Tugas Kecil 2 IF2211 Strategi Algoritma
Semester II Tahun 2022/2023

Penerapan Algoritma Divide and Conquer pada Closest Pair of Points Problem

Disusun oleh:

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PROGRAM STUDI
TEKNIK INFORMATIKA
SEKOLAH TEKNIK ELEKTRO
DAN INFORMATIKA
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1. ALGORITMA

1. Algoritma *Brute Force*
   a. Jarak terdekat ditetapkan sebagai jarak antara point pertama dan point kedua sebagai patokan pertama
   b. Kedua point terdekat disimpan pada variable masing-masing
   c. Iterasikan tiap pasangan point
   d. Jika memiliki jarak yang lebih dekat, maka jarak antara kedua point tersebut disimpan pada variable jarak terdekat bersama dengan pasangan point tersebut
   e. Terdapat pasangan point terdekat
2. Algoritma *Divide and Conquer*
   a. Semua point pada list point diurutkan berdasarkan koordinat pertama membesar
   b. Point di tengah list yang sudah diurutkan dijadikan midpoint sebagai patokan
   c. List point akan dibagi menjadi dua dengan size yang sama dan masing-masing dicari pasangan point terdekat
   d. Terdapat 2 pasangan point terdekat yang kemudian akan dipilih jarak yang terdekat di antara kedua pasangan point tersebut
   e. Membuat strip dimana jika jarak koordinat pertama dari point dengan midpoint lebih kecil dari jarak terdekat, maka akan dimasukkan ke list strip, membentuk *hyperplane* pada bidang ruang Euclidean R^n
   f. Point pada strip diurutkan berdasarkan koordinat kedua
   g. Iterasikan semua point pada strip tersebut dan menghitung jarak terdekat dari point pada strip
   h. Pasangan point dengan jarak terdekat telah terpilih
   i. Langkah b-h akan dilakukan secara rekursif sampai dengan LEAF_SIZE, dimana LEAF_SIZE merupakan batas bawah algoritma *divide and conquer* untuk melakukan brute force dan memasuki tahap *conquer*

CATATAN:

- Algoritma *Brute Force* dan *Divide and Conquer* dapat memberi hasil yang "terbalik" (<P1, P2> seharusnya ekivalen dengan <P3, P4> namun bisa jadi seperti <P1, P2> dengan <P4, P3> dimana P4 dan P3 tertukar), hal ini merupakan *by design* dan tidak ditangani oleh program.
- 3D plotting hanya akan bisa dijalankan jika GNUPlot terinstal pada instalasi Windows (sesuai dengan requirement pada GitHub).
- Jika masukan plotting (y/yes or n/no) salah, maka program akan asumsi pilihan "no". Ini merupakan *design choice*.
- Masukan n (jumlah point) tidak terbatas, namun minimal 2.
- Masukan dimensi dibataskan menjadi 1 sampai 10 (inklusif).

