Міністерство освіти і науки України

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Звіт

з лабораторної роботи № 4 з дисципліни

«Проектування алгоритмів»

„Проектування і аналіз алгоритмів для вирішення NP-складних задач ч.1”

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Перевірив

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Мета лабораторної роботи

Мета роботи – вивчити основні підходи формалізації метаеврестичних алгоритмів і вирішення типових задач з їхньою допомогою.

Завдання

Згідно варіанту, розробити алгоритм вирішення задачі і виконати його програмну реалізацію на будь-якій мові програмування.

Задача, алгоритм і його параметри наведені в таблиці 2.1.

Зафіксувати якість отриманого розв'язку (значення цільової функції) після кожних 20 ітерацій до 1000 і побудувати графік залежності якості розв'язку від числа ітерацій.

Зробити узагальнений висновок.

Варіант завдання

19	Задача про рюкзак (місткість P=250, 100 предметів, цінність предметів від 2 до 30 (випадкова), вага від 1 до 25 (випадкова)), генетичний алгоритм (початкова популяція 100 осіб кожна по 1 різному предмету, оператор схрещування триточковий 25%, мутація з ймовірністю 5% два випадкові гени міняються місцями). Розробити власний оператор локального покращення.

Виконання

Код програми

```
package org.example.lab4.populations;


import lombok.EqualsAndHashCode;
import lombok.NonNull;
import lombok.ToString;
import org.example.lab4.backpack.BackpackPacking;
import org.example.lab4.populations.individuals.AbstractIndividual;
import org.example.lab4.populations.individuals.Individual;


import java.util.Arrays;
import java.util.TreeMap;
import java.util.stream.IntStream;
```

```
@ToString
@EqualsAndHashCode
public abstract class AbstractPopulation implements Population, ObservablePopulation {
    private Individual[] individuals;
    private final double maxWeight;
    private final double[] values;
    private final double[] weights;

    protected AbstractPopulation(@NonNull Individual[] individuals, double maxWeight, double[] values, double[] weights) {
        if (individuals.length == 0) {
            throw new IllegalArgumentException("Individuals array must not be empty");
        }
        this.individuals = individuals;
        this.maxWeight = maxWeight;
        this.values = values;
        this.weights = weights;
    }

    @Override
    public Individual getFittest() {
        return Arrays.stream(individuals).max((a, b) -> {
            var aFitness = a.getFitnessFor(values, weights, maxWeight);
            var bFitness = b.getFitnessFor(values, weights, maxWeight);
            return Double.compare(aFitness, bFitness);
        }).orElseThrow();
    }

    @Override
    public void evolve() {
        var fittest = getFittest();
        var newIndividuals = new Individual[individuals.length];
        newIndividuals[0] = fittest;
        for (int i = 1; i < individuals.length; i++) {
            var randomIndex = (int) (Math.random() * individuals.length);
            var randomIndividual = individuals[randomIndex];
            var newIndividual = fittest.crossover(randomIndividual);
            if (newIndividual.isDead(weights, maxWeight)) {
                newIndividual = fittest.clone();
            }
            newIndividual.mutate();
            if (newIndividual.isDead(weights, maxWeight)) {
                newIndividual = fittest.clone();
            }
            newIndividual.improve(values, weights, maxWeight);
            newIndividuals[i] = newIndividual;
        }
        individuals = newIndividuals;
    }

    @Override
    public void evolve(int generations) {
        for (int i = 0; i < generations; i++) {
            evolve();
        }
    }

    @Override
    public EvolutionRecap evolveObservable(int generations, int interval) {
        var recap = new EvolutionRecap(new TreeMap<>());
        for (int i = 0; i < generations; i++) {
            if ((i+1) % interval == 0) {
                var fittest = getFittest();
