Design of Roller Coaster Tracks using Genetic Algorithm

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***Abstract*—In this project, we are focusing on designing the most exciting roller coaster that conforms to various constraints by considering different models of population. We are taking into account various factors such as G force, speed variation and the number of loops in the roller coaster track as variables which will in turn produce results to satisfy distinct levels of excitement of different groups of sensation seeking people based on their age. We will use a Genetic Algorithm to evolve the best combination of the aforementioned variables of design factors and come up with an optimum design.**

***Keywords*—Evolutionary Computation, Roller Coasters, Track Evolution**

I. Introduction

Roller-coasters are usually the main attraction of a theme park. A good roller-coaster design relies on different factors, such as the variety of track types, the differential G-Force acting on the individual and the ability to satisfy the preference of people in different age. The variety of track-type combinations increase the feeling of excitement of people. Unexpected turns, instant halts, loops, different slope of the track direction, all stimulate the sensation of individuals and provide the customers with the experience escaping from the original lives. Besides, another important factor contributing the goodness of roller-coaster design is the differential G-Force generated by the function of roller-coaster. The extra amount (or decrease) on G-force generated by roller-coaster changes the normal force occurring on human body, which increases the enjoyment for it. Moreover, the preference of people also influences whether a roller-coaster design is good or not. For example, people in adolescence period prefer more exciting factors such as steeper track and more loops in the roller-coaster while in adulthood prefer not so many loops. A good roller-coaster design should take people in different age into consideration and try to come to an optimal solution satisfying different aged people.

The process of designing roller-coaster is usually based on initial human design and the testing afterwards to check for safety or feasibility. However, in our approach, we will generate varieties of tracks using evolutionary algorithm. We begin with a starting point and randomly generate roller-coaster with random combination of different type of tracks. Then, the evolutionary operator comes to the scene to generate diversity of tracks. Finally, the multi-objective fitness function based on people at different ages leads to the optimal solution fulfilling the given constraints as we will illustrate in more detail in the following chapters.

II. Problem Statement

To design a roller coaster track using an Evolutionary Algorithm so that the thrill experienced by an individual is maximum.

III. Related Work

Let us first discuss the work that has been done in generation of tracks using content generating algorithms.

A. Procedural Content Generation

This technique uses simple algorithmic procedures to generate a huge amount of game content with very basic and limited resources. This technique was used in games such as Rogue5, where they used this method to generate game components on the spot. Other examples are Elite6, MidWinter7 etc. this technique is still used to minimize the design costs and generate content that would be too difficult and time consuming for human designers. There are a number of decisions that have to be made when it comes to using PCG. The first distinction to be made is if the content generation is done online or offline. It can be done at run time or at the game development stage. The second thing to be taken into consideration is whether the generated content is essential to the game or not. The Develop needs to make sure that the algorithm does not waste too many resources that are not essential to the game's advancement. The final concern for the generating algorithm is how much of it needs to be restricted under parameters. The parameter could range from something as simple as having a seed to the randomly generated input to something as big as making the input a multidimensional vector of real values parameters. There are two types of generating algorithms: constructive and what are called "generate-and-test". In a constructive content generating algorithm, content is generated only once and then not changed. It has to make sure that it is correct as it is being developed. The other type of generating algorithm is called the "generate and test" type where as soon as the content is generated, it is tested and has to meet some criteria. If for some reason it fails a test, it is regenerated till a good enough content is generated.

B. Search-Based Procedural Content Generation

This is an extension to the generate-and-test approach of procedural content generation. The fitness function is graded according to its fitness value which is usually one or a vector of real numbers. This way the content with the highest fitness is favored. This was used by [Togelius et al]. They combined SBPCG with an Evolutionary Algorithm to make a simple track game.

C. Neural networks

The car control methods are implemented using feed-forward neural networks. The topology is fixed but as the game track evolves, the weights are reset using back-propagation.

D. Imitating Realistic Environment

Another aspect of the game content generation problem is to make the game as fun and real as possible. There has been research done in making tracks as believable as possible and having various checkpoints in the game, different steering commands etc. The physics includes keeping a tab on inertia, drift and collision impact.

