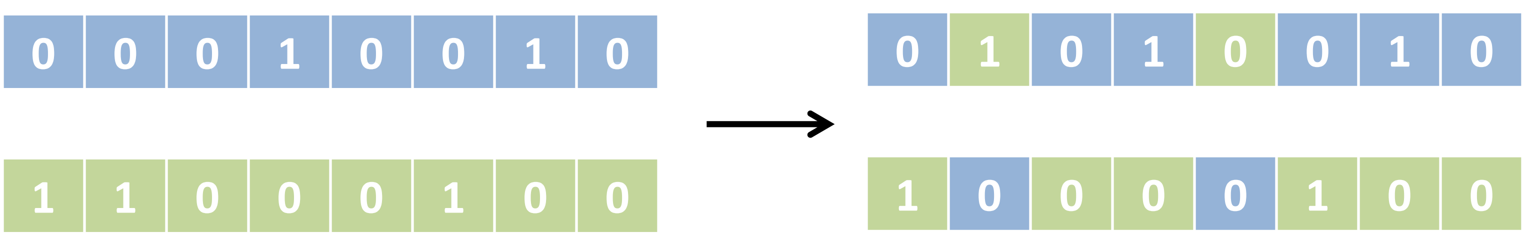
- Scramble, Insert, Inversion

Recombination

- Crossover is the main operation
  - One-point



  - Uniform (Pick a specific gene with probability p_c)

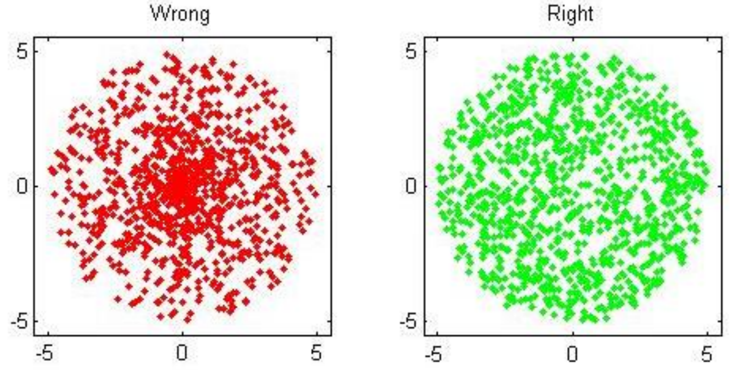


Survivor Selection

- Population is now μ parents and λ children
- Usually population remains constant over generations
- Must choose μ individuals from μ + λ
  - Age based
  - Fitness based
- Sometimes desirable to preserve elites
  - Best n individuals guaranteed survival

Initialization

- Usually completely random generation
- Can incorporate domain specific knowledge
  - Choose known good answers
  - Introduces some bias to the search



Termination Condition

- Prevent infinite or exhaustive searching
- N generations
- Absolute fitness threshold
- Minimum amount of change in fitness

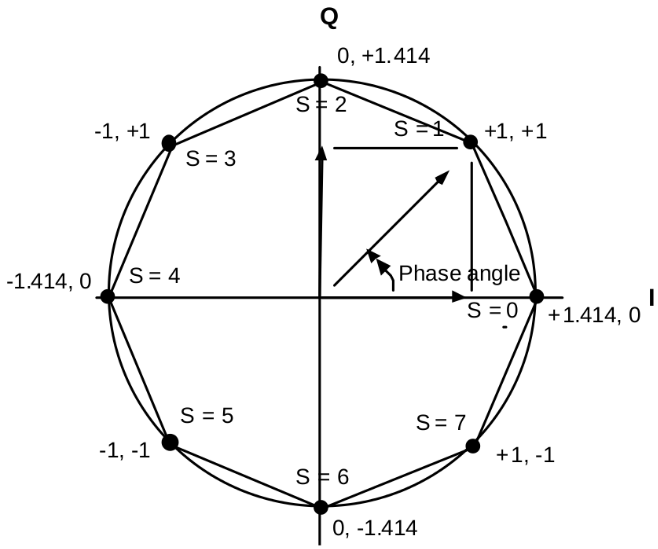
So it begins, now what?

