CS572 Project #1b Report

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1 Algorithm Descriptions

1.1 Data Structure

- In this project, I have implemented Object-Oriented(OO) design as suggested by Dr. Soule.
- There are two classes.
  - The base class is called Individual, indcludes member data indicating Individual point with a 30-dimension(length) dynamically allocated float values array, and a float fitness value.
  - The publicly derived class is called Population, indcludes member data indicating a int variable size storing the Population size, and a pointer to Individual dynamic array of Population size, pointer to dynamic int array for storing sample index, and pointer to float array storing the weight matrix for Roulette wheel selection method, together with constructor, copy constructor, destructor functions and some member functions.
- The base class pointer is not necessary. As the first time of implementing some OO design, I tried to manage pointer, but it ended up to be an fair experience. The advantages and disadvantages will be discussed in the discussion section.

1.2 Algorithm Step-Wise Descriptions

1.2.1 Generate Base Individual Class

To make the implementation step-wise, I Generated the base class and make sure it works first.

- Data members include float variable fitness, and a pointer to float array of dynamic size;

```
    float* point;        // pointer to dynamic array of dimension p
    float fitness;       // store fitness value for the point
```

- Since I have pointer included in my interface, I need to develop my own constructor, destructor, copy constructor, and assignment operator, as well as declaring the destructor and assignment operator virtual for later on potential dynamic binding at run time.

```
Individual::Individual(): fitness(INF) {
    point = new float[p];
}

Individual::Individual(const Individual &orig): fitness(orig.fitnes
{ }

Individual& Individual::operator=(const Individual &rhs) {
    // I didn't really use this function, it's complicated
    Individual* pOrig = this;
    point = new (Individual(*rhs)).point;
    delete [ ] pOrig;

    Individual temp(rhs);

    // need define my own specialized std::swap template,
    // template<class T> std::swap(T& a, T& b) {  }

    // instant the template with Individual object before use
    // template< > std::swap<Individual>(
    //                 Individual a, Individual b)
    // {a.swap(b); ...}
    std::swap(temp);

    return *this;
}

Individual::~Individual() {
    delete [ ] point;
}
```

- Initialized Individual point by Generate random float value for each dimension within valid range; And since point got Initialized already, calculate the fitness and store it.

```
    void Individual::generate() {
```

```
  for (int i = 0; i < p; ++i) {
    if ( (rand()%100/100.0) >= 0.50 )
    point[i] = rand() % 7 - (rand() % 100000)/100000.0;
    else
    point[i] = -rand() % 7 + (rand() % 100000)/100000.0;
    while (point[i] < sphl || point[i] > sphh) {
      if ( (rand()%100/100.0) >= 0.50 )
      point[i] = rand() % 7 - (rand() % 100000)/100000.0;
      else
      point[i] = -rand() % 7 + (rand() % 100000)/100000.0;
    }
  }
  fitness = getFitness();
}
```

- Write helper function print() to help visualization the Results.

```
void Individual::print() {
  for (int i = 0; i < p; ++i) {
    printf("%5.5f␣", point[i]);
    if (i % 5 == 4)
    printf("␣");
    if (i % 10 == 9)
    printf("\n");
  }
  printf("\n");
}
```

- Mutate Individual as will have overloaded function for subclass.

```
void Individual::mutate() {
  float delta, temp;

  for (int i = 0; i < p; ++i) {
    delta = ( rand() % 100000 ) / 100000.00000;
    if ( (rand()%100/100.0) < 0.5)   // pos
    temp = point[i] + delta;
    else                             // neg
    temp = point[i] - delta;
    while (temp < sphl || temp > sphh) {
      delta = ( rand() % 100000 ) / 100000.00000;
      if ( (rand()%100/100.0) < 0.5) // pos
      temp = point[i] + delta;
```

```
          else                              // neg
            temp = point[i] - delta;
          } // while
          point[i] = temp;
        }

        fitness = getFitness();
      }
```