IV. Proposed Work

Our focus is on designing a track for a roller coaster so that the person feels the most excited. We are taking into account various factors such as G force, speed variation and the number of loops in the roller coaster track as variables which will in turn produce results to satisfy distinct levels of excitement of different groups of sensation seeking people based on their age and gender. On the other hand, in formulation of population models, we will divide the population into three groups based on their ages: children under the age of 12, teenagers and adults. The reason for this demarcation is that people in different age groups respond differently to external factors that influence the level of excitement. Our aim is to maximize the positive sensation seeking points (Eg: Adrenaline Rush) and minimize the negative sensation seeking points (Eg: Fear) to compute the fitness of the design. We will use a Genetic Algorithm to evolve the best combination of the aforementioned variables of design factors and come up with an optimum design. The major roller coaster design factors include, but not limited to, height, turns and loops. We are looking to alter these factors to maximize the enjoyment. The following restrictions are applied on the GA :

1) Speed of roller coaster: We need to ensure that the speed at which the roller coaster is operated is not too high. This is because if the speed is too high, it will jump off the crest of a hill.
2) Speed at which the roller coaster cart enters the loop.
3) Length of the track
4) The radius of a circular track
5) Turning radius and turn angle for circular track
6) Optimum speed such that it will go around the loop (Roller coaster should not stall)
7) Max Gravitational Force any Human can take is +5.5 G's and -3G's ,anything exceeding this would mean death
8) Potential E = Weight • height
9) Kinetic E = 0.5 • m • V^2 (Since the roller coaster will be free-fall we will need to calculate KE and PE)
10) Drag (Friction, Air resistance, Brakes, etc anything that slows down the Coaster)
11) Mass of each individual (Constant during the ride)
12) Unladen weight of roller coaster
13) Minimum Turning Radius (Preventing derail)
14) Total Area that the roller coaster can occupy

V. Evolutionary Algorithm

A roller coaster does not have an engine to propel it forward. Before a ride begins, the carts are pushed to the top of a hill by an electric winch. The energy that the winch needs to pull the roller coaster is then amassed by the roller coaster as Potential energy which is used to come down the hill when the ride begins. This potential energy is then converted to kinetic energy as the force of gravity acts on the cars and pulls them down thereby accelerating them and converting the original potential energy completely into kinetic energy. This swapping of potential to kinetic energy keeps happening throughout the ride. For example, every time the cars go uphill, their potential energy increases and kinetic energy decreases and vice versa. Thus, whatever amount of potential energy they possessed at the start is the maximum energy that they can have at any time. A very important factor that needs to be considered here is the friction that the cars experience between their wheels and the track. This friction takes away some of the initial potential energy. Air resistance also comes into play and further takes away some energy. A lot of such factors contribute in reducing the overall energy of the roller coaster. Since they don't have engines, we can't make up for the energy that was lost. This is the main reason why the loops at the end of the track are modelled to be smaller.
G FORCES for the thrill factor:
The thrill that we experience on a roller coaster is mainly because of all the forces acting on our bodies. Even though we don't see them, these forces push and pull on our bodies and give the sense of excitement. The biggest force that is felt by an individual is his own weight, as well as the weight of the car and of the other people on the ride. This total weight does not act downwards; it pushes a person forward when going down a hill and backwards when going in an upward direction. The forces that are felt keep varying which makes the rides unpredictable and give a sense of thrill. When the car is in a loop, the direction keeps changing.
The total forces on a roller coaster are somewhere in the range of 2-4g. The G force felt by a person varies from point to point. The biggest g force is felt when the car is just about to roll down a hill. The position of the car also determines how much g

force is felt. If the train is long, each car's position decides how much force is felt.

The tracks are made of four types of track segments

1) Straight : The track starts with the path being straight. We have 2 arbitrary points that will be randomly generated that will decide the starting and ending point of the straight track segment.The identifier associated with a straight path is 10.
2) Curved track segment: We have a radius of curvature associated with a curved track segment.There are 2 types of curved tracks, namely left(track segments used to turn left) and right(track segments used to turn right). There are 3 types of curves for both types that we will consider; small, medium and harsh (almost perpendicular) curve.The angle of curvature decides which category it falls into. We pick 4 arbitrary points and decide their coordinates. The three types of right curved tracks are called 21,22 and 23 and the left curved ones are labelled as 31,32 and 33.
3) Inclined Paths: The roller coaster is made to go through straight tracks that have an angle of inclination associated with them. There are 3 types of inclined paths based on the angle of inclination-small, medium and high. They are labelled as 51,52 and 53 and have 2 points that decide the starting and ending point of the inclined path.
4) Loop: The radius of curvature, angle of entry, entry height and the length of the loop are associated with this track segment. [Ann-Marie Pendrill]