- Exploration
- Exploitation
- Premature Convergence
  - Local Optimum

PSK Constellations

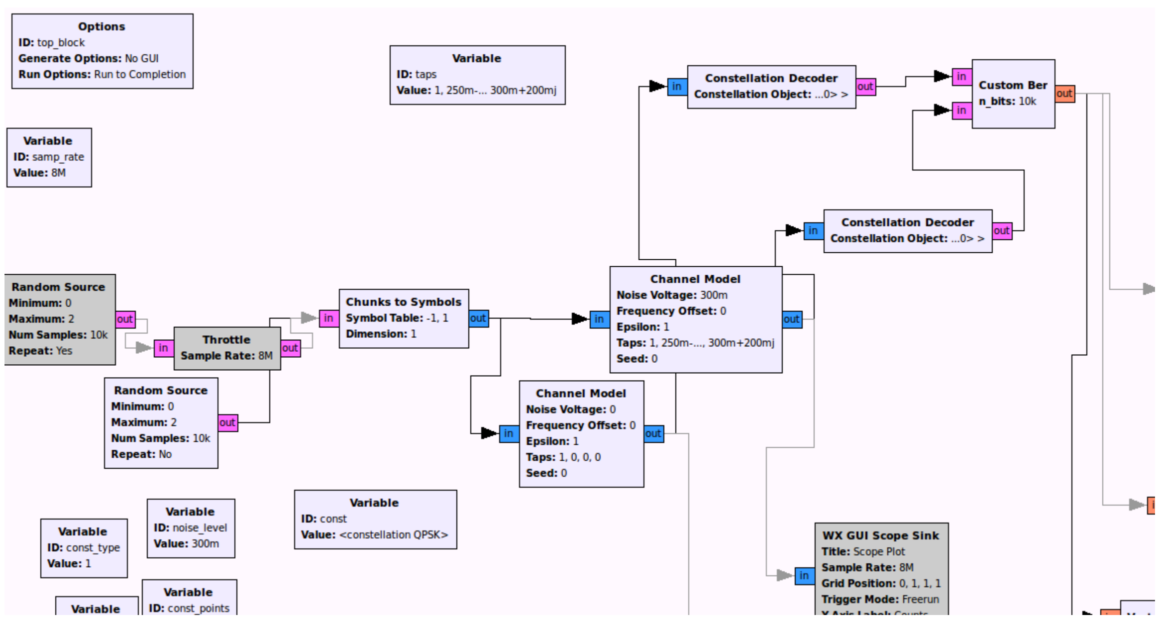
- A mapping of input bits to physically transmittable signals
- Can be represented as a string of integers

Input Bits	I	Q
000	1.414	0
001	1	1
010	0	1.414
011	-1	1
	…	



Setup

- Python implementations of algorithms
- Call GNU Radio simulation for fitness testing



Basic Evolutionary Strategy

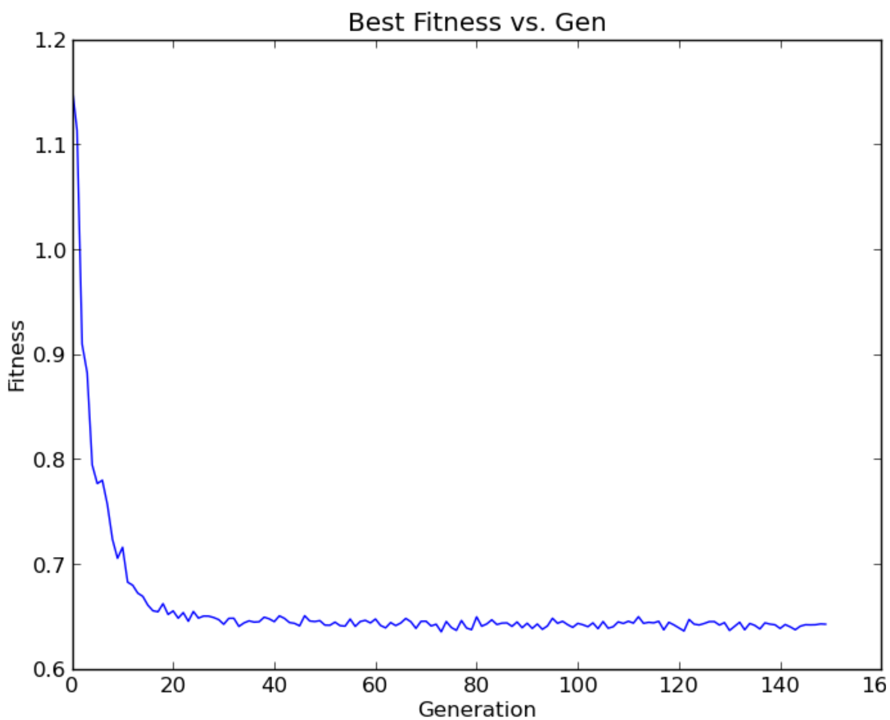
- Create 20 random constellations (individuals)
- Mutate and combine to create 140 constellations (children)
- Evaluate their fitness (BER + fudge factors)
- Select 20 survivors