                recap.evolutionPath().put(i+1,
                        new BackpackPacking(IntStream.range(0, fittest.getGenes().length)
                                .filter(fittest::isGeneActive)
                                .mapToObj(j -> new BackpackPacking.BackpackItem(j, weights[j], values[j]))
                                .toList()));
            }
            evolve();
        }
        return recap;
    }
}

package org.example.lab4.populations;
```

```
import lombok.NonNull;
import org.example.lab4.populations.individuals.AbstractIndividual;
import org.example.lab4.populations.individuals.DiscreteIndividual;
import org.example.lab4.populations.individuals.Individual;

public class DiscreteGenesPopulation extends AbstractPopulation {
    public DiscreteGenesPopulation(@NonNull Individual[] individuals, double maxWeight, double[] values, double[] weights) {
        super(individuals, maxWeight, values, weights);
    }

    public static DiscreteGenesPopulation random(int size, int genesCount, double maxWeight, double[] values, double[] weights) {
        if (size <= 0) {
            throw new IllegalArgumentException("Size must be > 0");
        }
        var individuals = new Individual[size];
        for (int i = 0; i < size; i++) {
            var genes = new double[genesCount];
            var randomIndex = (int) (Math.random() * genesCount);
            genes[randomIndex] = 1;
            individuals[i] = new DiscreteIndividual(genes);
        }
        return new DiscreteGenesPopulation(individuals, maxWeight, values, weights);
    }
}
```

```
package org.example.lab4.populations.individuals;

import lombok.EqualsAndHashCode;

import java.util.Arrays;
import java.util.stream.IntStream;
@EqualsAndHashCode
public abstract class AbstractIndividual implements Individual {

    public abstract Individual clone();
```

```
private static final float ACTIVE_VALUE = 0.02f;

@Override
public boolean isGeneActive(int index) {
    return Math.abs(getGenes()[index] - 1) < ACTIVE_VALUE;
}

@Override
public double getFitnessFor(double[] values, double[] weights, double maxWeight) {
    var totalWeight = IntStream.range(0, getGenes().length).mapToDouble(i -> {
        if (Math.abs(getGenes()[i] - 1) < 0.000001) {
            return weights[i];
        }
        return 0;
    }).sum();
    var totalValue = IntStream.range(0, getGenes().length).mapToDouble(i -> {
        if (Math.abs(getGenes()[i] - 1) < 0.000001) {
            return values[i];
        }
        return 0;
    }).sum();

    if (totalWeight > maxWeight) {
        return -1;
    }
    return totalValue;
}

@Override
public void mutate() {
    if ((int)(Math.random() * 20) == 0) {
        var randomIndex = (int) (Math.random() * getGenes().length);
        var randomIndex2 = (int) (Math.random() * getGenes().length);
        while (randomIndex2 == randomIndex) {
            randomIndex2 = (int) (Math.random() * getGenes().length);
        }
        var temp = getGenes()[randomIndex];
```

```
            setGene(randomIndex, getGenes()[randomIndex2]);
            setGene(randomIndex2, temp);
        }
    }

    private void copyPartOfGenes(Individual other, int left, int right) {
        for (int i = left; i < right; i++) {
            setGene(i, other.getGenes()[i]);
        }
    }

    @Override
    public Individual crossover(Individual other) {
        var newIndividual = (AbstractIndividual) this.clone();
        var pivots = IntStream.range(0, 3).map(i -> (int) (Math.random() * getGenes().length)).sorted().toArray();
        newIndividual.copyPartOfGenes(other, 0, pivots[0]);
        newIndividual.copyPartOfGenes(other, pivots[1], pivots[2]);
        return newIndividual;
    }

    @Override
    public boolean isDead(double[] weights, double maxWeight) {
        var sum = 0d;
        for (int i = 0; i < getGenes().length; i++) {
            if (Math.abs(getGenes()[i] - 1) < ACTIVE_VALUE) {
                sum += weights[i];
            }
        }