2. SOURCE CODE (C++)

main.cpp

```
#include <iostream>
```

```cpp
#include <vector>
#include <chrono>
#include "point.h"
#include "rand.h"
#include "sort.h"
#include "plot.h"
#include "getcpu.h"

#ifdef linux
#include <algorithm>
#endif

using namespace std;

const int LEAF_SIZE = 64; // leaf size for divide and conquer,
increase for more operations but slower, most optimal in my testing is
64

inline bool compareX(const Point& p1, const Point& p2, bool equals) {
    return equals ? p1.getCoordinate(0) <= p2.getCoordinate(0) :
p1.getCoordinate(0) < p2.getCoordinate(0);
}

inline bool compareY(const Point& p1, const Point& p2, bool equals) {
    return equals ? p1.getCoordinate(1) <= p2.getCoordinate(1) :
p1.getCoordinate(1) < p2.getCoordinate(1);
}

/**
 * @brief Brute force algorithm to find the closest pair of points
 * @param points
 * @return Closest pair of points
 */
Tuple<Point, Point> bruteForce(const vector<Point>& points) {
    double minDist = dist(points[0], points[1]);
    Point p1 = points[0];
    Point p2 = points[1];
    for (int i = 0; i < points.size(); i++) {
        for (int j = i + 1; j < points.size(); j++) {
            double distIJ = dist(points[i], points[j]);
```

```
            if (distIJ < minDist) {
                minDist = distIJ;
                p1 = points[i];
                p2 = points[j];
            }
        }
    }
    return {p1, p2};
}

/**
 * @brief Helper function for DnC
 * @param points
 * @return Closest pair of points
 */
Tuple<Point, Point> divAndConHelper(vector<Point>& points) {
    if (points.size() <= LEAF_SIZE) {
        return bruteForce(points);
    }
    const int dim = points[0].getDimension();
    Point midPoint = points[points.size() / 2];
    vector<Point> pointsXL(points.begin(), points.begin() +
points.size() / 2);
    vector<Point> pointsXR(points.begin() + points.size() / 2,
points.end());

    auto [p1, p2] = divAndConHelper(pointsXL);
    auto [p3, p4] = divAndConHelper(pointsXR);

    double d1 = dist(p1, p2);
    double d2 = dist(p3, p4);
    double minDist;
    Point p5(dim), p6(dim);
    if (d1 < d2) {
        p5 = p1;
        p6 = p2;
        minDist = d1;
    } else {
        p5 = p3;
        p6 = p4;
        minDist = d2;
```

```
    }

    vector<Point> strip;
    for (const auto & point : points) {
        if (abs(point.getCoordinate(0) - midPoint.getCoordinate(0)) <
minDist) {
            strip.push_back(point);
        }
    }

//    timsort(strip, compareY);
//    sort(strip.begin(), strip.end(), compareY);
    quickSort(strip, 0, strip.size() - 1, compareY);
    for (int i = 0; i < strip.size(); i++) {
        for (int j = i + 1; j < strip.size() &&
(strip[j].getCoordinate(1) - strip[i].getCoordinate(1)) < minDist;
j++) {
            double distIJ = dist(strip[i], strip[j]);
            if (distIJ < minDist) {
                minDist = distIJ;
                p5 = strip[i];
                p6 = strip[j];
            }
        }
    }
    return {p5, p6};
}

/**
 * @brief Divide and conquer algorithm to find the closest pair of
points
 * @param points
 * @return Closest pair of points
 */
Tuple<Point, Point> divideAndConquer(vector<Point>& points) {
    quickSort(points, 0, points.size() - 1, compareX);
//    timsort(points, compareX);
//    sort(points.begin(), points.end(), compareX);
    return divAndConHelper(points);
}
```

```cpp
/**
 * @brief Driver function
 */
int main() {
    int n, dim;
    string input;
    cout << "Enter number of points (must be greater than or equal to
2): ";
    while (true) {
        getline(cin >> ws, input);
        if (strtol(input.c_str(), nullptr, 10) < 2) {
            cout << "Invalid input. Must be greater than or equal to
2: ";
        } else {
            break;
        }
    }
    n = stoi(input);

    cout << "Enter the dimension: ";
    while (true) {
        getline(cin >> ws, input);
        auto in = strtol(input.c_str(), nullptr, 10);
        if (in < 1 || in > 10) {
            cout << "Invalid input. Must be from 1 to 10 (inclusive):
";
        } else {
            break;
        }
    }
    dim = stoi(input);

    vector<Point> points(n, Point(dim));
    for (auto& p : points) {
        for (auto& c : p) {
            c = getRand();
        }
    }

    cout << "Dimension: " << points[0].getDimension() << endl;
```

```
    cout << "Number of points: " << points.size() << endl;

    cout << endl;
    cout << "Processor: " << getProcessorInfo() << endl;
    cout << endl;

    cout << "-----------------------------------------" << endl;
    cout << "Brute force algorithm" << endl;
    cout << "-----------------------------------------" << endl;

    auto t1 = chrono::high_resolution_clock::now();
    auto [p1, p2] = bruteForce(points);
    auto t2 = chrono::high_resolution_clock::now();

    cout << "Number of operations: " << operations << endl;
    cout << "Closest pair of points: " << p1 << " and " << p2 << endl;
    cout << "Distance: " << dist(p1, p2) << endl << endl;

    auto duration = chrono::duration<double, milli>(t2 - t1).count();
    cout << duration << " ms" << endl;

    cout << "-----------------------------------------" << endl;
    cout << "Divide and conquer algorithm" << endl;
    cout << "-----------------------------------------" << endl;

    operations = 0;

    t1 = chrono::high_resolution_clock::now();
    auto [p3, p4] = divideAndConquer(points);
    t2 = chrono::high_resolution_clock::now();

    cout << "Number of operations: " << operations << endl;
    cout << "Closest pair of points: " << p3 << " and " << p4 << endl;
    cout << "Distance: " << dist(p3, p4) << endl << endl;

    duration = chrono::duration<double, milli>(t2 - t1).count();
    cout << duration << " ms" << endl;

    // Ask to save to file and plot
    if (dim == 3){
```

```
        cout << "Do you want to save the points to a file and plot
them? (y/n): ";
        getline(cin >> ws, input);
        transform(input.begin(), input.end(),
input.begin(), ::tolower);
        if (input == "y" || input == "yes") {
            saveToFile("points.txt", points, p1, p2);
            startPlot("points.txt");
        } else if (input == "n" || input == "no") {
            cout << "Exiting..." << endl;
        } else {
            cout << "Invalid input. Exiting..." << endl;
        }
    }
    return 0;
}
```

