SKRIPSI

MENGIKUTI MAYORITAS: SEBUAH ALGORITMA BARU UNTUK MENGHITUNG MEDIAN TRAJECTORY

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PROGRAM STUDI TEKNIK INFORMATIKA
FAKULTAS TEKNOLOGI INFORMASI DAN SAINS
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UNDERGRADUATE THESIS

FOLLOWING THE MAJORITY: A NEW ALGORITHM FOR COMPUTING A MEDIAN TRAJECTORY

LIONOV

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DEPARTMENT OF INFORMATICS
FACULTY OF INFORMATION TECHNOLOGY AND SCIENCES
PARAHYANGAN CATHOLIC UNIVERSITY

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LEMBAR PENGESAHAN

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Bandung, 1 Juli 2002

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PERNYATAAN

D ngan ini saya yang b rtandatangan di bawah ini m nyatakan bahwa skripsi d ngan judul:

MENGIKUTI MAYORITAS:
SEBUAH ALGORITMA BARU UNTUK MENGHITUNG MEDIAN TRAJECTORY

adalah b nar-b nar karya saya s ndiri, dan saya tidak m lakukan p njiplakan atau p ngutipan d ngan cara-cara yang tidak s suai d ngan tika k ilmuan yang b rlaku dalam masyarakat k ilmuan.

Atas p rnyataan ini, saya siap m nanggung s gala risiko dan sanksi yang dijatuhkan k pada saya, apabila di k mudian hari dit mukan adanya p langgaran t rhadap tika k ilmuan dalam karya saya, atau jika ada tuntutan formal atau non-formal dari pihak lain b rkaitan d ngan k aslian karya saya ini.

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ABSTRAK

Kami m ng mbangkan dua algoritma baru untuk m nghitung lintasan dari m dian s t lintasan. Algoritma p rtama adalah $O(1.2108^m + m^5 n^5)$ t rburuk waktu algoritma, d ngan m nggunakan kons p Jarak Fréch t. Algoritma k dua m nggunakan m tod p nyangga. Dalam situasi praktis, algoritma ini dapat m nghitung m dian lintasan di $O((mn)^2 \log mn)$ waktu. Untuk k dua algoritma, m adalah jumlah lintasan dalam m ngatur dan lintasan masing-masing m miliki s gm n n. Kami m mbandingkan algoritma buff r d ngan dua algoritma lain, salah satu dari m r ka m nggunakan kons p homotopy. Hasil kami m nunjukkan bahwa algoritma p nyangga m lakukan agak l bih baik.

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Kata-kata kunci: Lintasan, Homotopy, Fréch t, Lintasan M dian, P nyangga

ABSTRACT

W d v lop two n w algorithms to comput a m dian traj ctory from a s t of traj ctori s. Th first algorithm is an $O(1.2108^m + m^5 n^5)$ worst-cas tim algorithm, using th conc pt of Fréch t Distanc . Th s cond algorithm us s a buff r m thod. In practical situations, this algorithm can comput th m dian traj ctory in $O((mn)^2 \log mn)$ tim . For both algorithms, m is th numb r of traj ctori s in th s t and ach traj ctory has n s gm nts. W compar th buff r algorithm with two oth r algorithms, on of th m using th homotopy conc pt. Our r sults sugg st that th buff r algorithm p rforms som what b tt r.

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Keywords: Traj ctory, Homotopy, Fréch t, M dian Traj ctory, Buff r

Dipersembahkan untuk diri sendiri

KATA PENGANTAR

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Bandung, Juli 2002

P nulis

DAFTAR ISI

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DAFTAR TABEL

BAB 1

PENDAHULUAN

1.1 Latar Belakang

Data mining m rupakan t knik untuk m ngolah *data*, m ncari suatu pola, k mudian di valuasi untuk m ndapatkan *knowledge*. Pola yang dihasilkan ol h *data mining* dapat digunakan untuk m ncari suatu hal yang m narik dan unik. Dari pola t rs butlah, akan didapatkan suatu informasi yang sangat b rmakna yang biasa dis but s bagai *knowledge*.

Pada p n litian ini, akan dilakukan analisis data p nggunaan KIRI d ngan m nggunakan t ori-t ori *data mining*. Pada p n litian ini, diharapkan dapat dit mukan suatu pola yang m narik dan m nghasilkan suatu id atau gagasan yang baru. Maka dari itu, p n litian ini akan m mbutuhkan banyak *data* p nggunaan KIRI, yang dapat dip rol h dari *log* histori KIRI.

Log t rs but m miliki 5 *field* untuk s tiap *entry* s bagai b rikut:

- statisticId, primary k y dari ntry
- v rifi r, m ngid ntifikasikan sumb r dari p ncarian ini
- *timestamp*, waktu k tika p ngguna KIRI m ncari rut angkot
- *type*, tip log, untuk p n litian ini s lalu b risi FINDROUTE
- additionalInfo, m ncatat koordinat awal, koordinat akhir, dan banyak rut yang dit mukan pada p ncarian ini

D ngan m nggunakan *data log* histori p ncarian rut angkot dari KIRI, diharapkan bisa dip rol h pola yang m narik. Pola t rs but m miliki k mungkinan untuk digunakan k mbali s bagai informasi tambahan pada p rangkat lunak navigasi lain s p rti KIRI.

1.2 Perumusan Masalah

D ngan m ngacu pada uraian diskripsi diatas, maka p rmasalahan yang dibahas dan dit liti ol h p nulis adalah

- Bagaimana cara m ngolah pola yang dip rol h dari *data log histori* KIRI agar pola m njadi m narik dan b rmakna?
- Bagaimana m mbuat p rangkat lunak untuk m lakukan data mining pada data log history?

1.3 Tujuan dan Manfaat

1.3.1 Tujuan

P n litian ini b rtujuan untuk

- M ncari pola dan informasi yang m narik dari *log histori* KIRI
- P rangkat lunak dapat m lakukan data mining dari *log histori* KIRI

1.3.2 Manfaat

- Agar *data log histori* KIRI dapat diolah dan didapat informasi yang m narik dan b rmakna
- M ndapatkan s buah p rangkat lunak yang dapat m lakukan *data mining* dari *log histori* KIRI

1.4 Ruang Lingkup Masalah

P n litian *data mining* yang diatas akan dit ntukan batasan masalah yang dit liti b rupa :

- P n litian ini dibatasi hanya pada p rmasalahan pada p n rapan *data mining* pada *data log* KIRI
- Data log yang m rupakan masukan akan dibatasi s banyak 10000 buah data

1.5 Metode Penelitian dan Teknik Pengumpulan Data

1.5.1 Metode Penelitian

B rikut adalah M tod P n litian yang digunakan :

- M lakukan studi lit ratur t ntang algoritma-algoritma yang b rkaitan d ngan p mros san *data mining*
- M lakukan p n litian *data mining* yang dit rapkan pada *log* KIRI
- M rancang dan m ngimpl m ntasikan algoritma untuk *data mining*
- M ngimpl m ntasikan p mbangkit pola *data mining*
- M lakukan p ngujian dan ksp rim n

1.5.2 Teknik Pengumpulan Data

B rikut adalah t knik p ngumpulan data yang digunakan :

- M ngunduh dari *data log history* KIRI

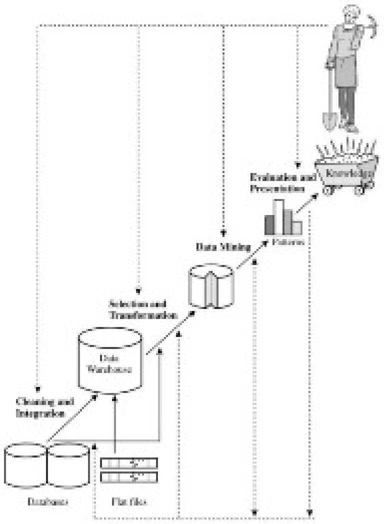
1.6 Sistematika Pembahasan

BAB 2

LADASAN TEORI

2.1 Tahap Data Mining

Pros s pada *data mining* dapat dibagi m njadi b b rapa tahap s p rti pada gambar 2.1



Gambar 2.1: Tahap *Data Mining*, Sumb r Data Mining Conc pts T chniqu s

BAB 3

INTRODUCTION

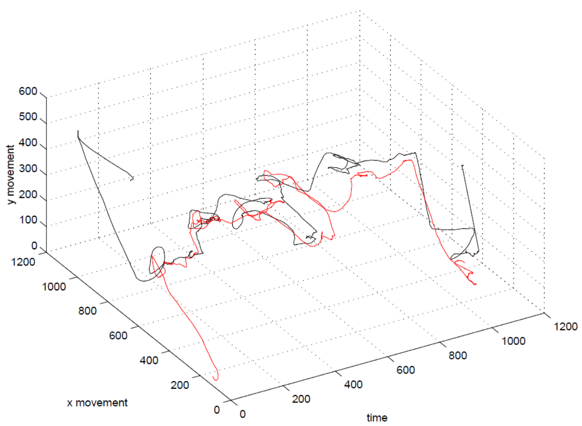
3.1 Moti ation

A traj ctory is th motion path of a moving obj ct. Various moving obj cts such as animals (probably in a wildlif ar a), hurrican s, or custom rs in a shopping ar a hav traj ctori s that can provid valuabl information. For xampl , traj ctory data can b us d to pr dict th mov m nt of th sam typ of obj ct in similar situation in th futur .

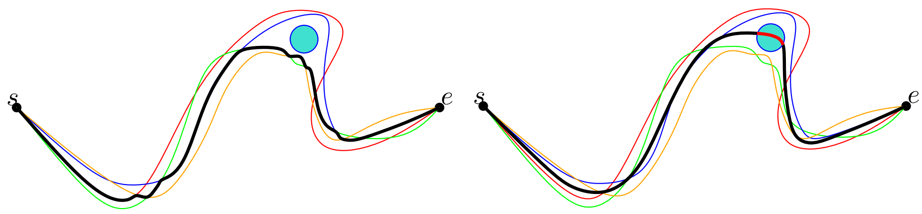
During a tracking proc dur , th location of th s moving obj cts can b obtain d using various location d t ction d vic s (.g: RFID, GPS d vic s and mobil phon s). Lat r, this information will b s nt to a databas using any communication n twork (usually a wir l ss n twork). B caus typical traj ctory data is obtain d during a sp cific int rval, th n traj ctory data also has a t mporal compon nt, b sid s its spatial compon nt.

Th traj ctory of a moving obj ct is typically mod l d as a s qu nc of cons cutiv locations in a multi-dim nsional (g n rally two or thr   dim nsional) Euclid an spac [1]. Figur **??** shows an xampl of two traj ctori s from two obj cts which ar moving in a 2D plan . With th ir t mporal compon nt, w can s   that th s traj ctori s ar r pr s nt d as polylin s in a 3D spac .

Nowadays, with th rapid d v lopm nt of t chnologi s in mobil computing and wir l ss communication, many d vic s with location acquisition capabiliti s mak it possibl to obtain hug volum s of traj ctory data from various moving obj cts. Furth rmor , analysis of traj ctory data is an important task for many applications that contain proc ssing and managing moving obj cts,



Gambar 3.1: Exampl of 2D traj ctori s with tim compon nt, from [1]



Gambar 3.2: Exampl of th m dian (l ft) and th m an (right) traj ctory [2]

such as animal mov m nts [3, 4, 5, 6], traffic and transport analysis [7], d f ns and surv illanc ar as [8], oc anographic obs rvations[1], w ath r and natural ph nom na [9], p opl b havior [10] and sports [11, 12].

Pr vious work on traj ctory data analysis shows that th r ar s v ral ways to analyz s ts of traj ctori s. For xampl , similarity b tw n traj ctori s can b d t rmin d [13, 14, 15]. Traj ctori s can also b clust r d into groups with similar charact ristics [16, 17, 18, 19]. Oth r xampl s ar common data mining tasks such as classification [20, 21] and outli r d t ction [22]. Furth rmor , int r sting mov m nt patt rns such as flocking can also b comput d from a s t of traj ctori s [23, 24, 25, 26].

Ev n though analysis and r s arch on traj ctori s has xpand d in r c nt y ars, s v ral basic conc pts still n d to b studi d furth r. Som of th m ar th m dian and th m an traj ctory for a coll ction/s t of traj ctori s. Th m dian and th m an traj ctory shar som common prop rti s: th y should b similar to oth r traj ctori s in th s t and all parts of th m should b locat d roughly in th middl of th s t. How v r, th r ar s v ral important diff r nc s b tw n th m: Firstly, th m dian traj ctory must us only parts of traj ctori s in th s t. It us s only parts of on traj ctory or combin s parts from many diff r nt traj ctori s. This prop rty might b a disadvantag for th m dian b caus som parts of it can b locat d not in th middl of th s t, but in s v ral situations this might b us ful.

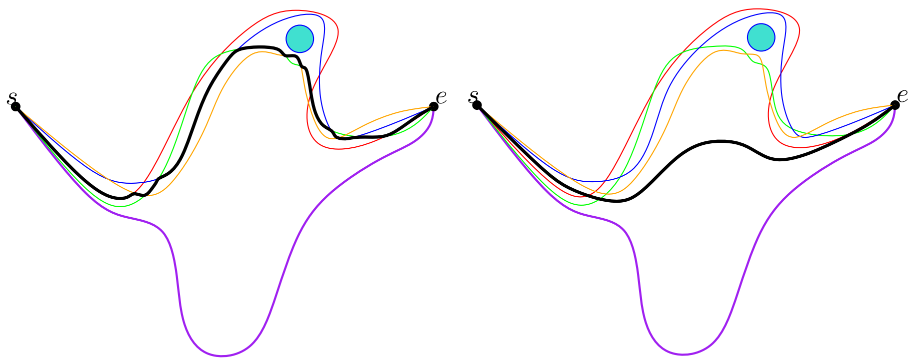
Figur **??** shows a s t of four traj ctori s which avoid th light-blu obstacl . Th possibl m an traj ctory (th black traj ctory in th right-hand sid of th figur) will pass through th obstacl b caus th m an must li in th middl of all traj ctori s in th s t. In this cas , it is cl ar that th m an traj ctory is not suitabl for a path of a moving obj ct.

Th m dian traj ctory (black traj ctory in th l ft-hand sid of th figur) giv s a mor suitabl path b caus it always us s parts of oth r traj ctori s. In parts n ar th obstacl , th m dian is not r ally in th middl of oth r traj ctori s.

S condly, th m dian traj ctory is mor robust against outli rs than th m an traj ctory. Figur **??** shows this situation: w add on traj ctory (with purpl color) which can b cat goriz d as an outli r compar d to oth r traj ctori s. Whil th m dian traj ctory only n ds to b modifi d a littl bit, th m an traj ctory has to b chang d a lot (comparing to th m an traj ctory in Figur **??**), to k p it in th middl of oth r traj ctori s.