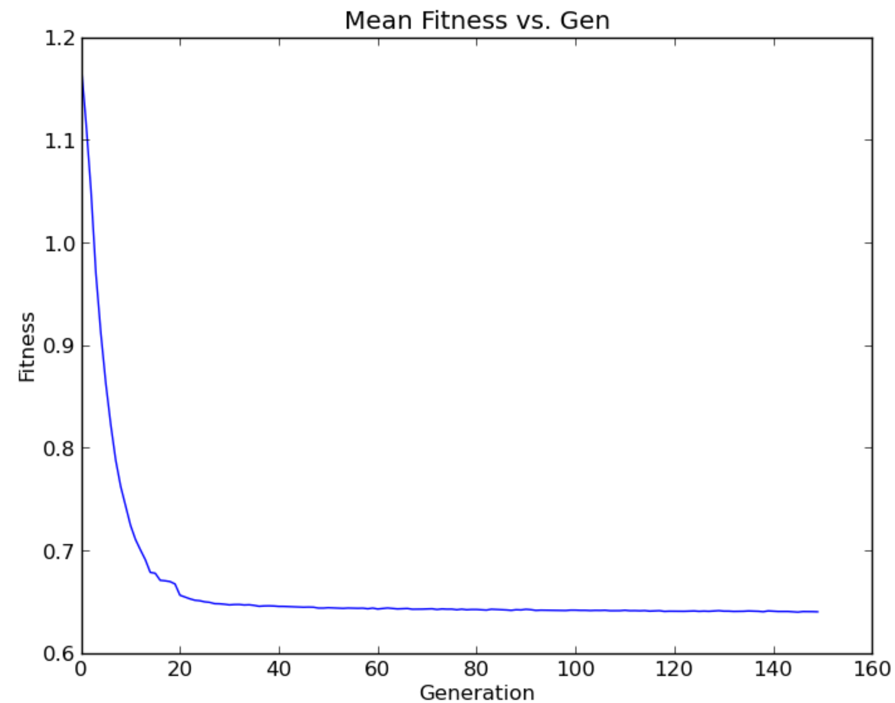
Parameters

- 150 Generations
- Parent pool of 20 individuals
- Child pool of 140
  - 100 the product of mutation
  - 40 from recombination