plot.cpp

```
//
// Created by ammar on 27/02/2023.
//

#include <fstream>
#include "plot.h"

/**
 * Saves the given points to a file
 * @param filename
 * @param points
 * @param p1
 * @param p2
 */
void saveToFile(const string& filename, const vector<Point>& points,
const Point& p1, const Point& p2) {
    ofstream file(filename);
    for (const Point& point : points) {
        for (auto& coord : point) {
            file << coord << " ";
        }
```

```
        if (point == p1 || point == p2) {
            file << 1;
        } else {
            file << 0;
        }
        file << endl;
    }
    file.close();
}

/**
 * Starts plotting the points in the given file
 * @param file
 */
void startPlot(const string& file = "points.txt") {
    cout << "Plotting..." << endl;
    FILE* pipe = popen("gnuplot -persist", "w");
    if (!pipe) {
        throw runtime_error("Could not open pipe to GNUPlot");
    }
    fprintf(pipe, "set title \"Nearest Points\"\n");
    fprintf(pipe, "splot \"%s\" using 1:2:3:($4==1 ? $3 : 1/0) with
points pointtype 7, \"%s\" using 1:2:3:($4==0 ? $3 : 1/0) with points
pointtype 5 \n", file.c_str(), file.c_str());
    pclose(pipe);
    cout << "Plotting done!" << endl;
}
```

plot.h

```
//
// Created by ammar on 27/02/2023.
//

#ifndef TUCIL2_13521136_PLOT_H
#define TUCIL2_13521136_PLOT_H

#include <string>
#include <vector>
#include "point.h"
```

```
void saveToFile(const string& filename, const vector<Point>& points,
const Point& p1, const Point& p2);
void startPlot(const string& file);

#endif
```