In this th sis, w will not cov r th m an traj ctory and only discuss th m dian traj ctory and algorithms to comput it. W also ignor th t mporal compon nt of th traj ctory b caus it is not cl ar y t how to tak it into account wh n computing th m dian traj ctory. How v r, som

[1] W.S. Kessler, "Argo work in the coral sea."http://faculty.washington.edu/kessler/noumea/gliders/argo_coral_sea.html, March 2010.



Gambar 3.3: Robustn ss of th m dian traj ctory

r s arch on motion and kin tic data structur s contains a t mporal compon nt and ar r lat d to th m dian/m an traj ctory [27, 28].

For oth r typ s of data, a m dian has a cl ar d finition. Th m dian from a population (or a sampl) of int g r numb rs is th numb r that s parat s th population into two halv s, wh r at most half of th population hav a small r valu and th oth r half of th population hav a larg r valu than th m dian.

For g om tric data typ s, th conc pt of m dian also xist. A *center point* of a s t P of n points in th plan is a point such that any clos d half-plan whos bounding lin contains th c nt r point, contains at l ast $n/3$ points of P [29]. If w forc th c nt r point to b on of th points from P, th n w obtain a 2-dim nsional v rsion of th m dian, although th "quality" of this m dian can b bad.

Th m dian traj ctory do s not hav any formal d finition y t. Bas d on s v ral prop rti s that w m ntion arli r, such as its similarity with oth r traj ctori s and lying approximat ly in th middl of th s t, w can d t rmin a possibl m dian, which can us ful in s v ral ways:

3.1.1 Determine the most typical trajectory

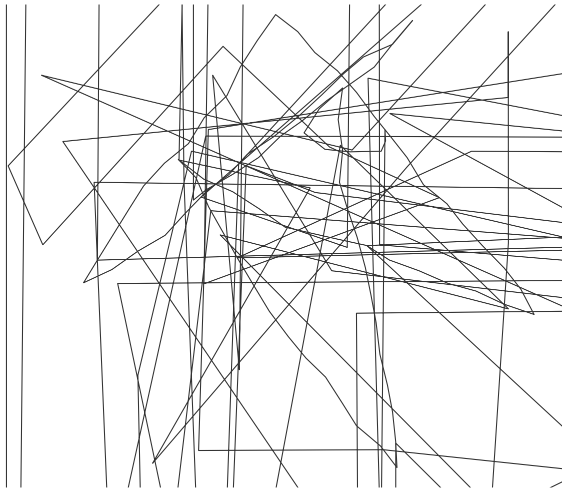
Th prop rty of th m dian traj ctory mak s it suitabl to analyz th mov m nt b havior or mov m nt patt rn from a group of sam obj cts b caus th m dian som how r pr s nts th whol traj ctori s in th s t/coll ction. Th m dian traj ctory prop rti s, such as th l ngth, th dir ction or th av rag sp d (if w includ th t mporal compon nt), could giv valuabl information.

Exampl applications includ th d t ction of outli rs, which can b don by analyzing th l ngth and th similarity of th shap of th m dian with oth r traj ctori s. Analyzing th av rag sp d tog th r with th shap of th m dian traj ctory might b us ful to und rstand th b havior and th mov m nt patt rn of p opl walking around in an ar a which has s v ral int r sting plac s to b visit d (.g., a zoo or an amus m nt park).

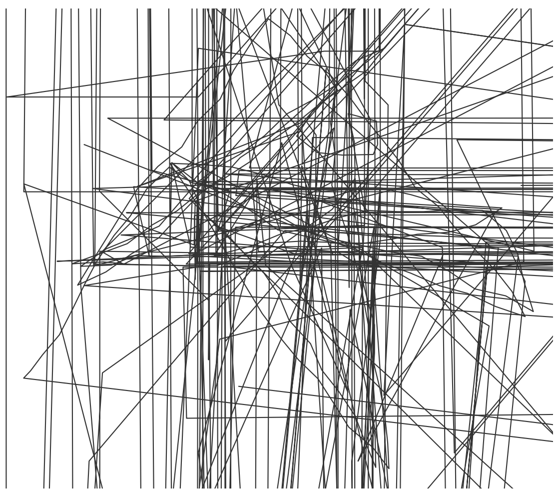
3.1.2 Better visualization for a set of trajectories

Visualization of th m dian traj ctory, tog th r with its s t of traj ctori s, might giv th vi w r a b tt r int rpr tation and information about th s t of traj ctori s.

W giv an xampl in Figur ??, wh r a s t has 30 traj ctori s, which is paths of 30 obj cts moving from th blu point to th gr n point. From this figur , w can hardly t ll anything



Gambar 3.4: Th s t of 30 traj ctori s,starting at th blu point & nding at th gr n point



Gambar 3.5: A s t of 30 traj ctori s with its possibl m dian traj ctory

about th g n ral b havior or th dir ction of th s traj ctori s. How v r, w know that s v ral traj ctori s ar diff r nt than oth rs and probably can pr dict what th majority do s, but it is still difficult to visualiz what th majority of th s traj ctori s do s.

In th following figur (Figur **??**), w pr s nt a possibl m dian traj ctory as th r d and thick traj ctory. From this visualization, it is cl ar what th majority of traj ctori s do s. Mor ov r, w can id ntify what parts of som traj ctori s ar compl t ly diff r nt from oth rs.

Th visualization of th m dian traj ctory could b us ful in som r al-lif applications: Th m dian traj ctory from traj ctori s of visitors in a national park can b us d to s th most common path tak n by visitors, which is probably th path that is pr f rr d by futur visitors. This information might b us ful if w want to cr at a map that can h lp thos visitors by providing valuabl information about a path and dir ction on that national park in th map, so that h /sh can d cid which path that h /sh will tak .

3.1.3 k-medoid clustering

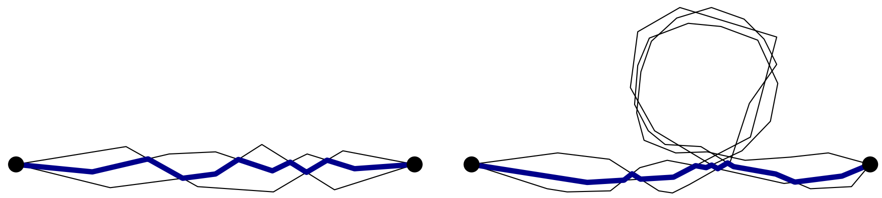
Anoth r application that could us th m dian traj ctory is th k-m doid algorithm, which is us d in clust r analysis. Th k-m doid clust ring algorithm is r lat d to th k-m ans algorithm, a m thod to partition/group a s t of obj cts into k diff r nt clust rs containing similar obj cts.

In g n ral, ach clust r in both algorithms has on obj ct act as a *central object* and oth r m mb rs of th clust r should b similar or having a small distanc to this obj ct. Th similarity or th distanc b tw n obj cts can b m asur d using diff r nt distanc functions (.g. Euclid - an distanc , Minkowski distanc , tc), d p nding on th typ of obj cts and th purpos of th clust ring.

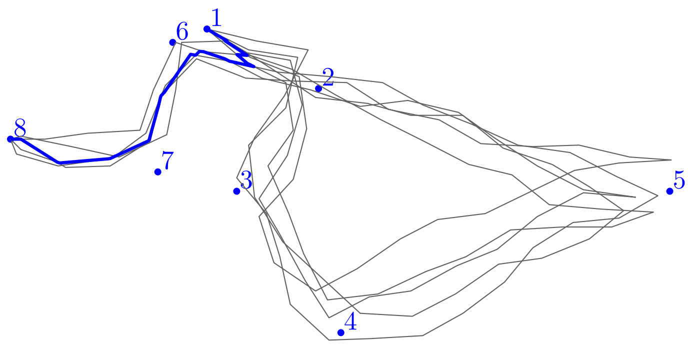
Th main diff r nc b tw n th two algorithms is on th s l ction of th c ntral obj ct for ach clust r. Whil th k-m ans simply us s th m an of obj cts, th k-m doid must us th m doid (an obj ct which has th small st av rag of dissimilarity/distanc to all oth r obj cts in th s t, but it must b a m mb r of th s t). This impli s that k-m ans could cr at a n w obj ct to b th c ntral obj ct wh r as th k-m doid must us on of th obj cts from th s t. Thus, th k-m doid algorithm is mor suitabl for spatial clust ring purpos s and l ss s nsitiv against nois and outli rs.

Partitioning Around M doids (PAM) [30] is a basic k-m doid clust ring algorithm. It works as follow:

1. D fin a valu k and choos k obj cts as a s t of m doids.
2. Assign v ry obj ct to its clos st/similar m doid and aft r that, comput th cost for th whol configuration.
3. Find anoth r configuration by s l cting a pair of m doid and non-m doid obj cts which hav th small st distanc cost and swapping th m t mporarily. Th n, w assign all oth r obj cts to this t mporary s t of m doids and obtain a n w configuration.
4. If th n w configuration has small r cost than th last configuration, th n w chang th s t of m doids and r turn to st p 3
5. Oth rwis , stop and w find th s t of m doids with th ir non-ov rlapping s t of clust rs.



Gambar 3.6: Illustration of th simpl id a using switching



Gambar 3.7: Th m dian traj ctory mak s a shortcut [2]

In cas w want to clust r a s t of traj ctori s, w can us th m dian traj ctory as a m doid in this algorithm. How v r, som chang s probably should b mad . For xampl , finding anoth r configuration is not don by simply swapping th m dian with oth r traj ctory, inst ad w can choos to swap part of th m (with th r quir m nt that both traj ctori s int rs ct on anoth r).

3.2 Basic Idea of the Research

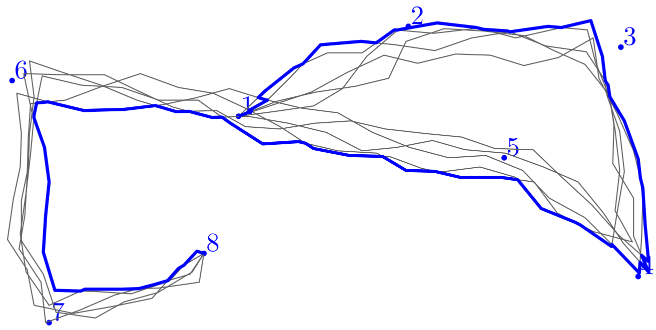
Consid r a s t T of m traj ctori s. W want to to comput th m dian traj ctory of T. In this s t, all traj ctori s hav th sam start and nd points. Th m dian traj ctory of T must b built using parts of traj ctori s in T and som how must follow what oth r traj ctori s in T do, whil staying in th “middl ” of oth r traj ctori s.

3.2.1 The Simple Switching Method

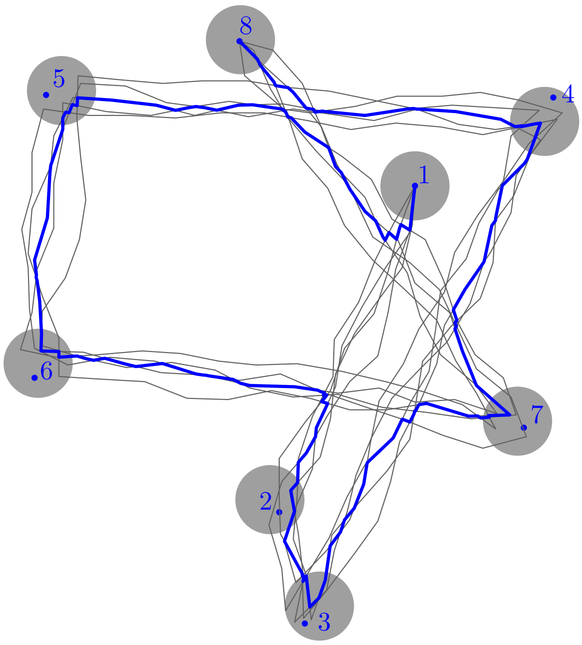
A simpl id a to obtain a m dian traj ctory from T is to start from th “middl ” traj ctory, which is th $(m+1)/2$-l v l of arrang m nt form d by all traj ctori s in T (w assum m is odd). At v ry int rs ction point, th m dian traj ctory will switch to anoth r traj ctory and k p $(m+1)/2$ traj ctori s abov and b low th m dian [31].

Figur **??** shows th r sult (th m dian traj ctory is th thick-blu traj ctory) of this approach for two diff r nt typ s of s t of traj ctori s, on of th m contains traj ctori s with s lf int rs ction. From th right-hand sid of th figur in Figur **??**, w can s   that this m thod cannot produ-c suitabl m dian traj ctory b caus th m dian do s not follow th loop cr at d by th thr   traj ctori s.

In g n ral, this m thod will not giv a suitabl m dian if a s t of traj ctori s contains s lf-int rs cting traj ctori s. Mor   xampl s from [2] show s v ral “incorr ct” m dian traj ctori s ob-tain d by using this simpl switching m thod. Th blu m dian traj ctory in Figur **??** mak s a



Gambar 3.8: Th m dian traj ctory do s not stay in th middl [2]



Gambar 3.9: Th m dian traj ctory do s not follow th corr ct s qu nc of r gions [2]

shortcut path to th   nd point.

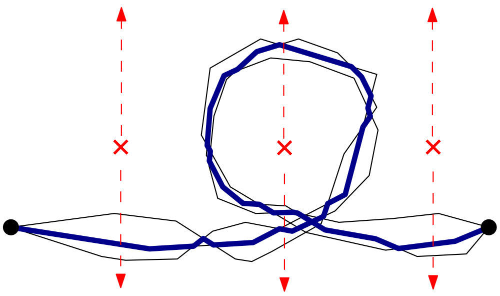
Th m dian traj ctory in Figur **??** do s not stay in th "middl " of oth r traj ctori s. Finally, in Figur **??**, th m dian traj ctory do s not follow th s qu nc of r gions as th oth r traj ctori s. Th corr ct s qu nc of r gions is $1-2-3-4-5-6-7-8$.

3.2.2 The Algorithm Using the Concept of Homotopy

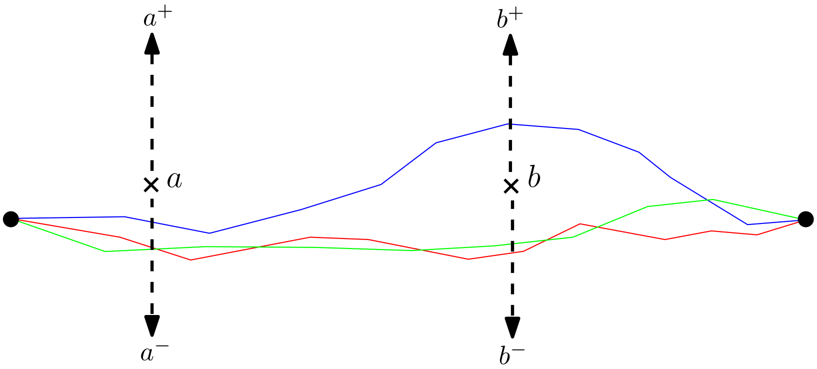
Anoth r algorithm to comput th m dian traj ctory us s th conc pt of homotopy (along with th modifi d simpl switching m thod) [31]. This algorithm works by placing cross in a r lativ ly larg fac bound d by s gm nts from a s t of traj ctori s. Figur **??** shows an xampl wh r cross is plac d in th r lativ ly larg bound d fac and two cross s ar plac d in th out r fac .