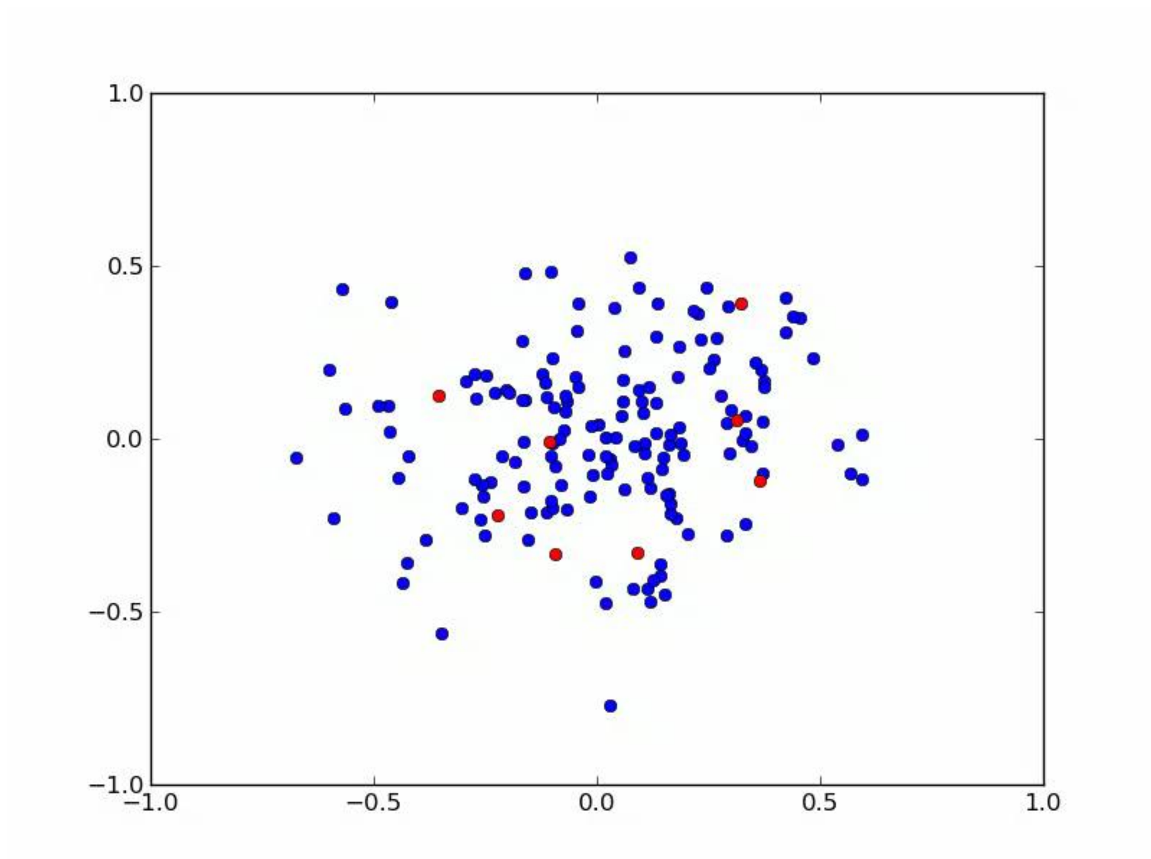
Basic ES Results

- Best Fitness: 0.6422





One Run



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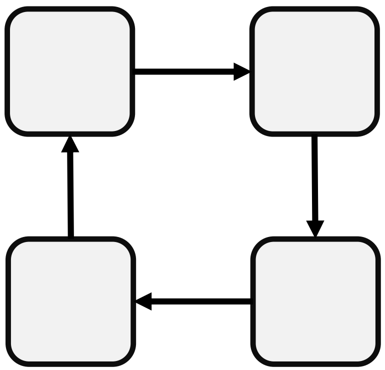
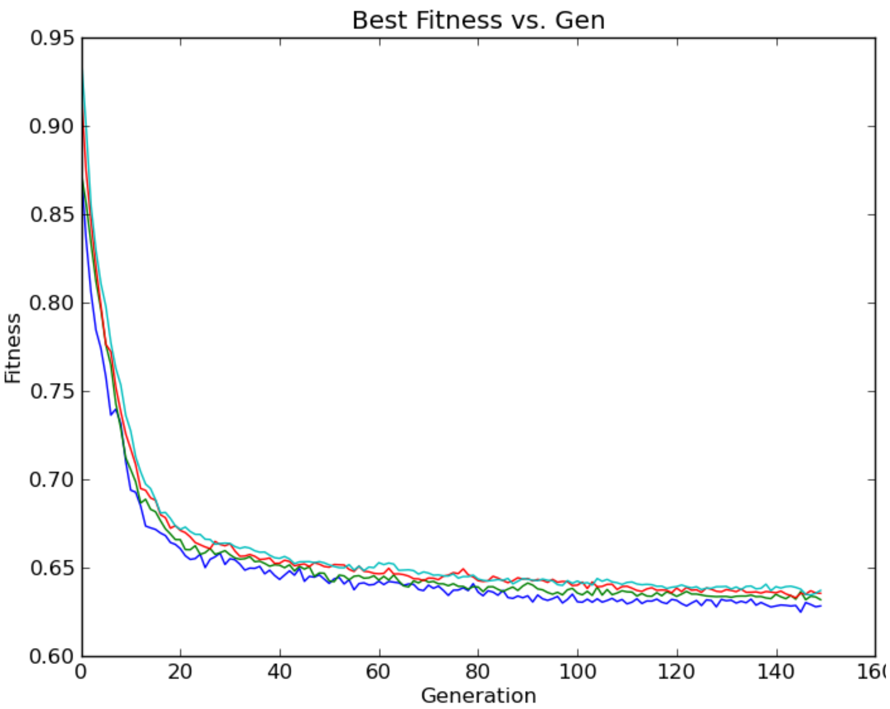
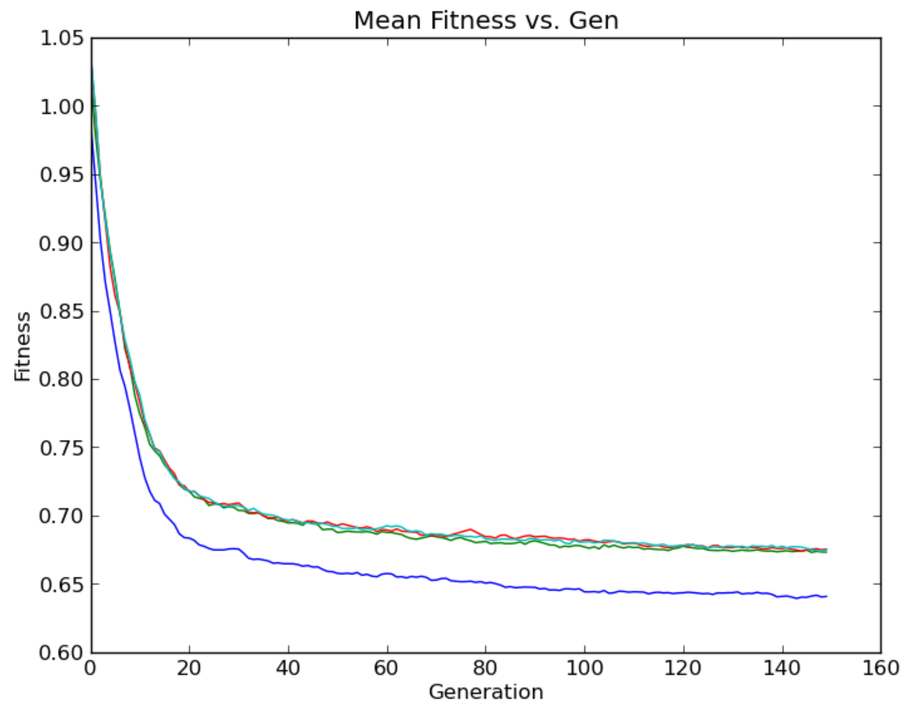
Island Model