Track Segment	Label	No. of arbitrary points
	11	2
	21	4
	22	4
	23	4
	31	4
	32	4
	33	4
	41	2
	42	2
	43	2
	51	2
	52	2
	53	2
	61	11
	62	11
	63	11

Figure 1. Various track segments with corresponding labels and number of arbitrary points required for generation

A. TRACK REPRESENTATION

In this section, we will describe how the individual is generated, the genotype and phenotype and ensuring that the generated tracks are closed paths.[Loiacono et al]

1) The Genotype: The genotype is an array containing track segments. The track segments are represented by numbers. Thus each individual is a series of randomly generated track segments which can be acted upon by evolutionary operators. It is important to note that the track generated as the result must be a closed track. An individual is basically an array of containing randomly generated track segments. Each individual has a fixed starting point, i.e, track segments 11 and 43. This is done to adhere to the rules of Physics wherein the roller coaster

Parameters	Multiplicative factor	Range	
		Adults and teenagers (weight= 60- 80 kg)	Children(mass=30kg)
Turns	15	8-33	8-33
Loops	30	1-7	0-2
Drops	25	1-10	1-5
Energy(m*g*h)	20	1.2-9kJ	0.15-0.9kJ
Maximum speed	10	19m/s – 54 m/s	10m/s-25m/s
Height	1	20-150 m	5-30m

Figure 2. Parameters and value ranges for fitness calculation

car gains potential energy by being taken atop a hill after going on a straight track segment.
An individual would look like: 11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 63 62 51 22 23 11 32 41 62 42 43 31 22 11 53 51 11 42 43 11 22 62 53 11 51 52 33 31 32 21 53 43 42

2) The Phenotype The phenotype is a series of points on the track in the 3-D space. Each point is represented as a set of 3 points (x, y and z) using arrays. The current location of the track is stored is a separate variable using the index of the array. The number of points on a track is restricted to 2000 for computational purposes.

B. Fitness Function

The fitness function is defined as the addition of turns, loops, drops, average speed and potential energy. The following table shows the parameters and their constraints. For an adult with mass 60 kg, setting the height to 80m and g= 9.8m/s, with number of turns, loops, drops and average speed as 10,3,3 and 39 respectively, the fitness function is calculated as : Fitness = M.F * turns + M.F * loops + M.F * drops + potential energy + M.F * max speed Where M.F. = multiplicative factor. Thus the calculated Fitness value = 150+90+75+940+390 = 1645 A penalty is added every time it exceeds the number of loops and turns. This is done to ensure that these track segments are not used excessively and the roller coaster is safe for any person to ride.

11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 63 62 51 22 23 10 32 41 | 62 42 43 31 22 11 53 51 11 42 43 11 22 62 53 11 51 52 33 31 32 21 53 43 42

11 43 21 33 42 41 53 52 61 11 63 22 23 21 33 32 43 51 53 22 21 11 51 62 61 | 23 22 21 43 41 42 53 61 63 62 53 43 42 11 11 22 22 42 43 61 11 32 42 62 61

Figure 3. Single Point Crossover between 2 parents

11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 63 62 51 22 23 10 32 41 23 22 21 43 41 42 53 61 63 62 53 43 42 11 11 22 22 42 43 61 11 32 42 62 61

11 43 21 33 42 41 53 52 61 11 63 22 23 21 33 32 43 51 53 22 21 11 51 62 61 62 42 43 31 22 11 53 51 11 42 43 11 22 62 53 11 51 52 33 31 32 21 53 43 42

Figure 4. Children formed after 1- point crossover

C. Selection operator

We have used tournament selection with tournament size set at 4. We will run tournaments among 4 individuals which are chosen at random from the population. At the end of each tournament, a winner is chosen based on the fitness values. This is given as: choose k (the tournament size) individuals from the population at random and then choose the best individual from pool/tournament with probability p.

D. Genetic Operators

CROSSOVER : We have done a one point crossover. We randomly select a single crossover point in both parents and then swap the data between them. Crossover is done with the probability (P_c) of 10%. For instance consider 2 individuals:
Individual 1 :
11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 63 62 51 22 23 10 32 41 62 42 43 31 22 11 53 51 11 42 43 11 22 62 53 11 51 52 33 31 32 21 53 43 42
Individual 2 :
11 43 21 33 42 41 53 52 61 11 63 22 23 21 33 32 43 51 53 22 21 11 51 62 61 23 22 21 43 41 42 53 61 63 62 53 43 42 11 11 22 22 42 43 61 11 32 42 62 61

For do a single point crossover at position 24. This is shown in 3. The resulting individual is shown in 4.