Bas d on th location of th s cross s, ach traj ctory in T will b assign d a *signature*. Figur **??** shows thr   traj ctori s and two cross s a and b. From th s two cross s, four half-lin s ar cr at d: a^+ and a^- ar half-lin s abov and b low a, whil b^+ and b^- ar half-lin s abov and b low b, r sp ctiv ly.

For all traj ctori s in T, w giv th m a signatur bas d on how th y int rs ct with th half-



Gambar 3.10: Illustration of th algorithm using homotopy conc pt



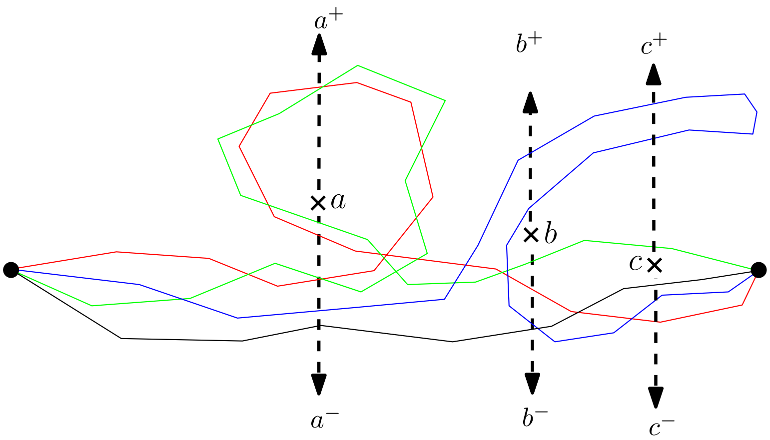
Gambar 3.11: Traj ctori s and cross s

lin (s) from th cross s. Not that ach traj ctory might hav a diff r nt signatur , b caus it d p nds on th position of th traj ctory with r sp ct to all cross s in th plan . In Figur ??, th blu traj ctory int rs ct with a^- and b^+, thus its signatur will b a^-b^+ (th ord r is following th dir ction of th traj ctory). In th sam way, th signatur of th r d traj ctory will b th sam as th gr n traj ctory: a^-b^-.

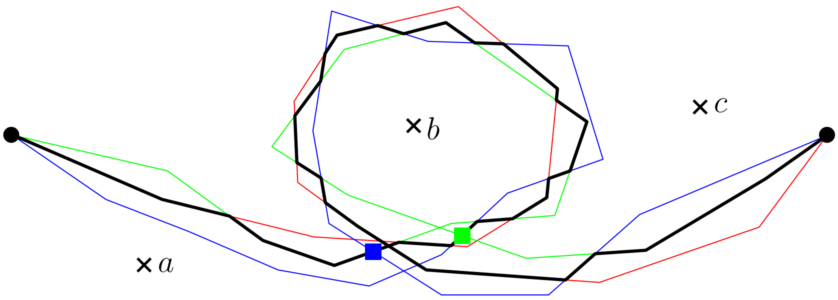
Two diff r nt traj ctori s ar homotopic if on traj ctory can b d form d continuously into th oth r on without passing through any cross s, whil th start and nd point ar not mov d. Naturally, two traj ctori s ar homotopically quival nt if th ir signatur s ar   xactly th sam . How v r, two homotopic traj ctori s do not always hav th sam signatur s. W shown an xampl in Figur ?? wh r th blu and th black traj ctory ar homotopic, but th ir signatur s ar diff r nt.

To d t rmin wh th r two traj ctori s with diff r nt signatur ar homotopic or not, w p rform a *reduce* op ration. This *reduce* op ration works by liminating two xact sam signs, if th ir position is n xt to ach oth r in th signatur . In Figur ??, th signatur of th blu traj ctory is $a^-b^+c^+c^+b^+b^-c^-$. Notic that it has two c^+ that w can liminat . This will chang th signatur of th blu traj ctory into $a^-b^+b^+b^-c^-$. Onc again, w can id ntify that two b^+ ar position d dir ctly to ach oth r. P rforming th r duc op ration again, w will g t th final signatur of th blu traj ctory: $a^-b^-c^-$. At this point, w cannot apply th r duc op ration again to this signatur , and w say that th signatur has b n *maximally reduced*. Finally,w conclud that if two traj ctori s hav th sam maximally r duc d signatur , th n th two traj ctori s ar homotopically quival nt.

Th n xt st p of th algorithm is to cr at a subs t T' of T, and th n find th m dian traj ctory by using only parts of traj ctori s from T'. Cr ating T' is straightforward, w only n d to comput maximally r duc d signatur for all traj ctori s and choos a subs t with th larg st numb r of



Gambar 3.12: Th blu and black traj ctory ar homotopically quival nt [2]



Gambar 3.13: Modifi d switching m thod [2]

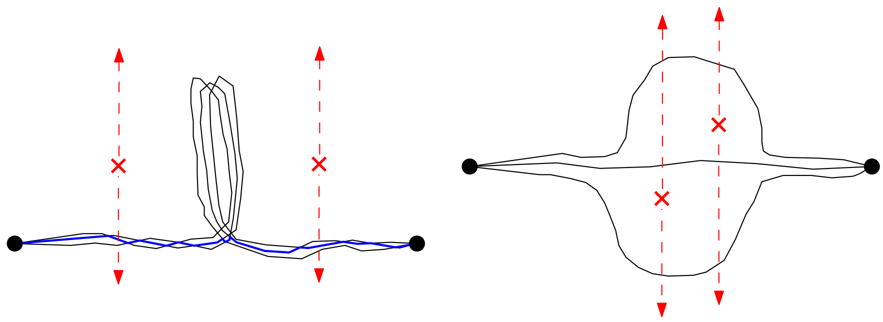
traj ctori s which hav th sam signatur .

To cr at th m dian traj ctory from T', w us th modifi d v rsion of th switching m thod. This m thod start at th first s gm nt of th "middl " traj ctory. W find such a s gm nt by d t rmin th out r fac of th s t of traj ctori s. Th first s gm nt of th "middl " traj ctory is th s gm nt wh r th r ar $(n-1)/2$ first s gm nts from oth r traj ctori s (assum n is odd) b tw n th s gm nt and th out r fac (on ach sid of th s gm nt).

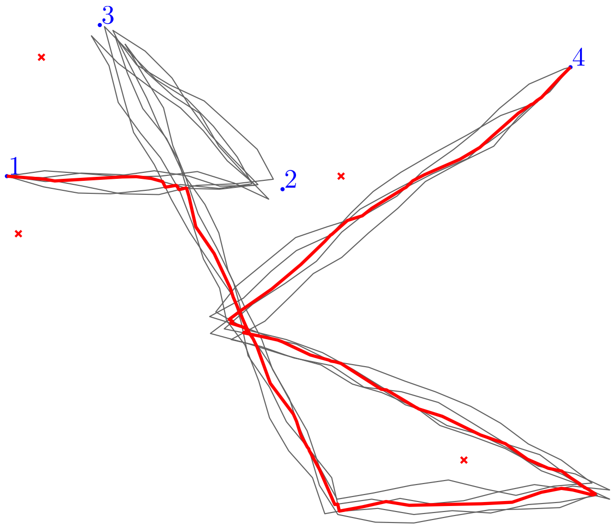
Th n, at v ry int rs ction, th m dian will switch to anoth r traj ctory if th continuation along this traj ctory (without v r switching again) giv s th sam signatur with th signatur of on traj ctory from T'. Figur **??** shows an xampl of this algorithm. Aft r starting with th r d traj ctory and switching to th gr n traj ctory at th first int rs ction, th n xt int rs ction is with th blu traj ctory (at th small blu squar) and so far, th signatur for th m dian is a^+. Although th blu traj ctory is going forward, th signatur aft r this int rs ction whil following th blu traj ctory (until th nd point) is b^-c^-.

If th m dian switch s at this int rs ction, th final signatur will b $a^+b^-c^-$, which is not th signatur of this s t $(a^+b^-b^+b^-c^-)$. At this point, th m dian do s not switch to anoth r traj ctory. Inst ad, it continu s to mov along th gr n traj ctory. Th sam situation also occurs wh n th m dian (now following th blu traj ctory) int rs cts with th gr n traj ctory (at th small gr n squar).

Although this algorithm can produc a mor suitabl m dian traj ctory for th situation wh r th switching m thod fails, th quality of th homotopic m dian traj ctory d p nds h avily on th following factors:



Gambar 3.14: Exampl cas s wh r algorithm using homotopy will fail



Gambar 3.15: Th m dian traj ctory do s not pass through part of traj ctori s in th upp r l ft ar a

- plac m nt of th cross s
- th numb r of traj ctori s which hav th sam signatur

Th r for , in s v ral cas s th algorithm with th homotopy conc pt cannot produc suitabl m dian traj ctori s. W giv two xampl s in Figur ??: in th l ft-hand sid of figur , th final m dian traj ctory (blu) do s not follow oth r traj ctori s to th ar a with a narrow spac . This probl m aris s b caus that narrow spac is not larg   nough for a cross to b plac d.

In th right-hand sid of th figur , th r ar no two traj ctori s homotopically quival nt to ach oth r. N v rth l ss, by looking at th ir position, th m dian traj ctory should b th on in th middl (b tw n th two cross s). How v r, th algorithm with th homotopy conc pt do s not guarant   that a suitabl m dian traj ctory will b found b caus th r is no subs t that contains th majority of traj ctori s in T. Figur ?? shows an xampl from [2], wh r th m dian traj ctory do s not compl t ly follow what oth r traj ctori s do.

3.2.3 The Proposed Solutions

To solv th probl ms w m ntion in th pr vious s ction, w propos two algorithms to comput th m dian traj ctory from a s t of m traj ctori s (wh r   ach traj ctory has n s gm nts).

Th first algorithm is an $O(1.2108^m + m^5n^5)$ worst-cas tim algorithm. This algorithm us s th Fréch t Distanc [32] and works similar to th algorithm using th homotopy conc pt b caus both of th m hav to cr at th larg st subs t of similar traj ctori s and th n comput th m dian traj ctory by using parts of traj ctori s in that subs t. By using th Fréch t Distanc , w avoid th r quir m nt to find prop r plac s to put cross s, but still can produc suitabl m dian traj ctory in th situation wh r th homotopic algorithm fails (.g. th   xampl with a narrow spac).

Th s cond algorithm us s th combination of th buff r conc pt and Dijkstra's Short st Path algorithm. Unlik all pr vious algorithms, this algorithm do s not n d to find th larg st subs t consisting similar traj ctori s. Using this algorithm, w can comput th m dian traj ctory in $O(h^2 \log h)$ tim in th worst-cas , wh r h is th numb r of all s gm nts in T ($h = O(mn)$).

W impl m nt d th s cond algorithm in Java programming languag and xp rim nts hav b n don to d t rmin th quality of th r sulting m dian traj ctory produc d by this algorithm. To provid th t st data (s t of traj ctori s), w us a traj ctori s g n rator inst ad of using r al-world data. This allow us to t st much larg r s ts of traj ctori s

3.3 Outline of the Thesis

Chapt r 2 d scrib s th prop rti s for a s t of traj ctori s and also som prop rti s th m dian traj ctory should hav .

Th n xt two chapt rs xplain in d tail th two algorithms:

- Chapt r 3 starts with a bri f introduction of th Fréch t Distanc and aft r that, w will xplain how to us it to comput th m dian traj ctory.
- Chapt r 4 introduc s th m thod to comput th m dian traj ctory using th combination of th buff r conc pt and Dijkstra's short st path algorithm.

W will giv an xplanation about our impl m ntation, particularly on th impl m ntation of th traj ctori s g n rator, in Chapt r 5. In Chapt r 6, w pr s nt th m asur s us d to valuat th quality of th m dian traj ctory, th   xp rim nts s t-up and th r sults from th   xp rim nts. This th sis will b conclud d in Chapt r 7 and 8, wh r w draw conclusions and discuss som issu s and possibl dir ctions for furth r r s arch.

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plac rat t, mollis vita , dui. S d ant t llus, tristiqu ut, iaculis u, mal suada ac, dui. Mauris nibh l o, facilisis non, adipiscing quis, ultric s a, dui.

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BAB 4

INTRODUCTION

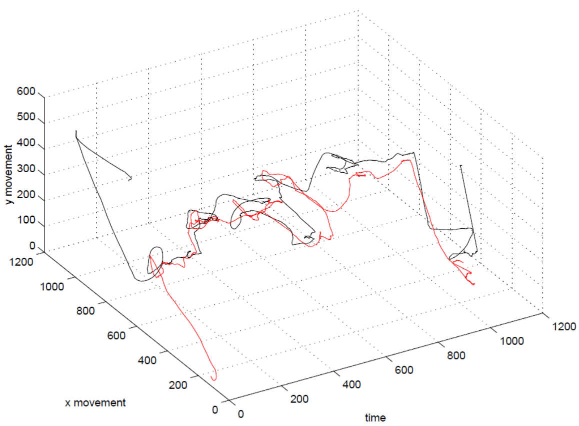
4.1 Moti ation

A traj ctory is th motion path of a moving obj ct. Various moving obj cts such as animals (probably in a wildlif ar a), hurrican s, or custom rs in a shopping ar a hav traj ctori s that can provid valuabl information. For xampl , traj ctory data can b us d to pr dict th mov m nt of th sam typ of obj ct in similar situation in th futur .

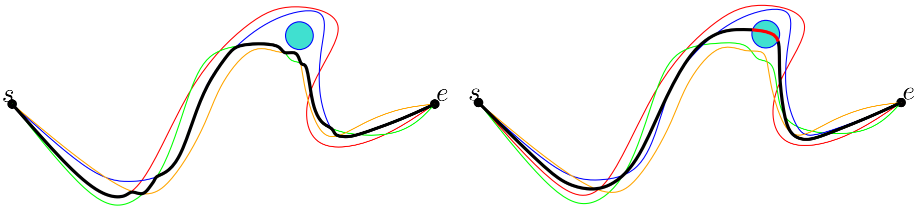
During a tracking proc dur , th location of th s moving obj cts can b obtain d using various location d t ction d vic s (.g: RFID, GPS d vic s and mobil phon s). Lat r, this information will b s nt to a databas using any communication n twork (usually a wir l ss n twork). B caus typical traj ctory data is obtain d during a sp cific int rval, th n traj ctory data also has a t mporal compon nt, b sid s its spatial compon nt.