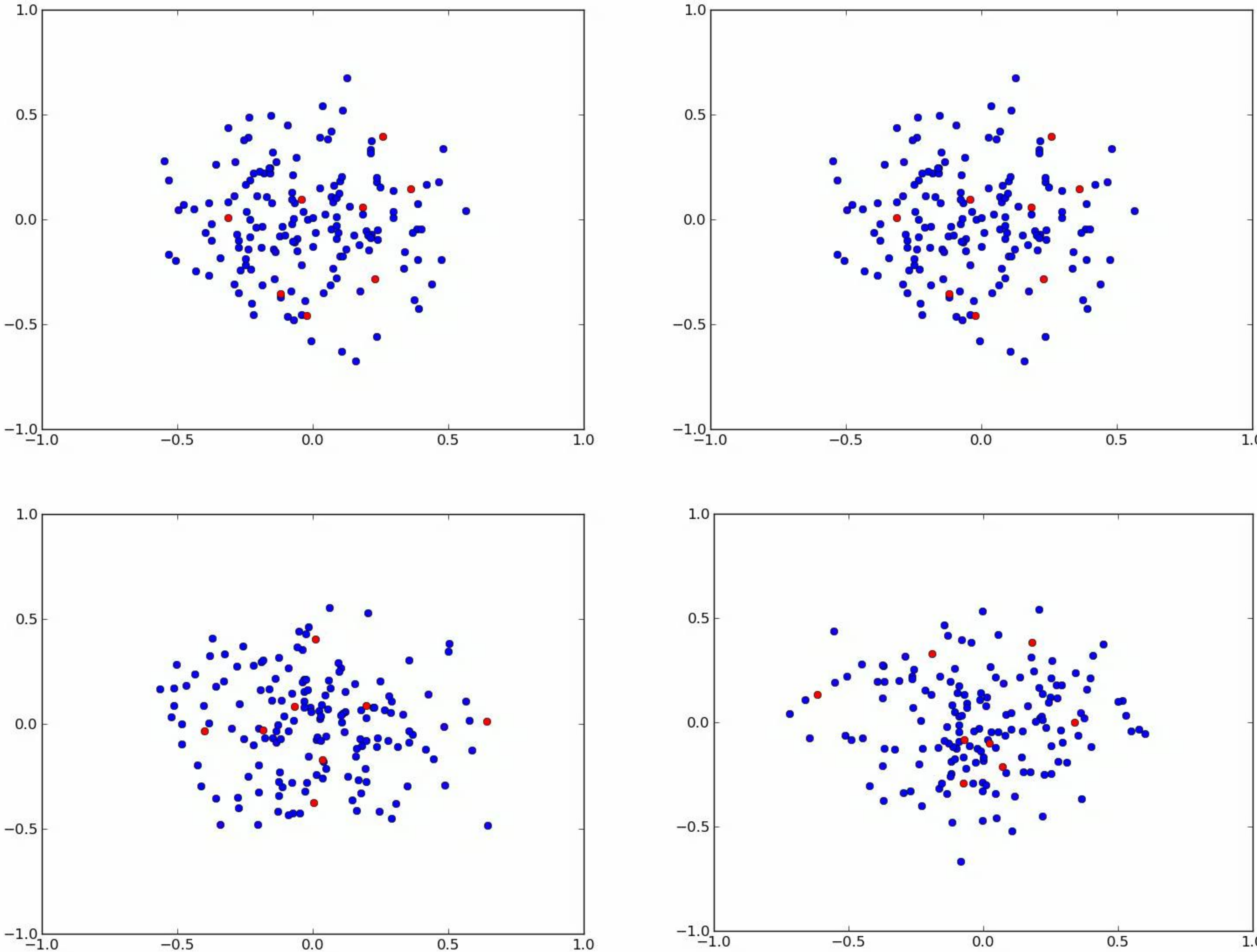
- Galapagos Islands
  - Population is divided with occasional migrations
- Run multiple populations in parallel
- Transfer small number of individuals when diversity converges on an island
- Use a fitness based survivor selection