point.h

```
#ifndef TUCIL2_13521136_POINT_H
#define TUCIL2_13521136_POINT_H

#include <iostream>
#include <string>
#include <cmath>

using namespace std;

static long long operations;

// n-dimensional point
class Point {
public:
    explicit Point(int n) : dimension(n), coordinates(n, 0) {}
    Point(int n, const vector<double>& coordinates) : dimension(n),
coordinates(coordinates) {}

    [[nodiscard]] int getDimension() const { return dimension; }
    [[nodiscard]] double getCoordinate(int i) const { return
coordinates[i]; }
    [[nodiscard]] const vector<double>& getCoordinates() const
{ return coordinates; }

    bool operator==(const Point& p) const {
        for (int i = 0; i < dimension; i++) {
            if (coordinates[i] != p.coordinates[i]) {
                return false;
            }
        }
        return true;
```

```
    }

    Point operator+(const Point& p) const {
        vector<double> newCoordinates(dimension);
        for (int i = 0; i < dimension; i++) {
            newCoordinates[i] = coordinates[i] + p.coordinates[i];
        }
        return {dimension, newCoordinates};
    }

    Point operator-(const Point& p) const {
        vector<double> newCoordinates(dimension);
        for (int i = 0; i < dimension; i++) {
            newCoordinates[i] = coordinates[i] - p.coordinates[i];
        }
        return {dimension, newCoordinates};
    }

    explicit operator string() const {
        string result = "(";
        for (int i = 0; i < dimension; i++) {
            result += std::to_string(coordinates[i]);
            if (i < dimension - 1) {
                result += ", ";
            }
        }
        result += ")";
        return result;
    }

    friend ostream& operator<<(ostream& os, const Point& p) {
        os << (string) p;
        return os;
    }

    vector<double>::iterator begin() { return coordinates.begin(); }
    vector<double>::iterator end() { return coordinates.end(); }
    [[nodiscard]] vector<double>::const_iterator begin() const
{ return coordinates.begin(); }
```

```
    [[nodiscard]] vector<double>::const_iterator end() const { return
coordinates.end(); }
private:
    int dimension;
    vector<double> coordinates;
};

// I want to use std::tuple, but I'm scared of breaking the rules :"
template <typename T1, typename T2>
class Tuple {
public:
    T1 first;
    T2 second;
};

inline double dist(const Point& p1, const Point& p2) {
    double result = 0;
    for (int i = 0; i < p1.getDimension(); i++) {
        result += pow(p1.getCoordinate(i) - p2.getCoordinate(i), 2);
    }
    operations++;
    return sqrt(result);
}

#endif
```

sort.h

```
//
// Created by ammar on 2/26/23.
//

#ifndef TUCIL2_13521136_SORT_H
#define TUCIL2_13521136_SORT_H

#include <vector>
#include "point.h"

#define RUN 32
```

```
using namespace std;

inline double min(double a, double b) {
    return a < b ? a : b;
}

void swap(Point &a, Point &b) {
    Point temp = a;
    a = b;
    b = temp;
}

void insertionSort(vector<Point>& points, int left, int right, bool
(*compare)(const Point&, const Point&)) {
    for (int i = left + 1; i <= right; i++) {
        const Point& temp = points[i];
        int j = i - 1;
        while (j >= left && compare(temp, points[j])) {
            points[j + 1] = points[j--];
        }
        points[j + 1] = temp;
    }
}

void merge(vector<Point>& points, int l, int m, int r, bool
(*compare)(const Point&, const Point&)) {
    int left = m - l + 1;
    int right = r - m;
    vector<Point> L(left, Point(points[0].getDimension())), R(right,
Point(points[0].getDimension()));
    for (int i = 0; i < left; i++) {
        L[i] = points.at(l + i);
    }
    for (int i = 0; i < right; i++) {
        R[i] = points[m + 1 + i];
    }
    int i = 0, j = 0, k = l;

    while (i < left && j < right) {
        if (L[i].getCoordinate(0) <= R[j].getCoordinate(0)) {
```

```
            points[k++] = L[i++];
        } else {
            points[k++] = R[j++];
        }
    }
    while (i < left) {
        points[k++] = L[i++];
    }
    while (j < right) {
        points[k++] = R[j++];
    }
}

// WHY DOES THIS NOT WORK IT WORKED ON MY PREVIOUS PROGRAMS
void timsort(vector<Point>& points, bool (*compare)(const Point&,
const Point&)) {
    int n = points.size();
    for (int i = 0; i < n; i += RUN) {
        insertionSort(points, i, min((i + RUN - 1), (n - 1)),
compare);
    }
    for (int size = RUN; size < n; size *= 2) {
        for (int left = 0; left < n; left += 2 * size) {
            int mid = left + size - 1;
            int right = min((left + 2 * size - 1), (n - 1));
            if (mid < right) merge(points, left, mid, right,
compare);
        }
    }
}

int partition(vector<Point>& points, int start, int end, bool
(*compare)(const Point&, const Point&, bool)) {
    Point pivot = points[start];
    int count = 0;
    for (int i = start + 1; i <= end; i++) {
        if (compare(points[i], pivot, true)) {
            count++;
        }
    }
```

```
    int index = start + count;
    swap(points[start], points[index]);
    int i = start, j = end;

    while (i < index && j > index) {
        while (compare(points[i], pivot, true)) i++;
        while (compare(pivot, points[j], false)) j--;
        if (i < index && j > index) {
            swap(points[i++], points[j--]);
        }
    }
    return index;
}

/**
 * Quick sort algorithm
 * @param points
 * @param start
 * @param end
 * @param compare
 */
void quickSort(vector<Point>& points, int start, int end, bool
(*compare)(const Point&, const Point&, bool)) {
    if (start < end) {
        int p = partition(points, start, end, compare);
        quickSort(points, start, p - 1, compare);
        quickSort(points, p + 1, end, compare);
    }
}

#endif
```