MUTATION: We randomly pick a point in the individual and swap the track segment with another track segment. For example, the track segment

11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 63 62 51 22 23 10 32 41 23 22 21 43 41 42 53 61 63 62 53 43 42 11 11 22 22 42 43 61 11 32 42 62 61

11 43 32 33 62 63 51 51 52 33 23 22 21 42 63 63 21 52 62 51 22 23 10 32 41 23 22 21 43 41 42 53 61 63 62 53 43 42 11 11 22 22 42 43 61 11 32 42 62 61

Figure 5. Mutation done on an Individual

51 could be swapped with another track segment 63. Probability of mutation(P_m) is fixed at 90%. An example is shown in 5.

E. Feasibility Check

We check the feasibility of a solution by continuously checking the highest G it reaches in the given limit. The G force is calculated at various points in the 3D space and we make sure that it does not exceed the maximum limit. Also we have a repair function that makes sure that the track formed after the execution of the genetic algorithm is always a closed track.

F. Replacement Strategy

At the end of each generation, we pick the individual with the worst fitness value through selection and then replace it with the individual that has the best fitness value.

VI. Results

We use a genetic algorithm with the aforementioned parameters to create a roller coaster track that would be the most exciting for a person belonging to a particular age group. We initialise the population with individuals with randomly generated track segments. The (x,y,z) coordinates of the track segments are calculated and the individuals with the best fitness are passed on to the next generation. For example, consider the following coordinates:

x	y	z
0	0	0
0	10	0
0	20	50
0	30	35
-1	33	35
-3	35	35
-5	35	35
-3	35	35
-1	35	36
-0.5	35	37
-1	35	39
-2	35.5	39
-3	36	39
-3	36	37
-3	36	36
-1	36	35
1	36	35
3	36	35
5	36	35
7	35	35
9	33	35
10	31	35

These coordinates translate to a track whose segments are : [11, 43, 53, 22, 33, 53, 63, 52, 51, 33, 22, 23, 51, 41, 23, 63, 31, 23, 42, 52, 22, 21, 23, 32, 21, 63, 32, 63, 51, 42, 43, 22, 63, 23, 32, 42, 42, 31]

This approach is used to evolve the final roller coaster track. The best track found after running the genetic algorithm had the following coordinates and corresponding track segments:

x	y	z
0	0	0
0	10	0
0	20	50
0	30	35
1	32	35
3	34	35
5	35	35
8	34	35
10	32	35
10	30	35
10	28	35
11	26	35
11	24	35
11	22	35
11	20	41
12	17	41
14	15	41
22	23	39
20	25	39
19	24	39
17	22	39
-2	17	49
-4	17	49

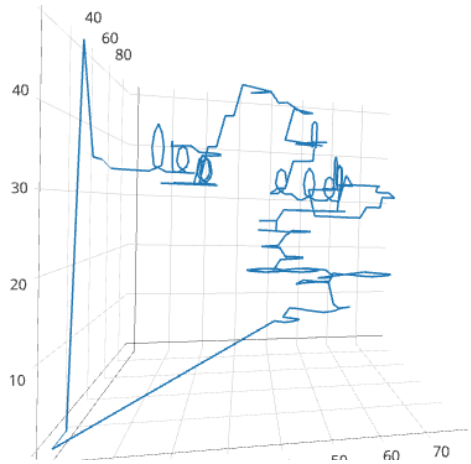

Figure 6. Roller Coaster track design after evolution by GA

-2	18	49
0	20	49
1	22	49
......		
-15	-12	1
-17	-10	1
-18	-8	1
-19	-6	1
-18	-5	1
-16	-3	1
-14	-1	1
-13	1	1
-11	3	1
0	0	0

These coordinates can be represented by track segments. The track segment sequence is given as : [11, 43, 53, 22, 21, 63, 42, 31, 53, 53, 32, 33, 33, 21, 52, 31, 42, 42, 33, 32, 21, 32, 22, 22, 52, 32, 23, 63, 22, 51, 53, 23, 63, 41, 52, 42, 23, 51, 21, 32, 32, 52, 41, 33, 52, 21, 53, 53, 32, 53, 63, 32, 63, 63, 32, 21, 63, 33, 51, 31, 63, 52, 63, 53, 52, 31, 32, 22, 33, 32, 33, 23, 22, 53, 53, 63, 23, 31, 22, 31, 51, 31, 63, 32, 22, 33, 23, 51, 31, 23, 51, 22, 23, 33, 53, 21, 32, 23, 22, 52, 52, 23, 31, 21, 23, 33, 31, 33, 53, 51, 32, 31, 23, 22, 22, 21, 23, 53, 32, 22, 51, 32, 53, 23, 22, 52, 22, 32, 33, 33, 52, 52, 21, 32, 33, 32, 52, 23, 22, 22, 33, 22, 11]

This track is shown can in Figure 6,7.