- Mean best fitness = 0.6369



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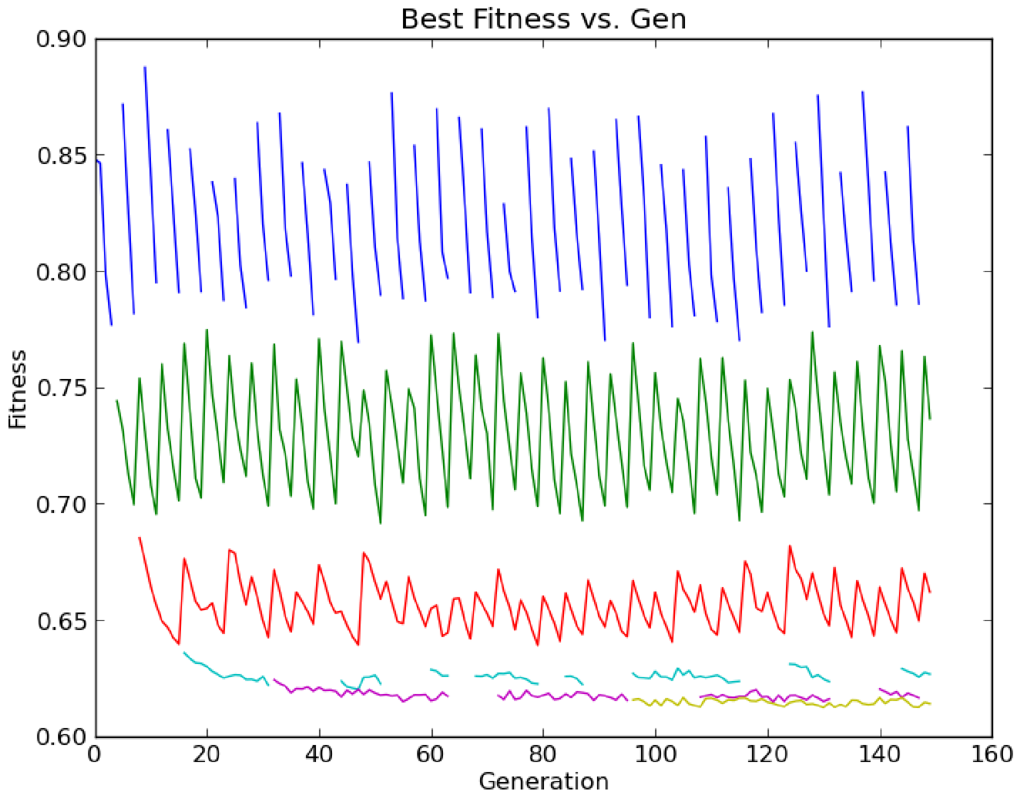
Age Layered Population Structure