rand.h

```
//
// Created by ammar on 2/26/23.
//

#ifndef TUCIL2_13521136_RAND_H
#define TUCIL2_13521136_RAND_H
```

```
/**
 * Generates a random number using the RDRAND instruction
 * @param bound
 * @return Random number
 */
double getRand(long double bound = 1e+18 /* Literally just a random
number so it's not huge */) {
    unsigned long long result;
    __builtin_ia32_rdrand64_step(&result);
    return (double) (result / bound);
}

#endif
```

getcpu.h

```
//
// Created by ammar on 01/03/2023.
//

#ifndef TUCIL2_13521136_GETCPU_H
#define TUCIL2_13521136_GETCPU_H

#ifdef _WIN32
#include <intrin.h>
#endif

#ifdef linux
#include <fstream>
#endif

#include <string>


using namespace std;

string getProcessorInfo() {
    string result;
#ifdef _WIN32
```

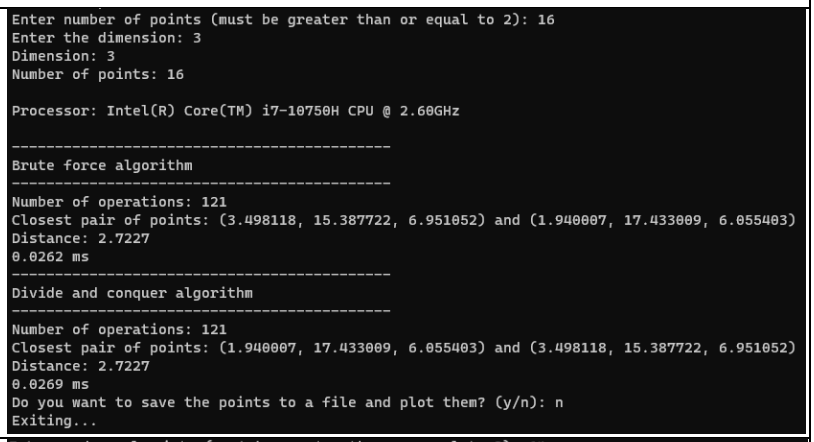
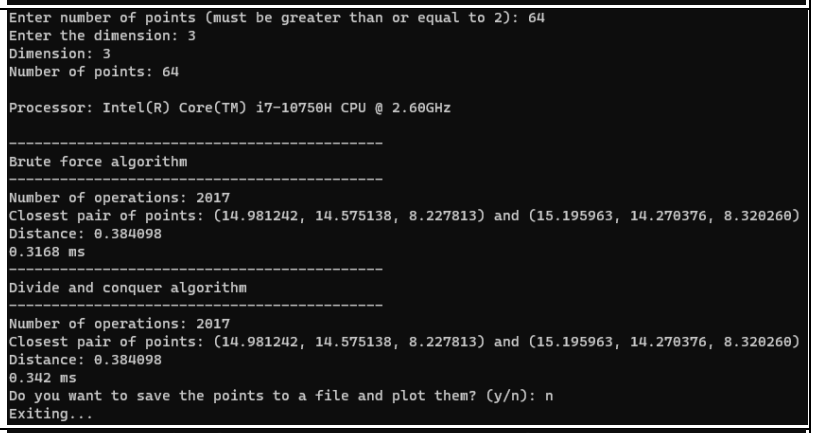
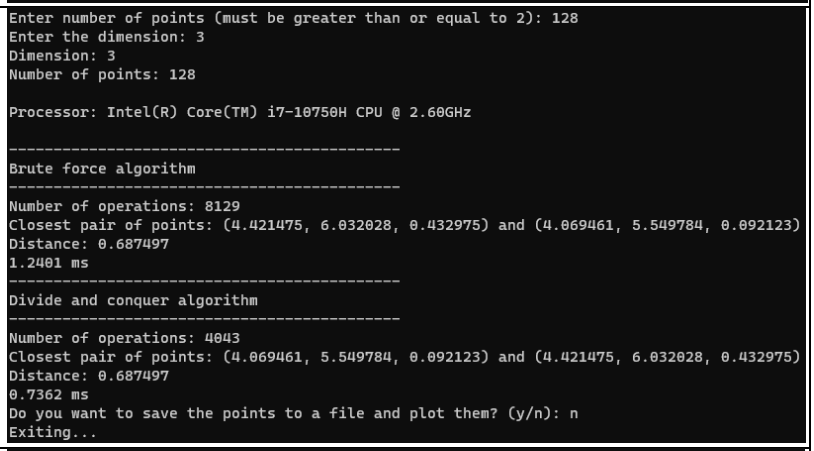