base class Individual interface is listed as below:

```
#ifndef INDIVIDUAL_H
#define INDIVIDUAL_H

#include <iostream>
#include "individual.h"
#include "pf.h"

using namespace std;

const float INF = 5.12*5.12*30;
const float sphl = -5.12;
const float sphh = 5.12;
const int p = 30;

class Individual {
 public:
    // copy management
    Individual();                             // default constructor
    Individual(const Individual& rhs);    // copy constructor
    Individual& operator=(const Individual &);//assign operator
    virtual ~Individual();

    // functions
    void generate();    // generate an individual
    void print();       // print out the individual
    float getFitness();// caculate the fitness when initialization
    void mutate();      // mutate individual

    float* point;       // pointer to dynamic array of dimension size p
    float fitness;      // store fitness value for the point
};
```

```cpp

#endif
```

1.2.2 Generate Derived Population Class

- Data members include int variable for Population size, pointer to Individual dynamic array, as well as a pointer to dynamical int array for Tournament selection method store the sample indexes.

```cpp
      int size;
      Individual* popu;
      int* idxArray;
```

- Data member includes pointer, so self-develop constructor, destructor, copy constructor and assignment operator, I guess I may need overload "->" and "[ ]" operators as well. But since pointers got crazy already, I tried to avoid complexity.

```cpp
      Population::Population(int n): size(n) {
        popu = new Individual[size];
      }

      Population::Population(const Population &orig):
      Individual(orig), size(orig.size) { }

      Population& Population::operator=(const Population &rhs) {
        if (this != &rhs) {
          Individual::operator=(rhs);    // assigns the base part
          size = rhs.size;
        }
        return *this;
      }

      Population::~Population() {
        // FOR loop delete individuals separately to make safe
        for (int i = 0; i < size; ++i)
        popu[i].Individual::~Individual();
        delete [] idxArray;
      }
```

- Generate the population by generate Individuals Population size times

```cpp
      void Population::generate() { // generate population
        for (int i = 0; i < size; ++i) {
            popu[i].Individual::generate();
        }
    }
```

- Wrote both selection methods for Tournament and Roulette Wheel to get better understanding.

  – Tournament Selection

```
    void Population::genRanIndi(int n) {
      idxArray = new int[n];
      for (int i = 0; i < n; ++i)
      idxArray[i] = rand() % size;
    }

    int Population::tourSelection(int len) {
      int winIdx = rand() % len;
      float winFitness = popu[idxArray[winIdx]].fitness;
      int temp;
      float tempFitness;
      for (int i = 0; i < len; ++i) {
        temp = idxArray[i];
        tempFitness = popu[temp].fitness;
        if (tempFitness < winFitness) {
          winFitness = tempFitness;
          winIdx = temp;
        }
      }
      return winIdx;
    }
```

  – Roulette Wheel Selection

```
    int Population::roulSelection() {
      float* weight = new float[size];

      float minFitness = Population::minFitness();
      float tempFitness;
      float sumFitness;
      bool negFlag = false;
      float sum = 0.0;

      if ( minFitness < 0.000001)
      negFlag = true;
```

```

        if (negFlag) {
          sumFitness = (avgFitness() - minFitness)*size;
          for (int i = 0; i < size; ++i) {
            tempFitness = popu[i].fitness - minFitness;
            sum += -minFitness + tempFitness;
            weight[i] = (float) (sum / sumFitness );
          }
        } else {
          sumFitness = avgFitness()*size;
          for (int i = 0; i < size; ++i) {
            tempFitness = popu[i].fitness;
            sum += tempFitness;
            weight[i] = (float) (sum / sumFitness );
          }
        }

        float prob = ( rand() % 1000 ) / 1000.0;
        for (int i = 0; i < size; ++i) {
          if (weight[i] < prob && weight[i+1] >= prob) {
            delete [] weight;
            return i+1;
          }
        }

        delete [] weight;
        return -1;
      }
```