        return sum > maxWeight;
    }

    @Override
    public void improve(double[] values, double[] weights, double maxWeight) {
        var totalWeight = IntStream.range(0, getGenes().length).mapToDouble(i -> {
            if (Math.abs(getGenes()[i] - 1) < 0.000001) {
                return weights[i];
            }
            return 0;
        }).sum();

        var min = Double.MAX_VALUE;
        var minIndex = -1;
        for (int i = 0; i < getGenes().length; i++) {
            if (Math.abs(getGenes()[i] - 1) < 0.000001) {
                continue;
            }
            var newWeight = totalWeight + weights[i];
            if (newWeight > maxWeight) {
                continue;
            }
            var newMin = maxWeight - newWeight;
            if (newMin < min) {
                min = newMin;
                minIndex = i;
            }
        }
        if (minIndex != -1) {
            setGene(minIndex, 1);
        }
    }
}

package org.example.lab4.populations.individuals;

import lombok.EqualsAndHashCode;
import lombok.ToString;

@ToString
@EqualsAndHashCode(callSuper = false)
public class DiscreteIndividual extends AbstractIndividual {
    private final boolean[] genes;
    public double[] getGenes() {
        var genes = new double[this.genes.length];
        for (int i = 0; i < genes.length; i++) {
            genes[i] = this.genes[i] ? 1d : 0d;
        }
        return genes;
    }

    @Override
    public void setGene(int index, double value) {
        this.genes[index] = Math.abs(Math.round(value) - 1d) < 0.000001;
    }

    @Override
    public Individual clone() {
        return new DiscreteIndividual(this.genes);
    }

    protected DiscreteIndividual(int size) {
        this.genes = new boolean[size];
    }

    protected DiscreteIndividual(boolean[] genes) {
        this(genes.length);
        System.arraycopy(genes, 0, this.genes, 0, genes.length);
    }

    public DiscreteIndividual(double[] genes) {
        this(toBooleanGenes(genes));
    }

    private static boolean[] toBooleanGenes(double[] genes) {
        var booleanGenes = new boolean[genes.length];
        for (int i = 0; i < genes.length; i++) {
            booleanGenes[i] = Math.abs(Math.round(genes[i]) - 1d) < 0.000001;
        }
        return booleanGenes;
    }
}

package org.example.lab4.backpack;
```

```
import lombok.EqualsAndHashCode;
import lombok.Getter;
import lombok.RequiredArgsConstructor;
import lombok.ToString;
import org.example.lab4.populations.DiscreteGenesPopulation;
import org.example.lab4.populations.EvolutionRecap;

import java.util.ArrayList;
import java.util.List;

public record Backpack(double[] values, double[] weights, double capacity) {

    public BackpackPacking getBestPacking() {
        var population = DiscreteGenesPopulation.random(100, values.length, capacity, values, weights);
        population.evolve(1000);
        var fittest = population.getFittest();
        var result = new ArrayList<Integer>();
        for (int i = 0; i < fittest.getGenes().length; i++) {
            if (fittest.getGenes()[i] > 0.9) {
                result.add(i);
            }
        }
        return new BackpackPacking(result.stream().map(i ->
                new BackpackPacking.BackpackItem(i, weights[i], values[i])).toList());
    }

    public EvolutionRecap getBestPackingEvolution() {
        var population = DiscreteGenesPopulation.random(100, values.length, capacity, values, weights);
        return population.evolveObservable(1000, 20);
    }

    public static Backpack random(int itemsCount, double capacity, double minValue, double maxValue,
double minWeight, double maxWeight) {
        var values = new double[itemsCount];
        var weights = new double[itemsCount];
        for (int i = 0; i < itemsCount; i++) {
            values[i] = Math.random() * maxValue + minValue;
            weights[i] = Math.random() * maxWeight + minWeight;
        }
        return new Backpack(values, weights, capacity);
    }
}
```