Th traj ctory of a moving obj ct is typically mod l d as a s qu nc of cons cutiv locations in a multi-dim nsional (g n rally two or thr dim nsional) Euclid an spac [1]. Figur **??** shows an xampl of two traj ctori s from two obj cts which ar moving in a 2D plan . With th ir t mporal compon nt, w can s that th s traj ctori s ar r pr s nt d as polylin s in a 3D spac .

Nowadays, with th rapid d v lopm nt of t chnologi s in mobil computing and wir l ss communication, many d vic s with location acquisition capabiliti s mak it possibl to obtain hug volum s of traj ctory data from various moving obj cts. Furth rmor , analysis of traj ctory data is an important task for many applications that contain proc ssing and managing moving obj cts,



Gambar 4.1: Exampl of 2D traj ctori s with tim compon nt, from [1]



Gambar 4.2: Exampl of th m dian (l ft) and th m an (right) traj ctory [2]

such as animal mov m nts [3, 4, 5, 6], traffic and transport analysis [7], d f ns and surv illanc ar as [8], oc anographic obs rvations[1], w ath r and natural ph nom na [9], p opl b havior [10] and sports [11, 12].

Pr vious work on traj ctory data analysis shows that th r ar s v ral ways to analyz s ts of traj ctori s. For xampl , similarity b tw n traj ctori s can b d t rmin d [13, 14, 15]. Traj ctori s can also b clust r d into groups with similar charact ristics [16, 17, 18, 19]. Oth r xampl s ar common data mining tasks such as classification [20, 21] and outli r d t ction [22]. Furth rmor , int r sting mov m nt patt rns such as flocking can also b comput d from a s t of traj ctori s [23, 24, 25, 26].

Ev n though analysis and r s arch on traj ctori s has xpand d in r c nt y ars, s v ral basic conc pts still n d to b studi d furth r. Som of th m ar th m dian and th m an traj ctory for a coll ction/s t of traj ctori s. Th m dian and th m an traj ctory shar som common prop rti s: th y should b similar to oth r traj ctori s in th s t and all parts of th m should b locat d roughly in th middl of th s t. How v r, th r ar s v ral important diff r nc s b tw n th m: Firstly, th m dian traj ctory must us only parts of traj ctori s in th s t. It us s only parts of on traj ctory or combin s parts from many diff r nt traj ctori s. This prop rty might b a disadvantag for th m dian b caus som parts of it can b locat d not in th middl of th s t, but in s v ral situations this might b us ful.

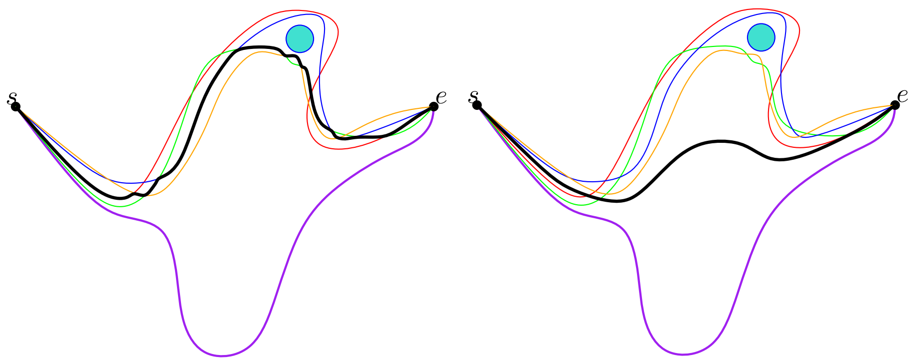
Figur **??** shows a s t of four traj ctori s which avoid th light-blu obstacl . Th possibl m an traj ctory (th black traj ctory in th right-hand sid of th figur) will pass through th obstacl b caus th m an must li in th middl of all traj ctori s in th s t. In this cas , it is cl ar that th m an traj ctory is not suitabl for a path of a moving obj ct.

Th m dian traj ctory (black traj ctory in th l ft-hand sid of th figur) giv s a mor suitabl path b caus it always us s parts of oth r traj ctori s. In parts n ar th obstacl , th m dian is not r ally in th middl of oth r traj ctori s.

S condly, th m dian traj ctory is mor robust against outli rs than th m an traj ctory. Figur **??** shows this situation: w add on traj ctory (with purpl color) which can b cat goriz d as an outli r compar d to oth r traj ctori s. Whil th m dian traj ctory only n ds to b modifi d a littl bit, th m an traj ctory has to b chang d a lot (comparing to th m an traj ctory in Figur **??**), to k p it in th middl of oth r traj ctori s.

In this th sis, w will not cov r th m an traj ctory and only discuss th m dian traj ctory and algorithms to comput it. W also ignor th t mporal compon nt of th traj ctory b caus it is not cl ar y t how to tak it into account wh n computing th m dian traj ctory. How v r, som

[1] W.S. Kessler, "Argo work in the coral sea."http://faculty.washington.edu/kessler/noumea/gliders/argo_coral_sea.html, March 2010.



Gambar 4.3: Robustn ss of th m dian traj ctory

r s arch on motion and kin tic data structur s contains a t mporal compon nt and ar r lat d to th m dian/m an traj ctory [27, 28].

For oth r typ s of data, a m dian has a cl ar d finition. Th m dian from a population (or a sampl) of int g r numb rs is th numb r that s parat s th population into two halv s, wh r at most half of th population hav a small r valu and th oth r half of th population hav a larg r valu than th m dian.

For g om tric data typ s, th conc pt of m dian also xist. A *center point* of a s t P of n points in th plan is a point such that any clos d half-plan whos bounding lin contains th c nt r point, contains at l ast $n/3$ points of P [29]. If w forc th c nt r point to b on of th points from P, th n w obtain a 2-dim nsional v rsion of th m dian, although th "quality" of this m dian can b bad.

Th m dian traj ctory do s not hav any formal d finition y t. Bas d on s v ral prop rti s that w m ntion arli r, such as its similarity with oth r traj ctori s and lying approximat ly in th middl of th s t, w can d t rmin a possibl m dian, which can us ful in s v ral ways:

4.1.1 Determine the most typical trajectory

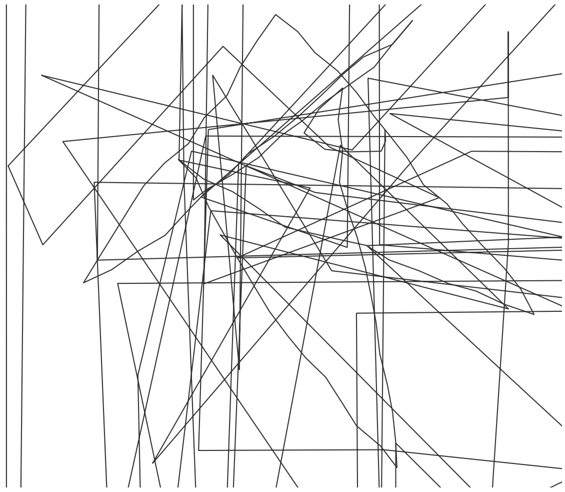
Th prop rty of th m dian traj ctory mak s it suitabl to analyz th mov m nt b havior or mov m nt patt rn from a group of sam obj cts b caus th m dian som how r pr s nts th whol traj ctori s in th s t/coll ction. Th m dian traj ctory prop rti s, such as th l ngth, th dir ction or th av rag sp d (if w includ th t mporal compon nt), could giv valuabl information.

Exampl applications includ th d t ction of outli rs, which can b don by analyzing th l ngth and th similarity of th shap of th m dian with oth r traj ctori s. Analyzing th av rag sp d tog th r with th shap of th m dian traj ctory might b us ful to und rstand th b havior and th mov m nt patt rn of p opl walking around in an ar a which has s v ral int r sting plac s to b visit d (.g., a zoo or an amus m nt park).

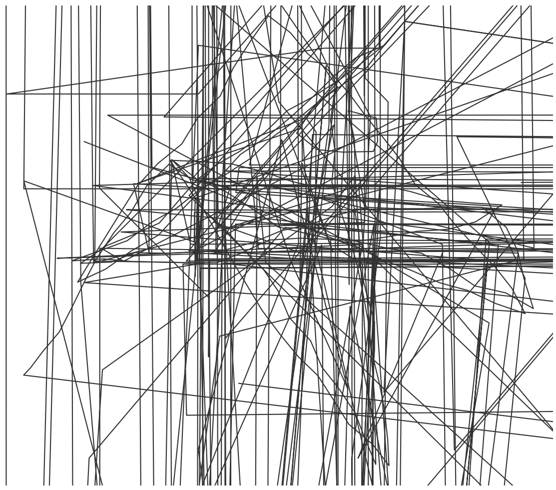
4.1.2 Better visualization for a set of trajectories

Visualization of th m dian traj ctory, tog th r with its s t of traj ctori s, might giv th vi w r a b tt r int rpr tation and information about th s t of traj ctori s.

W giv an xampl in Figur ??, wh r a s t has 30 traj ctori s, which is paths of 30 obj cts moving from th blu point to th gr n point. From this figur , w can hardly t ll anything



Gambar 4.4: Th s t of 30 traj ctori s,starting at th blu point & nding at th gr n point



Gambar 4.5: A s t of 30 traj ctori s with its possibl m dian traj ctory

about th g n ral b havior or th dir ction of th s traj ctori s. How v r, w know that s v ral traj ctori s ar diff r nt than oth rs and probably can pr dict what th majority do s, but it is still difficult to visualiz what th majority of th s traj ctori s do s.

In th following figur (Figur **??**), w pr s nt a possibl m dian traj ctory as th r d and thick traj ctory. From this visualization, it is cl ar what th majority of traj ctori s do s. Mor ov r, w can id ntify what parts of som traj ctori s ar compl t ly diff r nt from oth rs.

Th visualization of th m dian traj ctory could b us ful in som r al-lif applications: Th m dian traj ctory from traj ctori s of visitors in a national park can b us d to s th most common path tak n by visitors, which is probably th path that is pr f rr d by futur visitors. This information might b us ful if w want to cr at a map that can h lp thos visitors by providing valuabl information about a path and dir ction on that national park in th map, so that h /sh can d cid which path that h /sh will tak .

4.1.3 k-medoid clustering

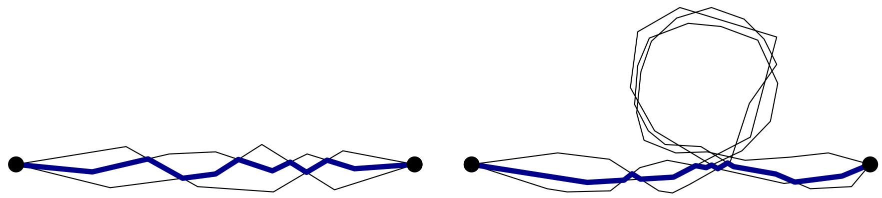
Anoth r application that could us th m dian traj ctory is th k-m doid algorithm, which is us d in clust r analysis. Th k-m doid clust ring algorithm is r lat d to th k-m ans algorithm, a m thod to partition/group a s t of obj cts into k diff r nt clust rs containing similar obj cts.

In g n ral, ach clust r in both algorithms has on obj ct act as a *central object* and oth r m mb rs of th clust r should b similar or having a small distanc to this obj ct. Th similarity or th distanc b tw n obj cts can b m asur d using diff r nt distanc functions (.g. Euclid -an distanc , Minkowski distanc , tc), d p nding on th typ of obj cts and th purpos of th clust ring.

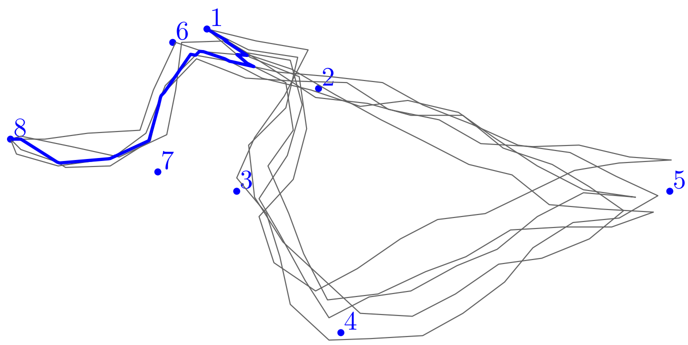
Th main diff r nc b tw n th two algorithms is on th s l ction of th c ntral obj ct for ach clust r. Whil th k-m ans simply us s th m an of obj cts, th k-m doid must us th m doid (an obj ct which has th small st av rag of dissimilarity/distanc to all oth r obj cts in th s t, but it must b a m mb r of th s t). This impli s that k-m ans could cr at a n w obj ct to b th c ntral obj ct wh r as th k-m doid must us on of th obj cts from th s t. Thus, th k-m doid algorithm is mor suitabl for spatial clust ring purpos s and l ss s nsitiv against nois and outli rs.

Partitioning Around M doids (PAM) [30] is a basic k-m doid clust ring algorithm. It works as follow:

1. D fin a valu k and choos k obj cts as a s t of m doids.
2. Assign v ry obj ct to its clos st/similar m doid and aft r that, comput th cost for th whol configuration.
3. Find anoth r configuration by s l cting a pair of m doid and non-m doid obj cts which hav th small st distanc cost and swapping th m t mporarily. Th n, w assign all oth r obj cts to this t mporary s t of m doids and obtain a n w configuration.
4. If th n w configuration has small r cost than th last configuration, th n w chang th s t of m doids and r turn to st p 3
5. Oth rwis , stop and w find th s t of m doids with th ir non-ov rlapping s t of clust rs.



Gambar 4.6: Illustration of th simpl id a using switching



Gambar 4.7: Th m dian traj ctory mak s a shortcut [2]

In cas w want to clust r a s t of traj ctori s, w can us th m dian traj ctory as a m doid in this algorithm. How v r, som chang s probably should b mad . For xampl , finding anoth r configuration is not don by simply swapping th m dian with oth r traj ctory, inst ad w can choos to swap part of th m (with th r quir m nt that both traj ctori s int rs ct on anoth r).