- helper functions include generate random Individuals, get Min and Max fitness functions, printer functions as well as mutateAll to mutate the whole population.

```
    void Population::mutateAll() {
      for (int i = 0; i < size; ++i) {
        popu[i].Individual::mutate();
      }
    }

    float Population::minFitness() {
      float minFitness = popu[0].fitness;
      float tempFitness;
    for (int i = 1; i < size; ++i) {
      tempFitness = popu[i].fitness;
      if (tempFitness < minFitness)
      minFitness = tempFitness;
    }
    return minFitness;
  }

  int Population::maxFitness() {
    float maxFitness = popu[0].fitness;
    float tempFitness;
    int worIdx = 0;
    for (int i = 1; i < size; ++i) {
      tempFitness = popu[i].fitness;
      if (tempFitness - maxFitness > 0.00001) {
        maxFitness = tempFitness;
        worIdx = i;
      }
    }
    return worIdx;
  }

  float Population::avgFitness() {
    float avgFitness = 0.0;
    for (int i = 0; i < size; ++i) {
      avgFitness += popu[i].fitness;
    }
    avgFitness = (float) (avgFitness / size);
    return avgFitness;
  }

  void Population::printRanIndi(int len) {
    for (int i = 0; i < len; ++i)
    printf("%d ", idxArray[i]);
    printf("\n");
  }
```

Derived class Population interface is listed as followed:

```
#ifndef POPULATION_H
#define POPULATION_H

```

```cpp
#include <iostream>
#include "individual.h"

using namespace std;

class Population : public Individual {
 public:
    Population(int n);
    Population(const Population&);
    //virtual Population& operator=(const Population&);
    Population& operator=(const Population&);
    //~Population();
    virtual ~Population();

    // functions
    int getSize();  // get population size
    void print();   // print population
    void generate();// generate population
    void mutateAll();

    void genRanIndi(int n);
    void printRanIndi(int len);
    int tourSelection(int len);

    float minFitness();
    int maxFitness();
    float avgFitness();
    int roulSelection();

    void newGen(int winIdx);
    bool reachBest();

    int* idxArray;
 private:
    int size;
    Individual* popu;
};

#endif
```

1.2.3 Ensemble Genetic Algorithm

In this Project, since I am trying to implement an OO design together with handling pointer, to try to avoid complexity, I have choose to use the easier to implemented Steady-state Algorithm at the cost and risk of slowing down and may not get the expected Results within limited time frame.

- Instance a Population object of Population size 100;

```
    int popuSize = 100;

    Population* popu = new Population(popuSize);
    popu->generate();
```

- Using Tournament selection method selected sample size of 5 Individuals during each generation;

```
    int sampleSize = 5;
    int* idxArray = new int[sampleSize];
    int winIdx;

    popu->genRanIndi(sampleSize);
    idxArray = popu->idxArray;
    // popu->printRanIndi(sampleSize);

    winIdx = popu->tourSelection(sampleSize);
```

- Compare sample fitnesses and keep the elite Individual untouched into new generation. Trying to speed up the evolution, I replaced the worst Individual in each parent generation with the mutated version of previously found sample elite Individual.

```
    void Population::newGen(int winIdx) {
      // keep sample elite
      // replace worst population individual with mutated elite

      int worIdx = maxFitness();
      for (int i =0; i < p; ++i) {
    popu[worIdx].point[i] = popu[winIdx].point[i];
    popu[worIdx].fitness = popu[winIdx].fitness;
      }
      popu[winIdx].Individual::mutate();
    }

    popu->newGen(winIdx);
```

- I loop through these steps trying to approach the final steady state. Loop will eventually end when best Individual get the fitness less than 0.0001.

```
    bool Population::reachBest() {
      float minF = minFitness();
      if (minF < 0.0001) {
    for (int i = 0; i < size; ++i) {
          if (popu[i].fitness == minF)
          printf("Best individual: \n");
          popu[i].Individual::print();
    }
    return true;
      }
      return false;
    }

    int counter = 0;
    while(!popu->reachBest()) {
      popu->genRanIndi(sampleSize);
      idxArray = popu->idxArray;
      popu->printRanIndi(sampleSize);

      winIdx = popu->tourSelection(sampleSize);

      popu->newGen(winIdx);
      ++counter;
    }
```