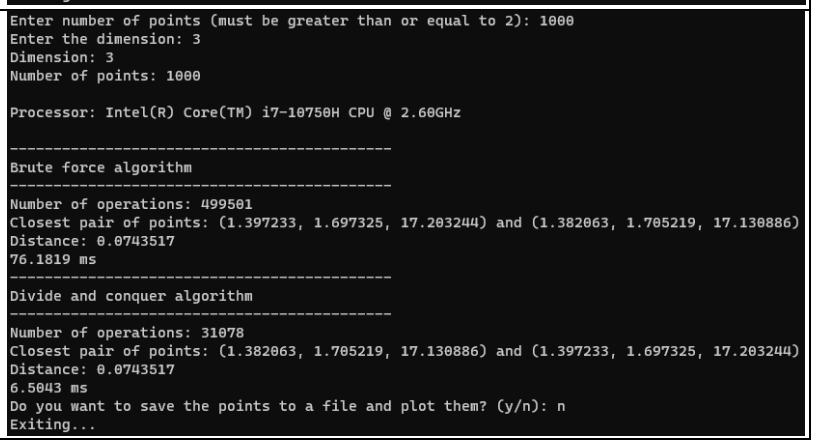
```
    int CPUInfo[4] = {-1};
    unsigned nExIds, i = 0;
    char CPUBrandString[0x40];
    __cpuid(CPUInfo, 0x80000000);
    nExIds = CPUInfo[0];
    for (i = 0x80000000; i <= nExIds; ++i) {
        __cpuid(CPUInfo, i);
        if (i == 0x80000002)
            memcpy(CPUBrandString, CPUInfo, sizeof(CPUInfo));
        else if (i == 0x80000003)
            memcpy(CPUBrandString + 16, CPUInfo, sizeof(CPUInfo));
        else if (i == 0x80000004)
            memcpy(CPUBrandString + 32, CPUInfo, sizeof(CPUInfo));
    }
    result = CPUBrandString;
#endif
#ifdef linux
    ifstream cpuinfo("/proc/cpuinfo");
    string line;
    while (getline(cpuinfo, line)) {
        if (line.find("model name") != string::npos) {
            result = line.substr(line.find(':') + 2);
            break;
        }
    }
    cpuinfo.close();
#endif
    return result;
}

#endif
```

