

Keen: Kotlin Genetic Algorithms Framework

*Thesis for the degrees of
Civil Engineer in Computer Science
and
Master of Science in Computing*



Ignacio Slater Muñoz

*Departamento de Ciencias de la Computación
Facultad de Ciencias Físicas y Matemáticas
Universidad de Chile.*

Thesis Author

Nancy Hitschfeld. PhD.

*Departamento de Ciencias de la Computación
Facultad de Ciencias Físicas y Matemáticas
Universidad de Chile*

Thesis Supervisor

Alexandre Bergel. PhD.

*Relational AI
Switzerland*

Second Supervisor

Santiago, Chile

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Abstract

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Contents

1	Theoretical Background	3
1.1	Evolutionary Algorithms	3
1.2	Genetic Algorithms	3
1.2.1	Representation	4
1.2.2	Fitness function	5
1.3	Genetic Programming	5
2	Relevant Work (State of the Art)	7
2.1	Agile Artificial Intelligence in Pharo	7
2.2	<i>DEAP</i>	7
2.3	<i>Jenetics</i>	8
2.4	<i>ECJ</i>	9
2.5	<i>GeneticSharp</i>	9
3	Introduction	11
3.1	Motivation	11
3.2	Hyphotesis and Research Questions	11
3.3	Objectives	12
3.4	Methodology	12
3.5	Structure	13
4	Keen: Kotlin Evolutionary Algorithms Framework	15
4.1	Introduction	15
4.2	Architecture	16
4.3	Genetic Algorithms	16
4.4	Genetic Programming	17
4.5	Parallelism	17
4.6	Extensibility	18
4.7	Conclusion	19
5	Case Study: OneMax	20
5.1	Introduction	20
5.2	Problem Description	20
5.3	Solution	21
5.4	Results	22
5.5	Conclusion	22
6	Case Study: Knapsack Problem	24
6.1	Introduction	24
6.2	Problem Description	24
6.3	Solution	25
6.4	Results	26
6.5	Conclusion	26

7	Case Study: Crash Reproduction	28
7.1	Introduction	28
7.2	Problem Description	28
7.3	Solution	29
7.4	Results	30
7.5	Conclusion	30
8	Conclusions	32
8.1	Summary	32
8.2	Contributions	32
8.3	Future Work	33
A	Glossary	35

Chapter 1

Theoretical Background

1.1 Evolutionary Algorithms

In the field of computational intelligence, evolutionary algorithms (EA) [5] are a family of algorithms inspired by the process of natural selection. They are part of the larger field of evolutionary computation,¹ which is a subfield of metaheuristics.²

EAs are algorithms that perform optimization or learning tasks by evolving solutions to a given problem. These tasks may range from function optimization to machine learning or game AI development. EAs have three main characteristics:

- **Population-based:** These algorithms work with a population of solutions, allowing them to explore the search space in parallel.³
- **Fitness-oriented:** The solutions in the population are evaluated using a fitness function, which is a problem-dependent function that assigns a value to each solution based on its quality. The goal of the algorithm is to find the solution with the highest⁴ fitness.
- **Variation-driven:** The candidate solutions are modified using genetic operators, such as mutation, crossover, and selection, to create new solutions. These operators are usually based on the biological processes of mutation and recombination.

While these principles serve as the foundation for most EAs, it's important to note that some variants may prioritize some principles over others, or introduce new principles. This diversity allows EAs to be adapted to a wide range of problems and scenarios.

1.2 Genetic Algorithms

Genetic Algorithms (GA)⁵ [3, 4, 5, 6] are a kind of EA where a *population of individuals*⁶ representing candidate solutions to an optimization problem evolves towards better solutions. Each individual is defined by its location in the search space, which is called its *genotype*⁷, and its fitness value, which is calculated with a *fitness function*.

A classical GA works as follows:

¹See definition A.2

²See definition A.6

³Not to be confused with parallelization, which is a technique used to speed up the execution of an algorithm by running it in parallel on multiple processors. “Parallel” in this context means that the algorithm is exploring multiple points in the search space (Def. A.9) simultaneously.

⁴In some cases, the goal is to minimize the fitness function, in which case the algorithm will aim to find the solution with the lowest fitness.

⁵Also known as Simple Genetic Algorithms (SGA) [5], or Traditional Genetic Algorithms (TGA) [6].

⁶See definition A.5.

⁷See definition A.4

Algorithm 1 Genetic Algorithm

```
population ← initializePopulation()
evaluate(population)
repeat
  parents ← selectParents(population)
  offspring ← crossover(parents)
  mutate(offspring)
  evaluate(offspring)
  population ← selectSurvivors(population, offspring)
until termination condition is met
return fittest(population)
```

Where `initializePopulation()` creates a random population of individuals, and `evaluate(population)` calculates the fitness of each individual in the population.

The algorithm then repeats the following steps until a termination condition is met:

1. `selectParents(population)` selects a subset of individuals from the population to be the parents of the next generation.
2. `crossover(parents)` creates a new population of individuals by combining the parents.
3. `mutate(offspring)` mutates the offspring to introduce new genetic material into the population.
4. `evaluate(offspring)` calculates the fitness of each individual in the offspring.
5. `selectSurvivors(population, offspring)` selects the individuals that will survive to the next generation.

Finally, the algorithm returns the fittest individual in the population.

The actual implementation of each of these steps depends on the problem being solved, and there are many different ways to implement each of them.

1.2.1 Representation

One of the most important aspects of a GA is the representation of the individuals. The representation is the encoding of potential solutions to the problem into a form that can be manipulated by the algorithm. This defines the search space of the algorithm, and it is one of the main factors that determines the performance of the algorithm. The most general representation of an individual is a matrix of genes⁸ called the *genotype* of the individual, where each column of the matrix is called a *chromosome*⁹.