The pseudo-algorithm is listed followed:

```

Generate a population of size 100

Loop until best Individual reaches threshold fitness value
    record the best Individual index, point, fitness
    loop do

        // pick elite Individual from random sample
        randomly select a sample of 5, save Population indexes as value
        winner Fitness = Sample[0].fitness
        winner index = sample[0]
        Loop ( sample size - 1 ) times
```

```
            temp Fitness =  Sample[i].fitness;
            if temp Fitness better than winner Fitness
                winner Fitness = temp Fitness
                winner index = temp index
        return win index

        // Get worst Individual index from Population:
        worst Fitness = Population[0].fitness
        worst index = 0
        Loop population size -1 times
            temp Fitness = Population[i].fitness;
            if temp Fitness worst than worst Fitness
                worst fitness = temp Fitness
                worst index = temp index
        return worst index

        // generate new child Population
        maintain current Population unchanged yet
        replace worst Population Individual with elite Individual
        mutate elite sample Individual in place, update its fitness

    End loop
```

1.3 Detail Attention:

- Check the range of the mutated dimensions. Each mutated dimension must be within the range of function definition.
- In class constructors, since I have to deal with pointers, constructor does only allocate memory space job. And corresponding, in the destructor, I will have to manually release system resource to delete [] the pointer to float array for Individual::point, Population::weight, Population::popu, Population::idxArray for Tournament selection sample indexes.
- I had thought by mutating all the other parent Individuals (elite kept untouched, worst got replaced by mutated elite, all the others mutated slightly as well (just like we have mutated the elite Individual) trying to speed up the evolution, but it turned out that most possible the mutation to other Individuals will pull the evolutionary trend to the opposite direction.
- When replace worst Individual with mutated version of elite Individual, since they are pointed by pointer, I will have to conduct deep copy to ensure parent Population and child Population is on the same memory

address, which also produces the trouble of frequent memory swap (and potentially increases cache miss rates?).

- By OO design, I have included the fitness float variable to record the fitness. So in my Steady-state Algorithm implement, when I deep copy my elite Individual to the worst Individual memory place, I need to deep copy the pointer to 30-dimension point, and I would also need to copy the elite's fitness as well. similarly, when I mutate my elite a little bit within each generation, I would also need to recalculate and update the fitness value accordingly for the mutation happened.

2 Results

Compared with the Generational Algorithm, Steady-state Algorithm is very slow because during each generation change, only the worst Population Individual got mutated.

My randomly generated Population best fitness is initialized and calculated to be around 200, after some generations, the best fitness dropped down pretty fast. But the program has run hours and hours in order to reduce the best fitness down from above 3 to below it.

I have copied and pasted the terminal last page as an indication that the Algorithm works.

- 69 61 62 2 72
- winFitness: : 2.67058
- worIdx 1st: 43
-
- 56 86 54 18 54
- worIdx 1st: 61
-
- 13 14 40 57 81
- winFitness: : 3.41477
- winFitness: : 3.20928
- worIdx 1st: 4
-
- 67 15 29 65 8
- winFitness: : 3.10817
- winFitness: : 3.03638
- worIdx 1st: 40
-
- 94 6 53 14 97
- winFitness: : 3.32845
- winFitness: : 2.96758
- worIdx 1st: 29
-
- 28 14 87 30 72
- winFitness: : 3.41477
- winFitness: : 2.93997
- worIdx 1st: 53
-
- 26 92 62 94 45
- winFitness: : 2.66032
- worIdx 1st: 87
-
- 16 19 22 88 5
- worIdx 1st: 26
-