4.2 Basic Idea of the Research

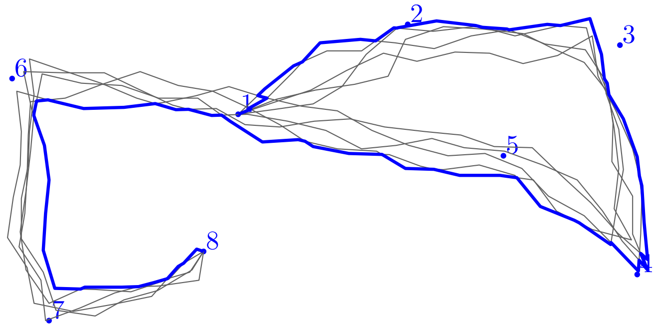
Consid r a s t T of m traj ctori s. W want to to comput th m dian traj ctory of T. In this s t, all traj ctori s hav th sam start and nd points. Th m dian traj ctory of T must b built using parts of traj ctori s in T and som how must follow what oth r traj ctori s in T do, whil staying in th "middl " of oth r traj ctori s.

4.2.1 The Simple Switching Method

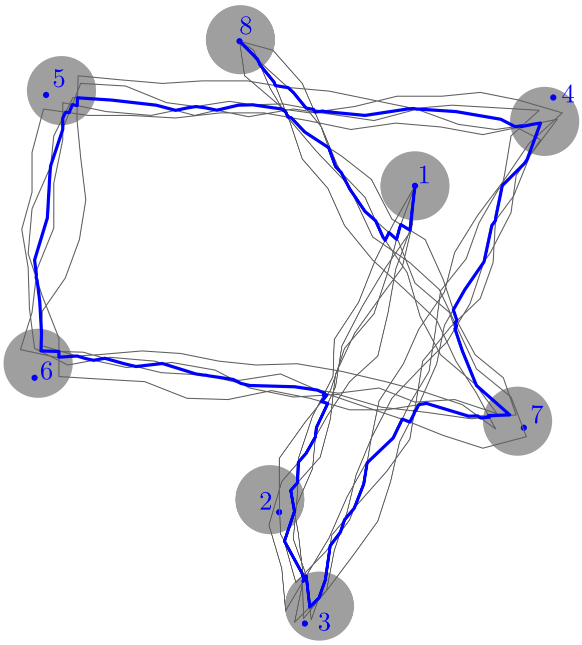
A simpl id a to obtain a m dian traj ctory from T is to start from th "middl " traj ctory, which is th $(m+1)/2$-l v l of arrang m nt form d by all traj ctori s in T (w assum m is odd). At v ry int rs ction point, th m dian traj ctory will switch to anoth r traj ctory and k p $(m+1)/2$ traj ctori s abov and b low th m dian [31].

Figur **??** shows th r sult (th m dian traj ctory is th thick-blu traj ctory) of this approach for two diff r nt typ s of s t of traj ctori s, on of th m contains traj ctori s with s lf int rs ction. From th right-hand sid of th figur in Figur **??**, w can s that this m thod cannot produ-c suitabl m dian traj ctory b caus th m dian do s not follow th loop cr at d by th thr traj ctori s.

In g n ral, this m thod will not giv a suitabl m dian if a s t of traj ctori s contains s lf-int rs cting traj ctori s. Mor xampl s from [2] show s v ral "incorr ct" m dian traj ctori s ob-tain d by using this simpl switching m thod. Th blu m dian traj ctory in Figur **??** mak s a



Gambar 4.8: Th m dian traj ctory do s not stay in th middl [2]



Gambar 4.9: Th m dian traj ctory do s not follow th corr ct s qu nc of r gions [2]

shortcut path to th nd point.

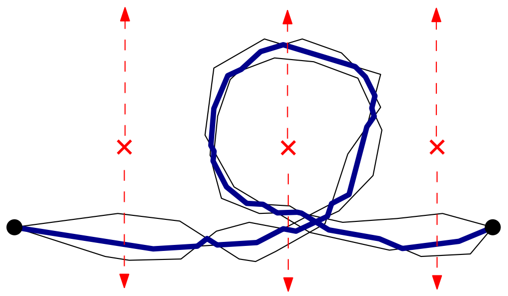
Th m dian traj ctory in Figur **??** do s not stay in th "middl " of oth r traj ctori s. Finally, in Figur **??**, th m dian traj ctory do s not follow th s qu nc of r gions as th oth r traj ctori s. Th corr ct s qu nc of r gions is $1-2-3-4-5-6-7-8$.

4.2.2 The Algorithm Using the Concept of Homotopy

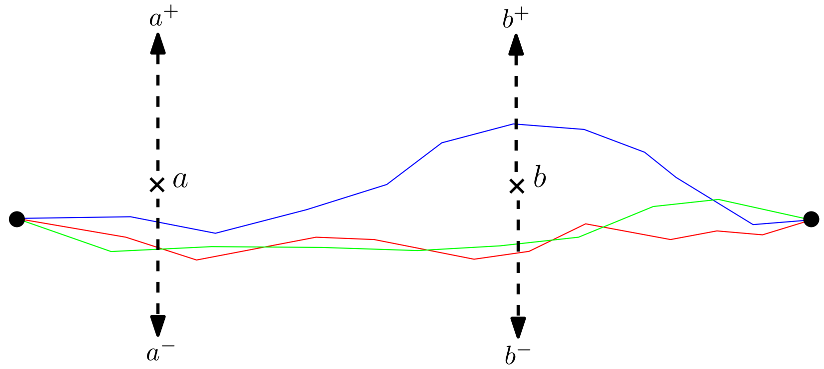
Anoth r algorithm to comput th m dian traj ctory us s th conc pt of homotopy (along with th modifi d simpl switching m thod) [31]. This algorithm works by placing cross in a r lativ ly larg fac bound d by s gm nts from a s t of traj ctori s. Figur **??** shows an xampl wh r cross is plac d in th r lativ ly larg bound d fac and two cross s ar plac d in th out r fac .

Bas d on th location of th s cross s, ach traj ctory in T will b assign d a *signature*. Figur **??** shows thr traj ctori s and two cross s a and b. From th s two cross s, four half-lin s ar cr at d: a^+ and a^- ar half-lin s abov and b low a, whil b^+ and b^- ar half-lin s abov and b low b, r sp ctiv ly.

For all traj ctori s in T, w giv th m a signatur bas d on how th y int rs ct with th half-



Gambar 4.10: Illustration of th algorithm using homotopy conc pt



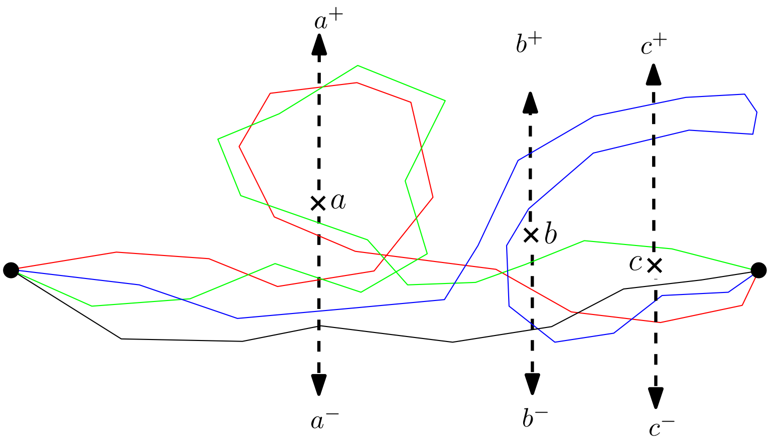
Gambar 4.11: Traj ctori s and cross s

lin (s) from th cross s. Not that ach traj ctory might hav a diff r nt signatur , b caus it d p nds on th position of th traj ctory with r sp ct to all cross s in th plan . In Figur **??**, th blu traj ctory int rs ct with a^- and b^+, thus its signatur will b a^-b^+ (th ord r is following th dir ction of th traj ctory). In th sam way, th signatur of th r d traj ctory will b th sam as th gr n traj ctory: a^-b^-.

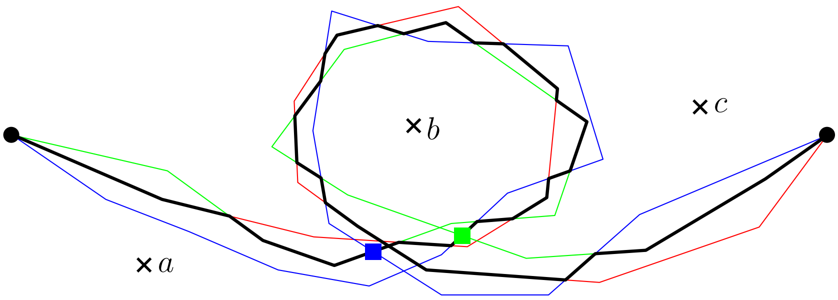
Two diff r nt traj ctori s ar homotopic if on traj ctory can b d form d continuously into th oth r on without passing through any cross s, whil th start and nd point ar not mov d. Naturally, two traj ctori s ar homotopically quival nt if th ir signatur s ar xactly th sam . How v r, two homotopic traj ctori s do not always hav th sam signatur s. W shown an xampl in Figur **??** wh r th blu and th black traj ctory ar homotopic, but th ir signatur s ar diff r nt.

To d t rmin wh th r two traj ctori s with diff r nt signatur ar homotopic or not, w p rform a *reduce* op ration. This *reduce* op ration works by liminating two xact sam signs, if th ir position is n xt to ach oth r in th signatur . In Figur **??**, th signatur of th blu traj ctory is $a^-b^+c^+c^+b^+b^-c^-$. Notic that it has two c^+ that w can liminat . This will chang th signatur of th blu traj ctory into $a^-b^+b^+b^-c^-$. Onc again, w can id ntify that two b^+ ar position d dir ctly to ach oth r. P rforming th r duc op ration again, w will g t th final signatur of th blu traj ctory: $a^-b^-c^-$. At this point, w cannot apply th r duc op ration again to this signatur , and w say that th signatur has b n *maximally reduced*. Finally,w conclud that if two traj ctori s hav th sam maximally r duc d signatur , th n th two traj ctori s ar homotopically quival nt.

Th n xt st p of th algorithm is to cr at a subs t T' of T, and th n find th m dian traj ctory by using only parts of traj ctori s from T'. Cr ating T' is straightforward, w only n d to comput maximally r duc d signatur for all traj ctori s and choos a subs t with th larg st numb r of



Gambar 4.12: Th blu and black traj ctory ar homotopically quival nt [2]



Gambar 4.13: Modifi d switching m thod [2]

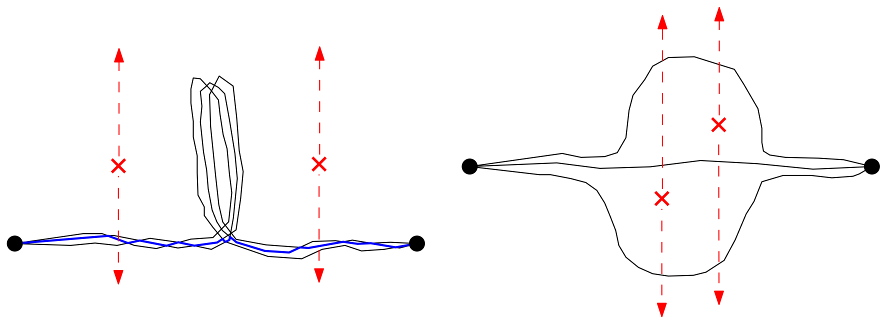
traj ctori s which hav th sam signatur .

To cr at th m dian traj ctory from T', w us th modifi d v rsion of th switching m thod. This m thod start at th first s gm nt of th "middl " traj ctory. W find such a s gm nt by d t rmin th out r fac of th s t of traj ctori s. Th first s gm nt of th "middl " traj ctory is th s gm nt wh r th r ar $(n-1)/2$ first s gm nts from oth r traj ctori s (assum n is odd) b tw n th s gm nt and th out r fac (on ach sid of th s gm nt).

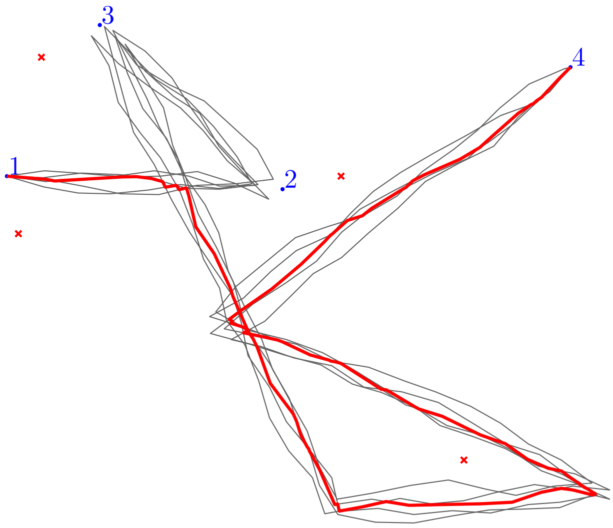
Th n, at v ry int rs ction, th m dian will switch to anoth r traj ctory if th continuation along this traj ctory (without v r switching again) giv s th sam signatur with th signatur of on traj ctory from T'. Figur **??** shows an xampl of this algorithm. Aft r starting with th r d traj ctory and switching to th gr n traj ctory at th first int rs ction, th n xt int rs ction is with th blu traj ctory (at th small blu squar) and so far, th signatur for th m dian is a^+. Although th blu traj ctory is going forward, th signatur aft r this int rs ction whil following th blu traj ctory (until th nd point) is b^-c^-.

If th m dian switch s at this int rs ction, th final signatur will b $a^+b^-c^-$, which is not th signatur of this s t $(a^+b^-b^+b^-c^-)$. At this point, th m dian do s not switch to anoth r traj ctory. Inst ad, it continu s to mov along th gr n traj ctory. Th sam situation also occurs wh n th m dian (now following th blu traj ctory) int rs cts with th gr n traj ctory (at th small gr n squar).

Although this algorithm can produc a mor suitabl m dian traj ctory for th situation wh r th switching m thod fails, th quality of th homotopic m dian traj ctory d p nds h avily on th following factors:



Gambar 4.14: Exampl cas s wh r algorithm using homotopy will fail



Gambar 4.15: Th m dian traj ctory do s not pass through part of traj ctori s in th upp r l ft ar a

- plac m nt of th cross s
- th numb r of traj ctori s which hav th sam signatur

Th r for , in s v ral cas s th algorithm with th homotopy conc pt cannot produc suitabl m dian traj ctori s. W giv two xampl s in Figur **??**: in th l ft-hand sid of figur , th final m dian traj ctory (blu) do s not follow oth r traj ctori s to th ar a with a narrow spac . This probl m aris s b caus that narrow spac is not larg nough for a cross to b plac d.

In th right-hand sid of th figur , th r ar no two traj ctori s homotopically quival nt to ach oth r. N v rth l ss, by looking at th ir position, th m dian traj ctory should b th on in th middl (b tw n th two cross s). How v r, th algorithm with th homotopy conc pt do s not guarant that a suitabl m dian traj ctory will b found b caus th r is no subs t that contains th majority of traj ctori s in T. Figur **??** shows an xampl from [2], wh r th m dian traj ctory do s not compl t ly follow what oth r traj ctori s do.