Приклади роботи

1. Backpack:

```
Item 0: value=4.914693246743952, weight=9.254244964361757
Item 1: value=8.232670008403565, weight=15.529011891852262
Item 2: value=31.62854232344185, weight=2.1821368748921204
Item 3: value=19.71358228101507, weight=15.308425146559516
Item 4: value=13.323540508989504, weight=8.093775170029412
Item 5: value=16.55130568560048, weight=14.51848512758395
Item 6: value=4.6253421514088595, weight=7.935687303998386
Item 7: value=22.76013059952173, weight=20.621496000725294
Item 8: value=27.868208831866397, weight=16.655614679421944
Item 9: value=11.378531311400835, weight=7.43107709294034
Item 10: value=5.350685821440492, weight=1.538654059583668
Item 11: value=19.075813474210108, weight=4.569915035205046
Item 12: value=10.848511193253335, weight=17.6433752113429
Item 13: value=16.483740049613964, weight=17.806557721789158
Item 14: value=2.3119361325728756, weight=15.294733116664373
Item 15: value=26.15590245644076, weight=14.341842681071784
Item 16: value=23.485197633128205, weight=20.513446412914696
Item 17: value=31.33689849121181, weight=6.5540212116978624
Item 18: value=6.433915967413309, weight=23.46560322576967
Item 19: value=3.440194524189764, weight=17.931363763293575
Item 20: value=29.651745398568035, weight=7.501632280246442
Item 21: value=14.287821223344245, weight=15.922022336464874
Item 22: value=17.540646434316816, weight=12.120346492649382
Item 23: value=30.75686947497051, weight=23.21313818397222
Item 24: value=26.6197063781322, weight=22.241645878271576
Item 25: value=24.507040257515396, weight=21.51466288981878
Item 26: value=21.815468199857794, weight=13.500553738512963
Item 27: value=17.93029385318062, weight=15.268095692050828
Item 28: value=12.622285448340437, weight=8.8856128311899
Item 29: value=19.367961407759253, weight=1.8263025037286487
Item 30: value=3.794254782422212, weight=15.93627354070324
Item 31: value=5.9824494769941925, weight=24.55782276620307
Item 32: value=28.540849394736394, weight=15.88675314706114
Item 33: value=11.449990433679925, weight=16.01753576787535
Item 34: value=3.946386009334619, weight=16.59795649626044
Item 35: value=27.85767681161899, weight=19.795294946155433
Item 36: value=8.519044724114103, weight=9.854382348494324
Item 37: value=6.842314110154783, weight=11.905100021707723
Item 38: value=20.398180350061605, weight=15.61955975500915
Item 39: value=4.10042533563602, weight=25.60962368704539
Item 40: value=21.80921576025359, weight=1.1413997965995062
Item 41: value=23.928038484581236, weight=17.388367107768858
Item 42: value=10.853471985781955, weight=6.377954982720564
Item 43: value=6.415688853783152, weight=21.352457847286292
Item 44: value=25.65580871581783, weight=14.074416542281531
Item 45: value=19.328350484484904, weight=24.78507544834227
Item 46: value=18.26601948144209, weight=22.963811320240726
Item 47: value=29.54182483194022, weight=8.64371093345159
Item 48: value=26.52045693255334, weight=15.986674014500542
Item 49: value=5.186406700991763, weight=8.798961135774066
Item 50: value=31.318427226721102, weight=12.129098920575736
Item 51: value=9.365432801950735, weight=16.504257379145848
Item 52: value=24.45341711271001, weight=25.46392059447559
Item 53: value=19.47063361589297, weight=25.09193676167586
Item 54: value=8.262282381760794, weight=3.246367307224817
Item 55: value=22.70799113555519, weight=19.173262462117226
Item 56: value=22.916068050593875, weight=1.46339012113997
Item 57: value=8.47711515812768, weight=17.68348915508701
Item 58: value=20.174175753592152, weight=6.064969281461701
Item 59: value=11.71393014079741, weight=22.957804224004562
Item 60: value=3.859136546267861, weight=21.216050680676265
Item 61: value=18.210777561915563, weight=19.64993190254933
Item 62: value=27.18231045670071, weight=22.2993695344295
Item 63: value=3.269834745208689, weight=9.712431321612582
Item 64: value=15.361354187204682, weight=11.07226679411714
Item 65: value=18.82503243669742, weight=12.846187731727802
Item 66: value=8.71837728898096, weight=13.334704780194732
Item 67: value=31.38446611851951, weight=5.796325791185743
Item 68: value=16.633222867434363, weight=25.70104577727854
Item 69: value=13.799591373876812, weight=18.622747248607684
Item 70: value=6.349383465681039, weight=22.58474928052235
Item 71: value=27.959279182432027, weight=1.6057241540644187
Item 72: value=2.690583118741767, weight=2.30301008315975