- 48 48 19 36 49
- winFitness: : 3.40592
- winFitness: : 3.26048
- winFitness: : 3.23172
- worIdx 1st: 0
-
- 52 63 17 30 15
- winFitness: : 3.35991
- winFitness: : 3.17226
- worIdx 1st: 49
-
- 93 68 88 57 74
- winFitness: : 3.19646
- worIdx 1st: 30
-
- 10 5 62 63 84
- winFitness: : 3.20610
- winFitness: : 3.03444
- worIdx 1st: 93
-
- 37 88 30 11 27
- winFitness: : 3.17233
- worIdx 1st: 62
-
- 64 87 68 39 15
- winFitness: : 2.66032
- worIdx 1st: 37
-
- 82 95 27 37 80
- winFitness: : 3.28034
- winFitness: : 2.66032
- worIdx 1st: 87
-
- 84 78 62 90 2
- worIdx 1st: 37
-
- 39 73 87 4 66
- winFitness: : 2.66032
- worIdx 1st: 4
-
- 54 61 95 26 54
- worIdx 1st: 87
-
- 44 48 2 96 96

Since the program had run hours to reach the minimum fitness of 3.0 for the best individual, I don't want to repeat the work in order to trace it.

Ideally, if I just generate the initial 1000 generations, and trace the best Sample Individual fitness, together with specific generation's average fitness, by plotting them, I would get a good idea about the Algorithm to see if it works.

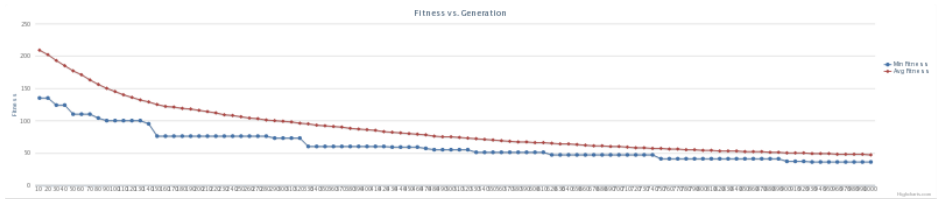
```
  while (counter < 1000) {
    popu->genRanIndi(sampleSize);
    idxArray = popu->idxArray;
    //popu->printRanIndi(sampleSize);

    winIdx = popu->tourSelection(sampleSize);

    popu->newGen(winIdx);
    ++counter;

    if (counter % 10 == 0)
```

```
        printf("%d\t%4.5f\t%4.5f\n",counter,popu->minFitness(),popu->avgFit
    }
```



Form the scatter plot of first 1000 generations, get sample from every 10 generation, we can see the trend that the Algorithm is working perfectly. minimum fitness curve and Population average fitness curve are extending towards the same trend, and they are not separated too far away as well. And we can also see the fact that the Algorithm evolves slowly.

3 Conclusions

- Genetic Algorithm is good evolutionary Algorithm to solve some problem that is difficult for regularly-based methods.
- Specifically, Steady-state Algorithm is slow compared with generational Algorithm.

4 Discussion

As the first trial of implementation of an OO design, just like the Decision tree project I have done for Artificial Intelligence course last spring semester, I consider this one is barely an experience. I tried to use pointer and dynamic allocation, but later on, when things got complicated, I had to give up and figure out work around solutions in order to finish the project. The currently working version is simply mutate one Individual each generation, but when we require more mutations, and more generations, or more generally speaking, when I will have multiple inheritance, this design will still produce problems. And even for this current design, I still don't think it is a good design at all.

Possible solutions to enhance the design and implementation from easy to difficult ones are listed in order in my point of view.

- Since the dynamic allocation is not necessary any way, simply allocate fixed size of arrays. Difficulties and issues will all go away.
- I can still keep my base class dynamic allocation, but for subclass, instead of using dynamic allocation again, choose standard containers like vector to

store Individuals as the Population. vector will handle the memory related issues by its own destructor or member functions.