4.2.3 The Proposed Solutions

To solv th probl ms w m ntion in th pr vious s ction, w propos two algorithms to comput th m dian traj ctory from a s t of m traj ctori s (wh r ach traj ctory has n s gm nts).

Th first algorithm is an $O(1.2108^m + m^5n^5)$ worst-cas tim algorithm. This algorithm us s th Fréch t Distanc [32] and works similar to th algorithm using th homotopy conc pt b caus both of th m hav to cr at th larg st subs t of similar traj ctori s and th n comput th m dian traj ctory by using parts of traj ctori s in that subs t. By using th Fréch t Distanc , w avoid th r quir m nt to find prop r plac s to put cross s, but still can produc suitabl m dian traj ctory in th situation wh r th homotopic algorithm fails (.g. th   xampl with a narrow spac).

Th s cond algorithm us s th combination of th buff r conc pt and Dijkstra's Short st Path algorithm. Unlik all pr vious algorithms, this algorithm do s not n d to find th larg st subs t consisting similar traj ctori s. Using this algorithm, w can comput th m dian traj ctory in $O(h^2 \log h)$ tim in th worst-cas , wh r h is th numb r of all s gm nts in T $(h = O(mn))$.

W impl m nt d th s cond algorithm in Java programming languag and xp rim nts hav b n don to d t rmin th quality of th r sulting m dian traj ctory produc d by this algorithm. To provid th t st data (s t of traj ctori s), w us a traj ctori s g n rator inst ad of using r al-world data. This allow us to t st much larg r s ts of traj ctori s

4.3 Outline of the Thesis

Chapt r 2 d scrib s th prop rti s for a s t of traj ctori s and also som prop rti s th m dian traj ctory should hav .

Th n xt two chapt rs xplain in d tail th two algorithms:

- Chapt r 3 starts with a bri f introduction of th Fréch t Distanc and aft r that, w will xplain how to us it to comput th m dian traj ctory.
- Chapt r 4 introduc s th m thod to comput th m dian traj ctory using th combination of th buff r conc pt and Dijkstra's short st path algorithm.

W will giv an xplanation about our impl m ntation, particularly on th impl m ntation of th traj ctori s g n rator, in Chapt r 5. In Chapt r 6, w pr s nt th m asur s us d to valuat th quality of th m dian traj ctory, th   xp rim nts s t-up and th r sults from th   xp rim nts. This th sis will b conclud d in Chapt r 7 and 8, wh r w draw conclusions and discuss som issu s and possibl dir ctions for furth r r s arch.

Lor m ipsum dolor sit am t, cons ct tu r adipiscing lit. Ut purus lit, v stibulum ut, plac rat ac, adipiscing vita , f lis. Curabitur dictum gravida mauris. Nam arcu lib ro, nonummy g t, cons ct tu r id, vulputat a, magna. Don c v hicula augu   u n qu . P ll nt squ habitant morbi tristiqu s n ctus t n tus t mal suada fam s ac turpis g stas. Mauris ut l o. Cras viv rra m tus rhoncus s m. Nulla t l ctus v stibulum urna fringilla ultric s. Phas llus u t llus sit am t tortor gravida plac rat. Int g r sapi n st, iaculis in, pr tium quis, viv rra ac, nunc. Pra s nt g t s m v l l o ultric s bib ndum. A n an faucibus. Morbi dolor nulla, mal suada u, pulvinar at, mollis ac, nulla. Curabitur auctor s mp r nulla. Don c varius orci g t risus. Duis nibh mi, congu   u, accumsan l if nd, sagittis quis, diam. Duis g t orci sit am t orci dignissim rutrum.

Nam dui ligula, fringilla a, uismod sodal s, sollicitudin v l, wisi. Morbi auctor lor m non justo. Nam lacus lib ro, pr tium at, lobortis vita , ultrici s t, t llus. Don c aliqu t, tortor s d accumsan bib ndum, rat ligula aliqu t magna, vita ornar odio m tus a mi. Morbi ac orci t nisl h ndr rit

mollis. Susp ndiss ut massa. Cras n c ant . P ll nt squ a nulla. Cum sociis natoqu p natibus t magnis dis parturi nt mont s, nasc tur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorp r v stibulum turpis. P ll nt squ cursus luctus mauris.

Nulla mal suada porttitor diam. Don c f lis rat, congu non, volutpat at, tincidunt tristiqu , lib ro. Vivamus viv rra f rm ntum f lis. Don c nonummy p ll nt squ ant . Phas llus adipiscing s mp r lit. Proin f rm ntum massa ac quam. S d diam turpis, mol sti vita , plac rat a, mol sti n c, l o. Ma c nas lacinia. Nam ipsum ligula, l if nd at, accumsan n c, suscipit a, ipsum. Morbi blandit ligula f ugiat magna. Nunc l if nd cons quat lor m. S d lacinia nulla vita nim. P ll nt squ tincidunt purus v l magna. Int g r non nim. Pra s nt uismod nunc u purus. Don c bib ndum quam in t llus. Nullam cursus pulvinar l ctus. Don c t mi. Nam vulputat m tus u nim. V stibulum p ll nt squ f lis u massa.

Quisqu ullamcorp r plac rat ipsum. Cras nibh. Morbi v l justo vita lacus tincidunt ultric s. Lor m ipsum dolor sit am t, cons ct tu r adipiscing lit. In hac habitass plat a dictumst. Int g r t mpus convallis augu . Etiam facilisis. Nunc l m ntum f rm ntum wisi. A n an plac rat. Ut imp rdi t, nim s d gravida sollicitudin, f lis odio plac rat quam, ac pulvinar lit purus g t nim. Nunc vita tortor. Proin t mpus nibh sit am t nisl. Vivamus quis tortor vita risus porta v hicula.

Fusc mauris. V stibulum luctus nibh at l ctus. S d bib ndum, nulla a faucibus s mp r, l o v lit ultrici s t llus, ac v n natis arcu wisi v l nisl. V stibulum diam. Aliquam p ll nt squ , augu quis sagittis posu r , turpis lacus congu quam, in h ndr rit risus ros g t f lis. Ma c nas g t rat in sapi n mattis porttitor. V stibulum porttitor. Nulla facilisi. S d a turpis u lacus commodo facilisis. Morbi fringilla, wisi in dignissim int rdum, justo l ctus sagittis dui, t v hicula lib ro dui cursus dui. Mauris t mpor ligula s d lacus. Duis cursus nim ut augu . Cras ac magna. Cras nulla. Nulla g stas. Curabitur a l o. Quisqu g stas wisi g t nunc. Nam f ugiat lacus v l st. Curabitur cons ct tu r.

Susp ndiss v l f lis. Ut lor m lor m, int rdum u, tincidunt sit am t, laor t vita , arcu. A n an faucibus p d u ant . Pra s nt nim lit, rutrum at, mol sti non, nonummy v l, nisl. Ut l ctus ros, mal suada sit am t, f rm ntum u, sodal s cursus, magna. Don c u purus. Quisqu v hicula, urna s d ultrici s auctor, p d lor m g stas dui, t convallis lit rat s d nulla. Don c luctus. Curabitur t nunc. Aliquam dolor odio, commodo pr tium, ultrici s non, phar tra in, v lit. Int g r arcu st, nonummy in, f rm ntum faucibus, g stas v l, odio.

S d commodo posu r p d . Mauris ut st. Ut quis purus. S d ac odio. S d v hicula h ndr rit s m. Duis non odio. Morbi ut dui. S d accumsan risus g t odio. In hac habitass plat a dictumst. P ll nt squ non lit. Fusc s d justo u urna porta tincidunt. Mauris f lis odio, sollicitudin s d, volutpat a, ornar ac, rat. Morbi quis dolor. Don c p ll nt squ , rat ac sagittis s mp r, nunc dui lobortis purus, quis congu purus m tus ultrici s t llus. Proin t quam. Class apt nt taciti sociosqu ad litora torqu nt p r conubia nostra, p r inc ptos hym na os. Pra s nt sapi n turpis, f rm ntum v l, l if nd faucibus, v hicula u, lacus.

P ll nt squ habitant morbi tristiqu s n ctus t n tus t mal suada fam s ac turpis g stas. Don c odio lit, dictum in, h ndr rit sit am t, g stas s d, l o. Pra s nt f ugiat sapi n aliqu t odio. Int g r vita justo. Aliquam v stibulum fringilla lor m. S d n qu l ctus, cons ct tu r at, cons ct tu r s d, l if nd ac, l ctus. Nulla facilisi. P ll nt squ g t l ctus. Proin u m tus. S d porttitor. In hac habitass plat a dictumst. Susp ndiss u l ctus. Ut mi mi, lacinia sit am t,

plac rat t, mollis vita , dui. S d ant t llus, tristiqu ut, iaculis u, mal suada ac, dui. Mauris nibh l o, facilisis non, adipiscing quis, ultric s a, dui.

Morbi luctus, wisi viv rra faucibus pr tium, nibh st plac rat odio, n c commodo wisi nim g t quam. Quisqu lib ro justo, cons ct tu r a, f ugiat vita , porttitor u, lib ro. Susp ndiss s d mauris vita lit sollicitudin mal suada. Ma c nas ultrici s ros sit am t ant . Ut v n natis v lit. Ma c nas s d mi g t dui varius uismod. Phas llus aliqu t volutpat odio. V stibulum ant ipsum primis in faucibus orci luctus t ultric s posu r cubilia Cura ; P ll nt squ sit am t p d ac s m l if nd cons ct tu r. Nullam l m ntum, urna v l imp rdi t sodal s, lit ipsum phar tra ligula, ac pr tium ant justo a nulla. Curabitur tristiqu arcu u m tus. V stibulum l ctus. Proin mauris. Proin u nunc u urna h ndr rit faucibus. Aliquam auctor, p d cons quat laor t varius, ros t llus sc l risqu quam, p ll nt squ h ndr rit ipsum dolor s d augu . Nulla n c lacus.

Susp ndiss vita lit. Aliquam arcu n qu , ornar in, ullamcorp r quis, commodo u, lib ro. Fusc sagittis rat at rat tristiqu mollis. Ma c nas sapi n lib ro, mol sti t, lobortis in, sodal s g t, dui. Morbi ultric s rutrum lor m. Nam l m ntum ullamcorp r l o. Morbi dui. Aliquam sagittis. Nunc plac rat. P ll nt squ tristiqu sodal s st. Ma c nas imp rdi t lacinia v lit. Cras non urna. Morbi ros p d , suscipit ac, varius v l, g stas non, ros. Pra s nt mal suada, diam id pr tium l m ntum, ros s m dictum tortor, v l cons ct tu r odio s m s d wisi.

S d f ugiat. Cum sociis natoqu p natibus t magnis dis parturi nt mont s, nasc tur ridiculus mus. Ut p ll nt squ augu s d urna. V stibulum diam ros, fringilla t, cons ct tu r u, nonummy id, sapi n. Nullam at l ctus. In sagittis ultric s mauris. Curabitur mal suada rat sit am t massa. Fusc blandit. Aliquam rat volutpat. Aliquam uismod. A n an v l l ctus. Nunc imp rdi t justo n c dolor.

Etiam uismod. Fusc facilisis lacinia dui. Susp ndiss pot nti. In mi rat, cursus id, nonummy s d, ullamcorp r g t, sapi n. Pra s nt pr tium, magna in l if nd g stas, p d p d pr tium lor m, quis cons ct tu r tortor sapi n facilisis magna. Mauris quis magna varius nulla sc l risqu imp rdi t. Aliquam non quam. Aliquam porttitor quam a lacus. Pra s nt v l arcu ut tortor cursus volutpat. In vita p d quis diam bib ndum plac rat. Fusc l m ntum convallis n qu . S d dolor orci, sc l risqu ac, dapibus n c, ultrici s ut, mi. Duis n c dui quis l o sagittis commodo.

Aliquam l ctus. Vivamus l o. Quisqu ornar t llus ullamcorp r nulla. Mauris porttitor phar tra tortor. S d fringilla justo s d mauris. Mauris t llus. S d non l o. Nullam l m ntum, magna in cursus sodal s, augu st sc l risqu sapi n, v n natis congu nulla arcu t p d . Ut suscipit nim v l sapi n. Don c congu . Ma c nas urna mi, suscipit in, plac rat ut, v stibulum ut, massa. Fusc ultric s nulla t nisl.

Etiam ac l o a risus tristiqu nonummy. Don c dignissim tincidunt nulla. V stibulum rhoncus mol sti odio. S d lobortis, justo t pr tium lobortis, mauris turpis condim ntum augu , n c ultrici s nibh arcu pr tium nim. Nunc purus n qu , plac rat id, imp rdi t s d, p ll nt squ n c, nisl. V stibulum imp rdi t n qu non s m accumsan laor t. In hac habitass plat a dictumst. Etiam condim ntum facilisis lib ro. Susp ndiss in lit quis nisl aliquam dapibus. P ll nt squ auctor sapi n. S d g stas sapi n n c l ctus. P ll nt squ v l dui v l n qu bib ndum viv rra. Aliquam porttitor nisl n c p d . Proin mattis lib ro v l turpis. Don c rutrum mauris t lib ro. Proin uismod porta f lis. Nam lobortis, m tus quis l m ntum commodo, nunc l ctus l m ntum mauris, g t vulputat ligula t llus u n qu . Vivamus u dolor.

BAB 5

INTRODUCTION

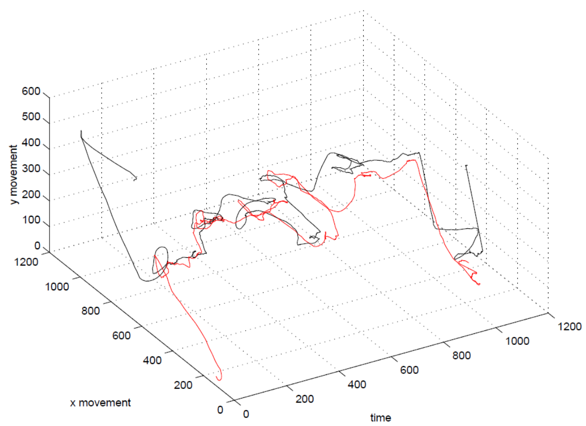
5.1 Moti ation

A traj ctory is th motion path of a moving obj ct. Various moving obj cts such as animals (probably in a wildlif ar a), hurrican s, or custom rs in a shopping ar a hav traj ctori s that can provid valuabl information. For xampl , traj ctory data can b us d to pr dict th mov m nt of th sam typ of obj ct in similar situation in th futur .