Item 73: value=13.03611724735207, weight=22.76045955212747
Item 74: value=5.244129959359343, weight=7.28743860767878
Item 75: value=14.879133630347585, weight=3.0292429346587038
Item 76: value=8.502666923252686, weight=22.747263607109254
Item 77: value=26.55141502751298, weight=19.09581593117489
Item 78: value=7.82901403017051, weight=15.77311389792807
Item 79: value=7.852888145075302, weight=2.4237834395426976
Item 80: value=19.919326623272198, weight=22.792302519323037
Item 81: value=2.9478440294977752, weight=12.559382354069767
Item 82: value=30.68785599429856, weight=2.4906370205893915
Item 83: value=9.933550626982598, weight=12.958653486701376
Item 84: value=6.182128526753866, weight=18.801123517548554
Item 85: value=4.340637204543632, weight=3.600029103209489
Item 86: value=3.260428826511318, weight=4.326538729056475
Item 87: value=30.147688202210976, weight=16.425575532062
Item 88: value=26.323990977840324, weight=3.6106988772770428
Item 89: value=16.92181900647524, weight=7.217625744723435
Item 90: value=4.394380033405021, weight=8.00234891479569
Item 91: value=10.163774964318595, weight=5.862228754361442
Item 92: value=9.262063313963468, weight=19.465954614755546
Item 93: value=3.8404063245775584, weight=16.076851834721644
Item 94: value=20.305239368980182, weight=19.585271589516825
Item 95: value=29.429168478480122, weight=10.58698616357823
Item 96: value=14.888530619845332, weight=22.178429149475473
Item 97: value=4.57858200324055, weight=23.42477311179725
Item 98: value=4.999189982694462, weight=3.397358000617164
Item 99: value=26.705402165819546, weight=22.492506401174126
Capacity: 250.0

Best fit: BackpackPacking[
items=[BackpackItem[index=2, weight=2.1821368748921204, value=31.62854232344185],
BackpackItem[index=4, weight=8.093775170029412, value=13.323540508989504],
BackpackItem[index=8, weight=16.655614679421944, value=27.868208831866397],
BackpackItem[index=9, weight=7.43107709294034, value=11.378531311400835],
BackpackItem[index=10, weight=1.538654059583668, value=5.350685821440492],
BackpackItem[index=11, weight=4.569915035205046, value=19.075813474210108],
BackpackItem[index=15, weight=14.341842681071784, value=26.15590245644076],
BackpackItem[index=17, weight=6.5540212116978624, value=31.33689849121181],
BackpackItem[index=20, weight=7.501632280246442, value=29.651745398568035],
BackpackItem[index=26, weight=13.500553738512963, value=21.815468199857794],
BackpackItem[index=28, weight=8.8856128311899, value=12.622285448340437],
BackpackItem[index=29, weight=1.8263025037286487, value=19.367961407759253],
BackpackItem[index=32, weight=15.88675314706114, value=28.540849394736394],
BackpackItem[index=40, weight=1.1413997965995062, value=21.80921576025359],
BackpackItem[index=42, weight=6.377954982720564, value=10.853471985781955],
BackpackItem[index=47, weight=8.64371093345159, value=29.54182483194022],
BackpackItem[index=48, weight=15.986674014500542, value=26.52045693255334],
BackpackItem[index=50, weight=12.129098920575736, value=31.318427226721102],
BackpackItem[index=54, weight=3.246367307224817, value=8.262282381760794],
BackpackItem[index=56, weight=1.46339012113997, value=22.916068050593875],
BackpackItem[index=58, weight=6.064969281461701, value=20.174175753592152],
BackpackItem[index=64, weight=11.07226679411714, value=15.361354187204682],
BackpackItem[index=67, weight=5.796325791185743, value=31.38446611851951],
BackpackItem[index=71, weight=1.6057241540644187, value=27.959279182432027],
BackpackItem[index=72, weight=2.30301008315975, value=2.690583118741767],
BackpackItem[index=75, weight=3.0292429346587038, value=14.879133630347585],
BackpackItem[index=79, weight=2.4237834395426976, value=7.852888145075302],
BackpackItem[index=82, weight=2.4906370205893915, value=30.68785599429856],
BackpackItem[index=85, weight=3.600029103209489, value=4.340637204543632],
BackpackItem[index=86, weight=4.326538729056475, value=3.260428826511318],
BackpackItem[index=87, weight=16.425575532062, value=30.147688202210976],
BackpackItem[index=88, weight=3.6106988772770428, value=26.323990977840324],
BackpackItem[index=89, weight=7.217625744723435, value=16.92181900647524],
BackpackItem[index=90, weight=8.00234891479569, value=4.394380033405021],
BackpackItem[index=95, weight=10.58698616357823, value=29.429168478480122],
BackpackItem[index=98, weight=3.397358000617164, value=4.999189982694462]],
value=700.1452190802412, weight=249.90960794589307]
```