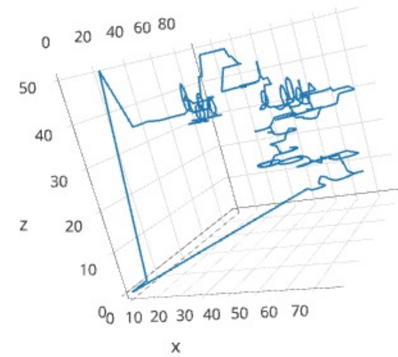

Figure 7. Roller Coaster track design after evolution by GA

VII. Conclusion

We evolved the track of a roller coaster after considering factors such as G force, speed of the roller coaster as well as human factors such as an individual's level of sensation seeking taking into consideration the effect of in different age groups. The final design yields a track such that the thrill experienced on the roller coaster is maximized for a generalized population who seek average levels of sensation/thrill. We introduced a penalty for ensuring the ride is safe as well as exciting and that it would not violate any safety or health norms. We found that mutation is more suitable than crossover for this problem. We also ensured that the track produced was always a closed track by implementing a repair function.

VIII. Future Work

There are a few aspects that can be worked upon in the future.

A. *Track segments*

We basically had 3 types of track segments with variations based on direction, inclination etc. A lot of other track segments can be introduced. There could be more track segments made shapes such as a spiral track segment. More variations could be generated and the track design in general would be more varied and exciting. Another example would be to have variations in the starting segments of the track. We have a fixed sequence of track segments only at the beginning. We could have different starting segments and see how the energy calculations are affected.

B. Higher Resolution

We can increase the resolution of track segments by increasing the number of arbitrary points per track segment. For example, for a curved left turning track segment, the number of points could be increased from 4 to a higher number to have a smoother, more defined curve. This would make the track plotting easier as well as enhance the overall look of the track.

C. Intelligent Models

We can use more intelligent selection and replacement strategies so that the least fit individuals are favored less and better tracks are evolved. We also need to make sure that the diversity is maintained and that the individuals with lower fitness do get a chance to reproduce.

APPENDIX
PSYCHOLOGY BEHIND ROLLER COASTERS

"Roller coasters, despite being safe, still trigger fear, and still provoke a fight or flight response. The flight or fight response, also called the "acute stress response" was "first described by Walter Cannon in the 1920s as a theory that animals react to threats with a general discharge of the sympathetic nervous system." When we are scared and want to escape from something, we produce more adrenaline, which rates heart rate, increases breathing, tightens muscles and gives that 'butterfly tummy' feeling. Additionally, though many of the thrills are illusory, you are sometimes experiencing forces you don't in your everyday life. "Right now you are experiencing a 1-G force-the normal gravitational pull that holds you to that couch. But if you go fast enough, in a car or a roller coaster, you're pushed with a force equal to the weight you normally feel due to Earth's gravity. . . . Once your body begins moving it will continues in a straight line until something forces it to change–such as a roller coaster curve or loop. Your body resists the change, so you feel thrown outward. That's centrifugal force, G-force or, as astronauts say, "pulling Gs." The Revolution roller coaster at Six Flags, Magic Mountain in Valencia, California, gives you a whopping 4.9 Gs–1.5 more than a shuttle launch–double that and jet pilots begin to black out. Although the G force becomes very large, it is usually only momentary and therefore poses next to no risk to the riders.Due to the limitations of rider's bodies, roller coaster designers are starting to use illusions rather than trying to increase speed or G force in order to create more thrilling rides. Also, other rides such as haunted houses are normally very slow but still manage to scare people. Another illusion is sense of speed. Roller coasters create thrills primarily through a sense of illusion and the psychology of fear."[Daniel Hearne]

ACKNOWLEDGMENT

The authors would like to thank Dr. Khaled Rasheed (Director, Institute for Artificial Intelligence), for his support and encouragement. We would also like to thank Dr. Adam Goodie(Professor, Department of Psychology) for helping us figure out the psychology related aspect for optimizing the thrill factor.

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