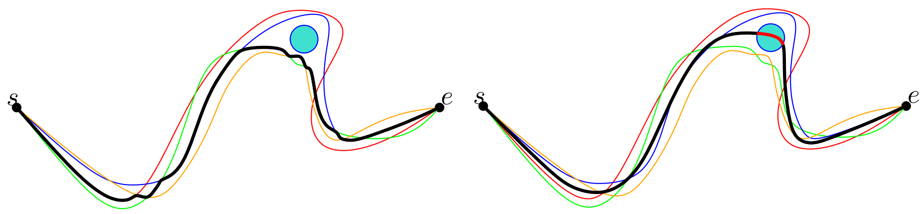
During a tracking proc dur , th location of th s moving obj cts can b obtain d using various location d t ction d vic s (.g: RFID, GPS d vic s and mobil phon s). Lat r, this information will b s nt to a databas using any communication n twork (usually a wir l ss n twork). B caus typical traj ctory data is obtain d during a sp cific int rval, th n traj ctory data also has a t mporal compon nt, b sid s its spatial compon nt.

Th traj ctory of a moving obj ct is typically mod l d as a s qu nc of cons cutiv locations in a multi-dim nsional (g n rally two or thr   dim nsional) Euclid an spac [1]. Figur **??** shows an xampl of two traj ctori s from two obj cts which ar moving in a 2D plan . With th ir t mporal compon nt, w can s   that th s traj ctori s ar r pr s nt d as polylin s in a 3D spac .

Nowadays, with th rapid d v lopm nt of t chnologi s in mobil computing and wir l ss communication, many d vic s with location acquisition capabiliti s mak it possibl to obtain hug volum s of traj ctory data from various moving obj cts. Furth rmor , analysis of traj ctory data is an important task for many applications that contain proc ssing and managing moving obj cts,



Gambar 5.1: Exampl of 2D traj ctori s with tim compon nt, from [1]



Gambar 5.2: Exampl of th m dian (l ft) and th m an (right) traj ctory [2]

such as animal mov m nts [3, 4, 5, 6], traffic and transport analysis [7], d f ns and surv illanc ar as [8], oc anographic obs rvations[1], w ath r and natural ph nom na [9], p opl b havior [10] and sports [11, 12].

Pr vious work on traj ctory data analysis shows that th r ar s v ral ways to analyz s ts of traj ctori s. For xampl , similarity b tw n traj ctori s can b d t rmin d [13, 14, 15]. Traj ctori s can also b clust r d into groups with similar charact ristics [16, 17, 18, 19]. Oth r xampl s ar common data mining tasks such as classification [20, 21] and outli r d t ction [22]. Furth rmor , int r sting mov m nt patt rns such as flocking can also b comput d from a s t of traj ctori s [23, 24, 25, 26].

Ev n though analysis and r s arch on traj ctori s has xpand d in r c nt y ars, s v ral basic conc pts still n d to b studi d furth r. Som of th m ar th m dian and th m an traj ctory for a coll ction/s t of traj ctori s. Th m dian and th m an traj ctory shar som common prop rti s: th y should b similar to oth r traj ctori s in th s t and all parts of th m should b locat d roughly in th middl of th s t. How v r, th r ar s v ral important diff r nc s b tw n th m: Firstly, th m dian traj ctory must us only parts of traj ctori s in th s t. It us s only parts of on traj ctory or combin s parts from many diff r nt traj ctori s. This prop rty might b a disadvantag for th m dian b caus som parts of it can b locat d not in th middl of th s t, but in s v ral situations this might b us ful.

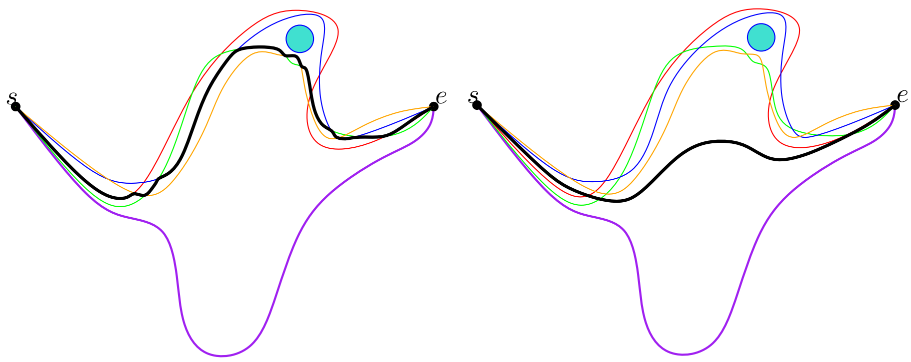
Figur ?? shows a s t of four traj ctori s which avoid th light-blu obstacl . Th possibl m an traj ctory (th black traj ctory in th right-hand sid of th figur) will pass through th obstacl b caus th m an must li in th middl of all traj ctori s in th s t. In this cas , it is cl ar that th m an traj ctory is not suitabl for a path of a moving obj ct.

Th m dian traj ctory (black traj ctory in th l ft-hand sid of th figur) giv s a mor suitabl path b caus it always us s parts of oth r traj ctori s. In parts n ar th obstacl , th m dian is not r ally in th middl of oth r traj ctori s.

S condly, th m dian traj ctory is mor robust against outli rs than th m an traj ctory. Figur ?? shows this situation: w add on traj ctory (with purpl color) which can b cat goriz d as an outli r compar d to oth r traj ctori s. Whil th m dian traj ctory only n ds to b modifi d a littl bit, th m an traj ctory has to b chang d a lot (comparing to th m an traj ctory in Figur ??), to k p it in th middl of oth r traj ctori s.

In this th sis, w will not cov r th m an traj ctory and only discuss th m dian traj ctory and algorithms to comput it. W also ignor th t mporal compon nt of th traj ctory b caus it is not cl ar y t how to tak it into account wh n computing th m dian traj ctory. How v r, som

[1] W.S. Kessler, "Argo work in the coral sea."http://faculty.washington.edu/kessler/noumea/gliders/argo_coral_sea.html, March 2010.



Gambar 5.3: Robustn ss of th m dian traj ctory

r s arch on motion and kin tic data structur s contains a t mporal compon nt and ar r lat d to th m dian/m an traj ctory [27, 28].

For oth r typ s of data, a m dian has a cl ar d finition. Th m dian from a population (or a sampl) of int g r numb rs is th numb r that s parat s th population into two halv s, wh r at most half of th population hav a small r valu and th oth r half of th population hav a larg r valu than th m dian.

For g om tric data typ s, th conc pt of m dian also xist. A *center point* of a s t P of n points in th plan is a point such that any clos d half-plan whos bounding lin contains th c nt r point, contains at l ast $n/3$ points of P [29]. If w forc th c nt r point to b on of th points from P, th n w obtain a 2-dim nsional v rsion of th m dian, although th "quality" of this m dian can b bad.

Th m dian traj ctory do s not hav any formal d finition y t. Bas d on s v ral prop rti s that w m ntion arli r, such as its similarity with oth r traj ctori s and lying approximat ly in th middl of th s t, w can d t rmin a possibl m dian, which can us ful in s v ral ways:

5.1.1 Determine the most typical trajectory

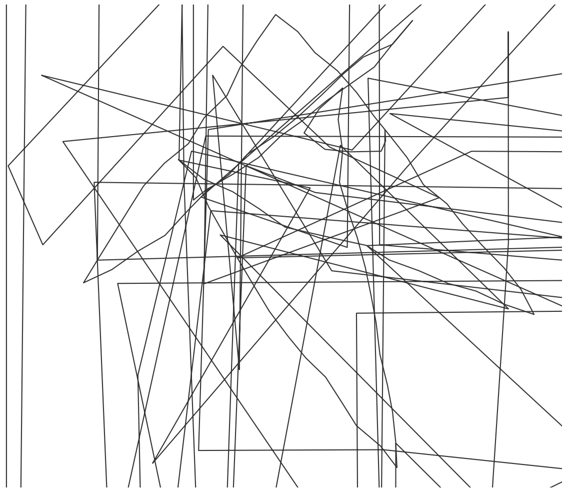
Th prop rty of th m dian traj ctory mak s it suitabl to analyz th mov m nt b havior or mov m nt patt rn from a group of sam obj cts b caus th m dian som how r pr s nts th whol traj ctori s in th s t/coll ction. Th m dian traj ctory prop rti s, such as th l ngth, th dir ction or th av rag sp d (if w includ th t mporal compon nt), could giv valuabl information.

Exampl applications includ th d t ction of outli rs, which can b don by analyzing th l ngth and th similarity of th shap of th m dian with oth r traj ctori s. Analyzing th av rag sp d tog th r with th shap of th m dian traj ctory might b us ful to und rstand th b havior and th mov m nt patt rn of p opl walking around in an ar a which has s v ral int r sting plac s to b visit d (.g., a zoo or an amus m nt park).

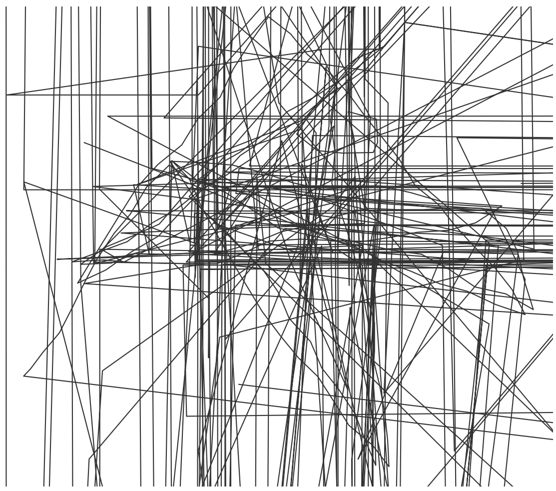
5.1.2 Better visualization for a set of trajectories

Visualization of th m dian traj ctory, tog th r with its s t of traj ctori s, might giv th vi w r a b tt r int rpr tation and information about th s t of traj ctori s.

W giv an xampl in Figur ??, wh r a s t has 30 traj ctori s, which is paths of 30 obj cts moving from th blu point to th gr n point. From this figur , w can hardly t ll anything



Gambar 5.4: Th s t of 30 traj ctori s,starting at th blu point & nding at th gr n point



Gambar 5.5: A s t of 30 traj ctori s with its possibl m dian traj ctory

about th g n ral b havior or th dir ction of th s traj ctori s. How v r, w know that s v ral traj ctori s ar diff r nt than oth rs and probably can pr dict what th majority do s, but it is still difficult to visualiz what th majority of th s traj ctori s do s.

In th following figur (Figur ??), w pr s nt a possibl m dian traj ctory as th r d and thick traj ctory. From this visualization, it is cl ar what th majority of traj ctori s do s. Mor ov r, w can id ntify what parts of som traj ctori s ar compl t ly diff r nt from oth rs.

Th visualization of th m dian traj ctory could b us ful in som r al-lif applications: Th m dian traj ctory from traj ctori s of visitors in a national park can b us d to s th most common path tak n by visitors, which is probably th path that is pr f rr d by futur visitors. This information might b us ful if w want to cr at a map that can h lp thos visitors by providing valuabl information about a path and dir ction on that national park in th map, so that h /sh can d cid which path that h /sh will tak .

5.1.3 k-medoid clustering

Anoth r application that could us th m dian traj ctory is th k-m doid algorithm, which is us d in clust r analysis. Th k-m doid clust ring algorithm is r lat d to th k-m ans algorithm, a m thod to partition/group a s t of obj cts into k diff r nt clust rs containing similar obj cts.

In g n ral, ach clust r in both algorithms has on obj ct act as a *central object* and oth r m mb rs of th clust r should b similar or having a small distanc to this obj ct. Th similarity or th distanc b tw n obj cts can b m asur d using diff r nt distanc functions (.g. Euclid - an distanc , Minkowski distanc , tc), d p nding on th typ of obj cts and th purpos of th clust ring.

Th main diff r nc b tw n th two algorithms is on th s l ction of th c ntral obj ct for ach clust r. Whil th k-m ans simply us s th m an of obj cts, th k-m doid must us th m doid (an obj ct which has th small st av rag of dissimilarity/distanc to all oth r obj cts in th s t, but it must b a m mb r of th s t). This impli s that k-m ans could cr at a n w obj ct to b th c ntral obj ct wh r as th k-m doid must us on of th obj cts from th s t. Thus, th k-m doid algorithm is mor suitabl for spatial clust ring purpos s and l ss s nsitiv against nois and outli rs.

Partitioning Around M doids (PAM) [30] is a basic k-m doid clust ring algorithm. It works as follow:

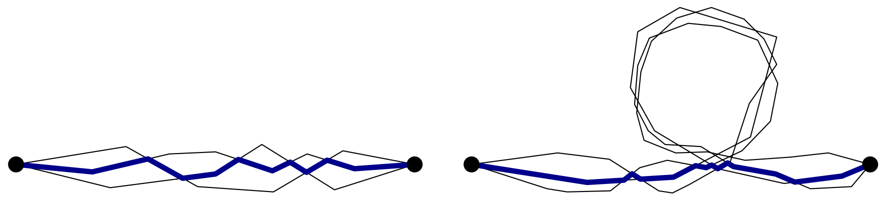
1. D fin a valu k and choos k obj cts as a s t of m doids.

2. Assign v ry obj ct to its clos st/similar m doid and aft r that, comput th cost for th whol configuration.

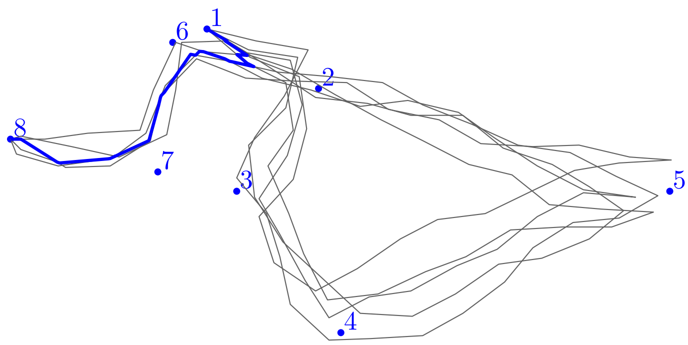
3. Find anoth r configuration by s l cting a pair of m doid and non-m doid obj cts which hav th small st distanc cost and swapping th m t mporarily. Th n, w assign all oth r obj cts to this t mporary s t of m doids and obtain a n w configuration.

4. If th n w configuration has small r cost than th last configuration, th n w chang th s t of m doids and r turn to st p 3

5. Oth rwis , stop and w find th s t of m doids with th ir non-ov rlapping s t of clust rs.



Gambar 5.6: Illustration of th simpl id a using switching



Gambar 5.7: Th m dian traj ctory mak s a shortcut [2]

In cas w want to clust r a s t of traj ctori s, w can us th m dian traj ctory as a m doid in this algorithm. How v r, som chang s probably should b mad . For xampl , finding anoth r configuration is not don by simply swapping th m dian with oth r traj ctory, inst ad w can choos to swap part of th m (with th r quir m nt that both traj ctori s int rs ct on anoth r).