2. Bacpack:

```
Item 0: value=2.5887647702077103, weight=2.4881566412925844
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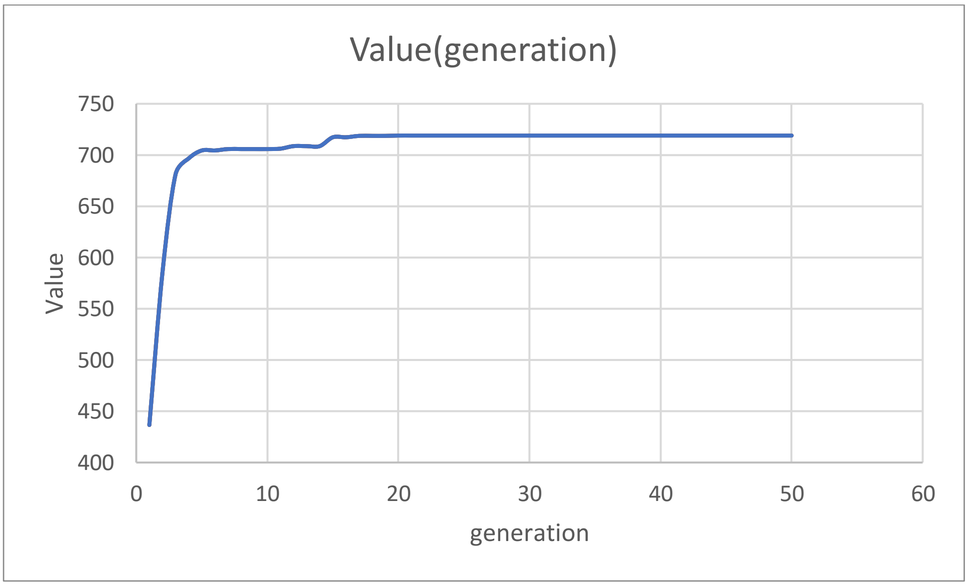
Графік залежності



Висновок

Виконання цієї лабораторної роботи дозволило глибше зрозуміти основні принципи формалізації метаевристичних алгоритмів, зокрема, через розробку та програмну реалізацію генетичного алгоритму для розв'язання задачі про рюкзак. Використання генетичного алгоритму з початковою популяцією 100 осіб, триточковим оператором схрещування та мутацією з ймовірністю 5% ефективно демонструє, як метаевристичні підходи можуть оптимізувати пошук рішень у складних задачах. Особливо цінним є розробка власного оператора локального покращення, що додало унікальності до стандартного процесу генетичного алгоритму. Аналіз якості розв'язків на різних етапах ітерацій і побудова графіка залежності якості розв'язку від числа ітерацій дозволили візуально оцінити ефективність алгоритму та його здатність до оптимізації. Такий підхід підкреслює важливість ітеративного покращення та налаштування параметрів алгоритму для досягнення оптимальних результатів.