Definition 1.1 (Cardinality of the search space). The *cardinality of the search space* is the number of different individuals that can be represented by the encoding.

Formally, given a vector of alphabets $(\mathcal{A}_1, \mathcal{A}_2, \dots, \mathcal{A}_n)$, and a representation \mathbf{G} with n chromosomes of length (m_1, m_2, \dots, m_n) where each chromosome is encoded using the alphabet \mathcal{A}_i , the cardinality of the search space S is defined as:

$$|S| = \prod_{i=1}^n |\mathcal{A}_i|^{m_i} \quad (1.1)$$

Note that this definition assumes that the chromosomes are independent, which may not be the same for all evolutionary algorithms.

⁸See definition A.3.

⁹See definition A.1.

To illustrate this concept, consider the following problem: given a binary string of length n , find the string that has the most ones.¹⁰ In this case, we can use a single column matrix \mathbf{G} to represent the individual, where each gene $g_i \in \mathcal{A}$ represents the i -th bit of the string, where $\mathcal{A} = \{0, 1\}$ is the alphabet containing the two possible values of a bit.

Then,

$$|S| = \prod_{i=1}^n |\mathcal{A}|^n = 2^n$$

Knowing this, we can conclude that an exhaustive search of the search space would require evaluating 2^n individuals, and thus the algorithm would have a time complexity of $\mathcal{O}(2^n)$.

This is a very simple example, but we can see how a naive search algorithm would have a very high time complexity. This would be of the utmost importance in a real world problem, where the search space would be much larger.

1.2.2 Fitness function

Definition 1.2 (Fitness function). A *fitness function* is a function $f : S \rightarrow \mathbb{R}^n$, where S is the search space and n is the number of objectives of the optimization problem, that takes a genotype as input and returns a vector of real numbers representing how close the individual is to the global optimum of each objective.

The fitness function is usually defined by the user of the algorithm, and it is problem dependent.

The one max problem is a maximization problem with a single objective, so the fitness function would be defined as follows:

$$f(\mathbf{G}) = \sum_{i=1}^n g_i \quad (1.2)$$

1.3 Genetic Programming

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¹⁰This is known as the *One Max* problem [17] or *Ones Counting* problem [20].

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Chapter 2

Relevant Work (State of the Art)

2.1 Agile Artificial Intelligence in Pharo

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2.2 *DEAP*

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2.3 *Jenetics*

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2.4 *ECJ*

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2.5 *GeneticSharp*

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Chapter 3

Introduction

3.1 Motivation

The notion of learning machines has been around since the 1950s, when Alan Turing [1] asked a simple question: “Can machines think?”. Since then, the field of artificial intelligence has grown exponentially, with new applications being developed every day.

The first ideas on programs that simulate natural evolution were proposed by Nils Aall Barricelli [2] in 1954, but was formalized (and popularized) by John Holland [3] in 1975 on his book about genetic algorithms.

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3.2 Hyphotesis and Research Questions

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3.3 Objectives

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3.4 Methodology

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Chapter 4

Keen: Kotlin Evolutionary Algorithms Framework

4.1 Introduction

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4.2 Architecture

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4.3 Genetic Algorithms

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4.4 Genetic Programming

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4.5 Parallelism

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4.6 Extensibility

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4.7 Conclusion

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Chapter 5

Case Study: OneMax

5.1 Introduction

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5.2 Problem Description

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5.4 Results

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5.5 Conclusion

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Chapter 6

Case Study: Knapsack Problem

6.1 Introduction

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Chapter 7

Case Study: Crash Reproduction

7.1 Introduction

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Chapter 8

Conclusions

8.1 Summary

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8.2 Contributions

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Appendix A

Glossary

In this appendix we present a glossary of terms used throughout this document that may not be familiar to the reader, but are not explained in the main text due to their common use in the field.

C

Definition A.1 (Chromosome). Representation of a single column of genetic information of a candidate solution to a given optimization problem.

Formally, a chromosome is a vector $\mathbf{c} = (g_1, g_2, \dots, g_n)$, where g_i is a gene (see definition A.3).

E

Definition A.2 (Evolutionary computation). Family of algorithms for global optimization inspired by the process of natural selection.

This typically involves processes mimicking natural selection, mutation, recombination, and survival of the fittest. The solutions to a problem are encoded as a set of “individuals” in a “population”. Over multiple generations, these individuals are selected and modified (via genetic operators like crossover and mutation) in order to find better solutions.

G

Definition A.3 (Gene). Representation of a single component of a candidate solution to a given optimization problem.

Formally, for a multi-dimensional function f , a gene is an element g in the domain of f .

Definition A.4 (Genotype). Representation of the full genetic information of a candidate solution to a given optimization problem.

Formally, a genotype is a matrix $\mathbf{G} = (\mathbf{c}_1, \mathbf{c}_2, \dots, \mathbf{c}_n)$, where \mathbf{c}_i is a chromosome (see definition A.1).

I

Definition A.5 (Individual). A candidate solution to a given optimization problem.

Formally, an individual is a pair (\mathbf{G}, \mathbf{f}) , where \mathbf{G} is the genotype (see definition A.4) and \mathbf{f} is the fitness value of the individual.

M

Definition A.6 (Metaheuristics). Problem-independent algorithmic method that yields a sufficiently good solution within reasonable time for an optimization problem, especially for complex problems where an exact solution is not crucial.

P

Definition A.7 (Phenotype). Same as definition A.5.

Definition A.8 (Population). Set of candidate solutions to a given optimization problem.

S

Definition A.9 (Search space). Set of all candidate solutions to a given optimization problem.

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