3. CONTOH MASUKAN DAN LUARAN

Semua contoh dijalankan pada komputer dengan processor Intel Core i7 10750H @ 2.6GHz (5GHz single core).

Dimensi 3

Test case (ukuran N)	Screenshot
16	
64	
128	
1000	

Masukan yang tidak sesuai	Enter number of points (must be greater than or equal to 2): 10a00 Enter the dimension: 3 Dimension: 3 Number of points: 10 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz --- Brute force algorithm --- Number of operations: 46 Closest pair of points: (11.017740, 12.479443, 14.071938) and (14.097717, 14.672246, 12.553024) Distance: 4.07452 0.0143 ms --- Divide and conquer algorithm --- Number of operations: 46 Closest pair of points: (11.017740, 12.479443, 14.071938) and (14.097717, 14.672246, 12.553024) Distance: 4.07452 0.0133 ms Do you want to save the points to a file and plot them? (y/n): n Exiting...
	Enter number of points (must be greater than or equal to 2): 1 Invalid input. Must be greater than or equal to 2: 1000 Enter the dimension: 0 Invalid input. Must be from 1 to 10 (inclusive): 3 Dimension: 3 Number of points: 1000 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz --- Brute force algorithm --- Number of operations: 499501 Closest pair of points: (4.661481, 9.302379, 5.469532) and (4.758716, 9.360383, 5.397924) Distance: 0.133966 75.9189 ms --- Divide and conquer algorithm --- Number of operations: 30926 Closest pair of points: (4.661481, 9.302379, 5.469532) and (4.758716, 9.360383, 5.397924) Distance: 0.133966 6.717 ms Do you want to save the points to a file and plot them? (y/n): n Exiting...

Dimensi n > 3 (contoh yang dipakai adalah dimensi 10)

Test case (ukuran N)	Screenshot
16	Enter number of points (must be greater than or equal to 2): 16 Enter the dimension: 10 Dimension: 10 Number of points: 16 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz --- Brute force algorithm --- Number of operations: 121 Closest pair of points: (10.078845, 18.357886, 12.534344, 3.006379, 3.752638, 8.026691, 7.226141, 10.726669, 9.078306, 14.511348) and (9.913325, 12.277278, 11.249827, 6.524814, 6.652230, 5.272032, 4.426205, 8.651846, 12.886110, 15.192349) Distance: 9.70227 0.0634 ms --- Divide and conquer algorithm --- Number of operations: 121 Closest pair of points: (9.913325, 12.277278, 11.249827, 6.524814, 6.652230, 5.272032, 4.426205, 8.651846, 12.886110, 15.192349) and (10.078845, 18.357886, 12.534344, 3.006379, 3.752638, 8.026691, 7.226141, 10.726669, 9.078306, 14.511348) Distance: 9.70227 0.065 ms