- Gregory Hornby (UC Santa Cruz)
- Divide population by age cohorts
- Move population onwards and re
- Restart lowest level each epoch

ALPS Results

- Best fitness: 0.6140



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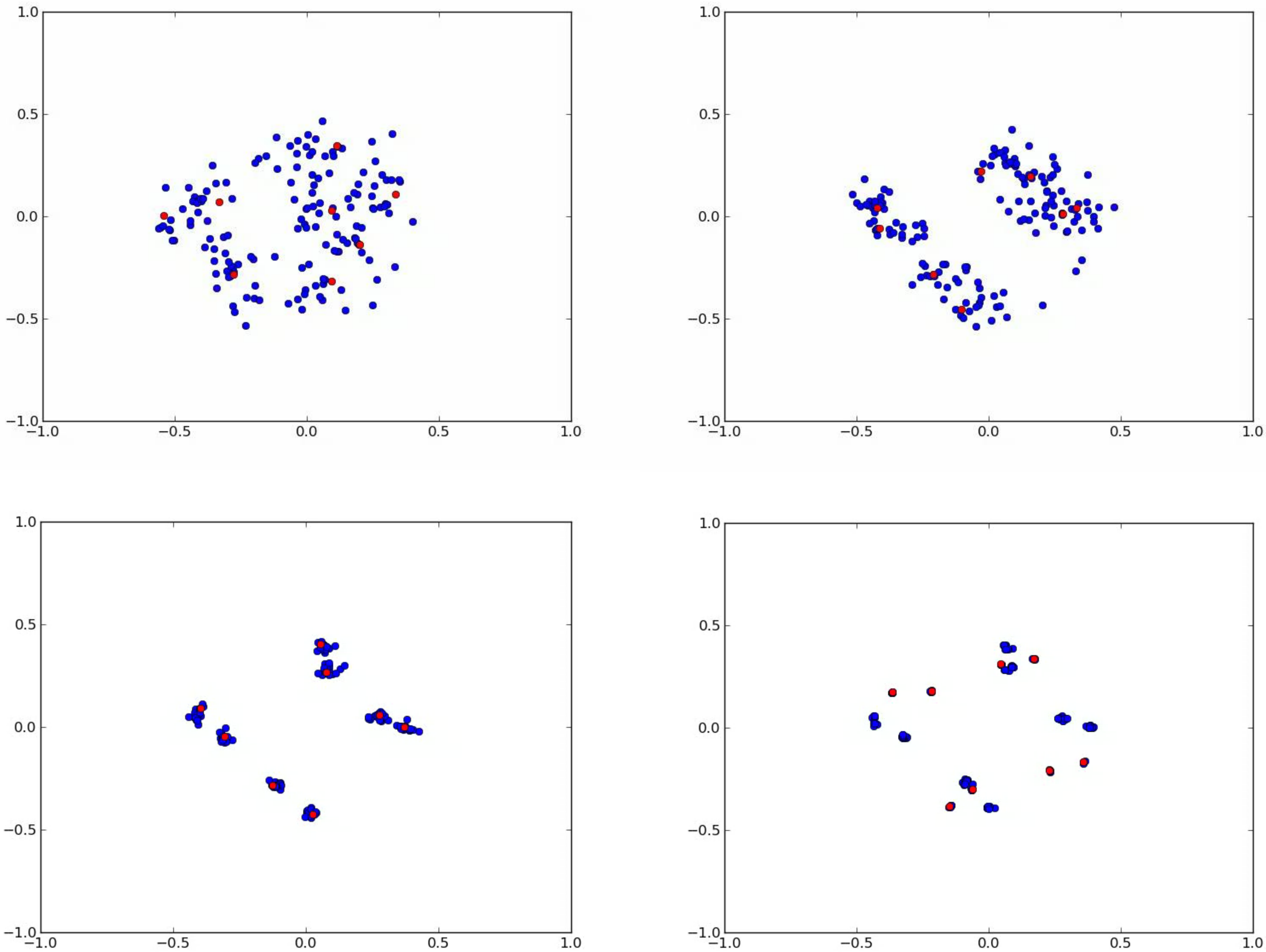

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Future Extensions

- Additional fitness tests
  - Variety of SNR and channel condition tests
- Longer tests, more bits, over the air
- Add additional transmission parameters to individuals
- Improve simulation
  - Framing, sync, complex channels

Thanks

https://github.com/dkozel/Evolving-Constellations

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