64	Enter number of points (must be greater than or equal to 2): 64 Enter the dimension: 10 Dimension: 10 Number of points: 64 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz ---------- Brute force algorithm ---------- Number of operations: 2017 Closest pair of points: (2.435927, 10.787817, 18.074857, 6.823902, 14.910959, 3.306583, 8.332226, 12.648748, 10.658381, 17.201347) and (0.899857, 6.855713, 15.690084, 8.577708, 13.079801, 5.391012, 8.546338, 11.395181, 14.924682, 14.908886) Distance: 7.70428 0.9121 ms ---------- Divide and conquer algorithm ---------- Number of operations: 2017 Closest pair of points: (0.899857, 6.855713, 15.690084, 8.577708, 13.079801, 5.391012, 8.546338, 11.395181, 14.924682, 14.908886) and (2.435927, 10.787817, 18.074857, 6.823902, 14.910959, 3.306583, 8.332226, 12.648748, 10.658381, 17.201347) Distance: 7.70428 0.9437 ms
128	Enter number of points (must be greater than or equal to 2): 128 Enter the dimension: 10 Dimension: 10 Number of points: 128 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz ---------- Brute force algorithm ---------- Number of operations: 8129 Closest pair of points: (2.609041, 9.339022, 14.931640, 8.194200, 11.858752, 4.226243, 8.667690, 14.948171, 14.615452, 1.406323) and (0.545802, 9.019314, 15.482641, 9.829320, 13.152789, 6.542169, 9.553836, 17.851957, 14.991983, 5.118894) Distance: 6.12508 3.6321 ms ---------- Divide and conquer algorithm ---------- Number of operations: 6028 Closest pair of points: (0.545802, 9.019314, 15.482641, 9.829320, 13.152789, 6.542169, 9.553836, 17.851957, 14.991983, 5.118894) and (2.609041, 9.339022, 14.931640, 8.194200, 11.858752, 4.226243, 8.667690, 14.948171, 14.615452, 1.406323) Distance: 6.12508 2.9111 ms
1000	Enter number of points (must be greater than or equal to 2): 1000 Enter the dimension: 10 Dimension: 10 Number of points: 1000 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz ---------- Brute force algorithm ---------- Number of operations: 499501 Closest pair of points: (1.699215, 6.548788, 7.635439, 2.240172, 16.678067, 8.873968, 9.280033, 11.359031, 7.747741, 1.606483) and (1.822765, 6.368387, 7.663864, 2.007743, 14.526741, 9.524518, 10.401304, 8.709648, 5.608468, 1.050861) Distance: 4.27969 222.825 ms ---------- Divide and conquer algorithm ---------- Number of operations: 278174 Closest pair of points: (1.699215, 6.548788, 7.635439, 2.240172, 16.678067, 8.873968, 9.280033, 11.359031, 7.747741, 1.606483) and (1.822765, 6.368387, 7.663864, 2.007743, 14.526741, 9.524518, 10.401304, 8.709648, 5.608468, 1.050861) Distance: 4.27969 131.421 ms
10000	Enter number of points (must be greater than or equal to 2): 10000 Enter the dimension: 10 Dimension: 10 Number of points: 10000 Processor: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz ---------- Brute force algorithm ---------- Number of operations: 49995001 Closest pair of points: (14.129969, 2.383146, 9.957376, 4.695121, 0.645960, 11.147245, 4.569764, 13.119425, 12.042313, 10.330694) and (13.154459, 3.087775, 9.554614, 6.110019, 0.952933, 12.576642, 5.183032, 12.977170, 13.399337, 10.758161) Distance: 2.85837 22284.9 ms ---------- Divide and conquer algorithm ---------- Number of operations: 14885612 Closest pair of points: (14.129969, 2.383146, 9.957376, 4.695121, 0.645960, 11.147245, 4.569764, 13.119425, 12.042313, 10.330694) and (13.154459, 3.087775, 9.554614, 6.110019, 0.952933, 12.576642, 5.183032, 12.977170, 13.399337, 10.758161) Distance: 2.85837 6818.84 ms

4. LINK GITHUB

Link Repo GitHub: https://github.com/ammarasyad/Tucil2_13521136

Poin	Ya	Tidak

1. Program berhasil dikompilasi tanpa kesalahan	✓	
2. Program berhasil *running*	✓	
3. Program dapat menerima masukan dan menuliskan luaran	✓	
4. Luaran program sudah benar (solusi *closest pair* benar)	✓	
5. Bonus 1 dikerjakan	✓	
6. Bonus 2 dikerjakan	✓	