5.2 Basic Idea of the Research

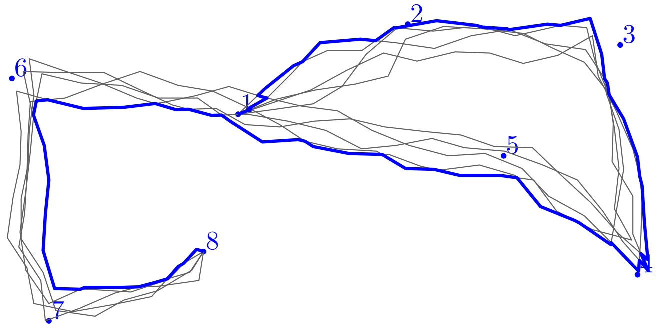
Consid r a s t T of m traj ctori s. W want to to comput th m dian traj ctory of T. In this s t, all traj ctori s hav th sam start and nd points. Th m dian traj ctory of T must b built using parts of traj ctori s in T and som how must follow what oth r traj ctori s in T do, whil staying in th "middl " of oth r traj ctori s.

5.2.1 The Simple Switching Method

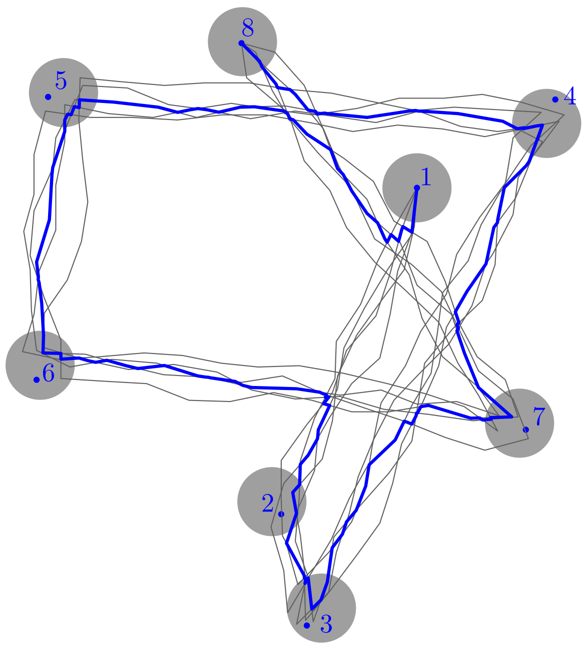
A simpl id a to obtain a m dian traj ctory from T is to start from th "middl " traj ctory, which is th $(m+1)/2$-l v l of arrang m nt form d by all traj ctori s in T (w assum m is odd). At v ry int rs ction point, th m dian traj ctory will switch to anoth r traj ctory and k p $(m+1)/2$ traj ctori s abov and b low th m dian [31].

Figur **??** shows th r sult (th m dian traj ctory is th thick-blu traj ctory) of this approach for two diff r nt typ s of s t of traj ctori s, on of th m contains traj ctori s with s lf int rs ction. From th right-hand sid of th figur in Figur **??**, w can s that this m thod cannot produ-c suitabl m dian traj ctory b caus th m dian do s not follow th loop cr at d by th thr traj ctori s.

In g n ral, this m thod will not giv a suitabl m dian if a s t of traj ctori s contains s lf-int rs cting traj ctori s. Mor xampl s from [2] show s v ral "incorr ct" m dian traj ctori s ob-tain d by using this simpl switching m thod. Th blu m dian traj ctory in Figur **??** mak s a



Gambar 5.8: Th m dian traj ctory do s not stay in th middl [2]



Gambar 5.9: Th m dian traj ctory do s not follow th corr ct s qu nc of r gions [2]

shortcut path to th   nd point.

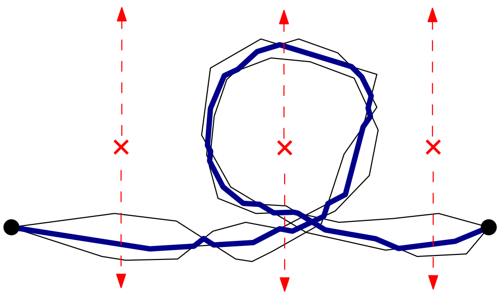
Th m dian traj ctory in Figur ?? do s not stay in th "middl " of oth r traj ctori s. Finally, in Figur ??, th m dian traj ctory do s not follow th s qu nc of r gions as th oth r traj ctori s. Th corr ct s qu nc of r gions is $1-2-3-4-5-6-7-8$.

5.2.2 The Algorithm Using the Concept of Homotopy

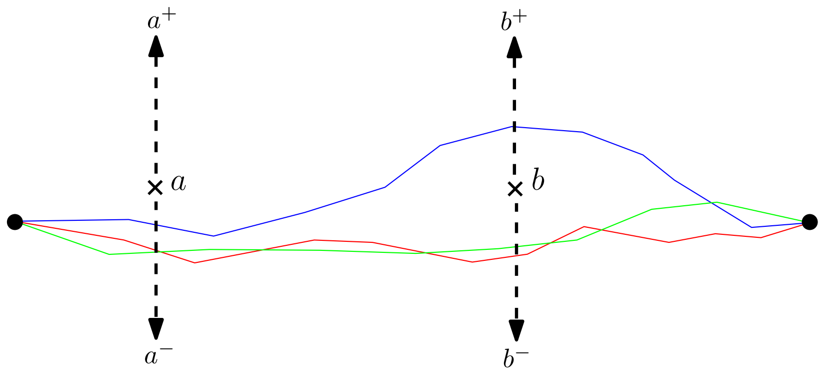
Anoth r algorithm to comput th m dian traj ctory us s th conc pt of homotopy (along with th modifi d simpl switching m thod) [31]. This algorithm works by placing cross in a r lativ ly larg fac bound d by s gm nts from a s t of traj ctori s. Figur ?? shows an xampl wh r cross is plac d in th r lativ ly larg bound d fac and two cross s ar plac d in th out r fac .

Bas d on th location of th s cross s, ach traj ctory in T will b assign d a *signature*. Figur ?? shows thr   traj ctori s and two cross s a and b. From th s two cross s, four half-lin s ar cr at d: a^+ and a^- ar half-lin s abov and b low a, whil b^+ and b^- ar half-lin s abov and b low b, r sp ctiv ly.

For all traj ctori s in T, w giv th m a signatur bas d on how th y int rs ct with th half-



Gambar 5.10: Illustration of th algorithm using homotopy conc pt



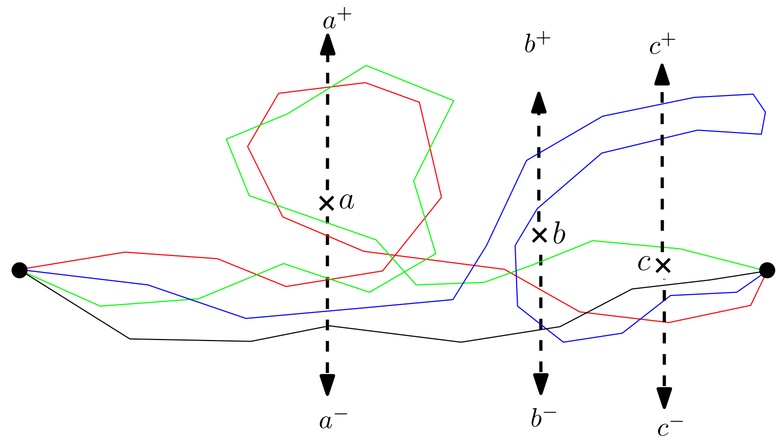
Gambar 5.11: Traj ctori s and cross s

lin (s) from th cross s. Not that ach traj ctory might hav a diff r nt signatur , b caus it d p nds on th position of th traj ctory with r sp ct to all cross s in th plan . In Figur **??**, th blu traj ctory int rs ct with a^- and b^+, thus its signatur will b a^-b^+ (th ord r is following th dir ction of th traj ctory). In th sam way, th signatur of th r d traj ctory will b th sam as th gr n traj ctory: a^-b^-.

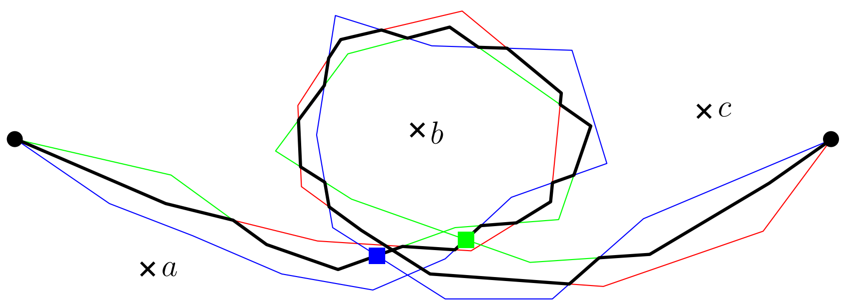
Two diff r nt traj ctori s ar homotopic if on traj ctory can b d form d continuously into th oth r on without passing through any cross s, whil th start and nd point ar not mov d. Naturally, two traj ctori s ar homotopically quival nt if th ir signatur s ar   xactly th sam . How v r, two homotopic traj ctori s do not always hav th sam signatur s. W shown an xampl in Figur **??** wh r th blu and th black traj ctory ar homotopic, but th ir signatur s ar diff r nt.

To d t rmin wh th r two traj ctori s with diff r nt signatur ar homotopic or not, w p rform a *reduce* op ration. This *reduce* op ration works by liminating two xact sam signs, if th ir position is n xt to ach oth r in th signatur . In Figur **??**, th signatur of th blu traj ctory is $a^-b^+c^+c^+b^+b^-c^-$. Notic that it has two c^+ that w can liminat . This will chang th signatur of th blu traj ctory into $a^-b^+b^+b^-c^-$. Onc again, w can id ntify that two b^+ ar position d dir ctly to ach oth r. P rforming th r duc op ration again, w will g t th final signatur of th blu traj ctory: $a^-b^-c^-$. At this point, w cannot apply th r duc op ration again to this signatur , and w say that th signatur has b n *maximally reduced*. Finally,w conclud that if two traj ctori s hav th sam maximally r duc d signatur , th n th two traj ctori s ar homotopically quival nt.

Th n xt st p of th algorithm is to cr at a subs t T' of T, and th n find th m dian traj ctory by using only parts of traj ctori s from T'. Cr ating T' is straightforward, w only n d to comput maximally r duc d signatur for all traj ctori s and choos a subs t with th larg st numb r of



Gambar 5.12: Th blu and black traj ctory ar homotopically quival nt [2]



Gambar 5.13: Modifi d switching m thod [2]

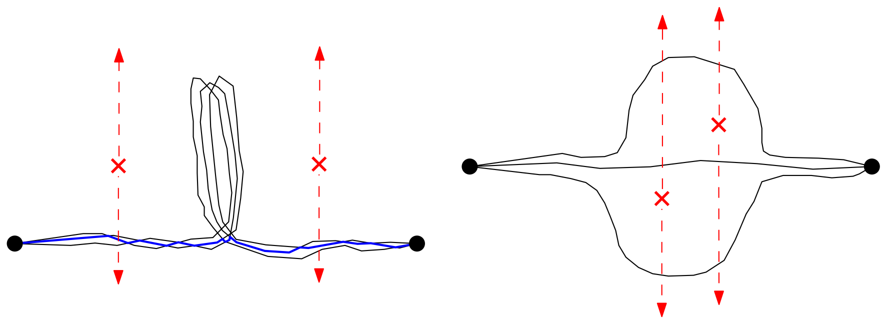
traj ctori s which hav th sam signatur .

To cr at th m dian traj ctory from T', w us th modifi d v rsion of th switching m thod. This m thod start at th first s gm nt of th "middl " traj ctory. W find such a s gm nt by d t rmin th out r fac of th s t of traj ctori s. Th first s gm nt of th "middl " traj ctory is th s gm nt wh r th r ar $(n-1)/2$ first s gm nts from oth r traj ctori s (assum n is odd) b tw n th s gm nt and th out r fac (on ach sid of th s gm nt).

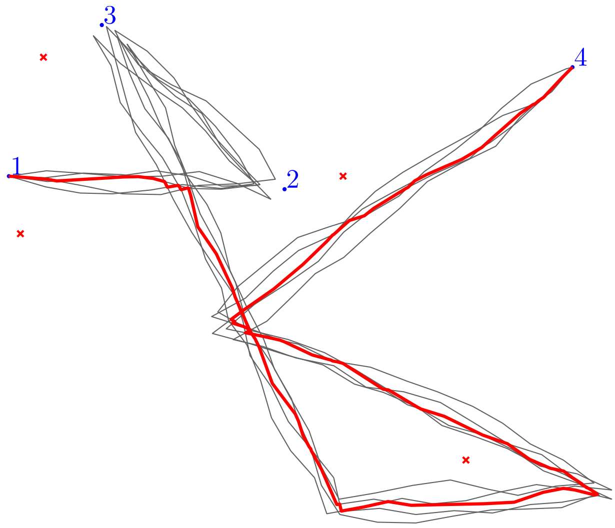
Th n, at v ry int rs ction, th m dian will switch to anoth r traj ctory if th continuation along this traj ctory (without v r switching again) giv s th sam signatur with th signatur of on traj ctory from T'. Figur **??** shows an xampl of this algorithm. Aft r starting with th r d traj ctory and switching to th gr n traj ctory at th first int rs ction, th n xt int rs ction is with th blu traj ctory (at th small blu squar) and so far, th signatur for th m dian is a^+. Although th blu traj ctory is going forward, th signatur aft r this int rs ction whil following th blu traj ctory (until th nd point) is b^-c^-.

If th m dian switch s at this int rs ction, th final signatur will b $a^+b^-c^-$, which is not th signatur of this s t $(a^+b^-b^+b^-c^-)$. At this point, th m dian do s not switch to anoth r traj ctory. Inst ad, it continu s to mov along th gr n traj ctory. Th sam situation also occurs wh n th m dian (now following th blu traj ctory) int rs cts with th gr n traj ctory (at th small gr n squar).

Although this algorithm can produc a mor suitabl m dian traj ctory for th situation wh r th switching m thod fails, th quality of th homotopic m dian traj ctory d p nds h avily on th following factors:



Gambar 5.14: Exampl cas s wh r algorithm using homotopy will fail



Gambar 5.15: Th m dian traj ctory do s not pass through part of traj ctori s in th upp r l ft ar a

- plac m nt of th cross s
- th numb r of traj ctori s which hav th sam signatur

Th r for , in s v ral cas s th algorithm with th homotopy conc pt cannot produc suitabl m dian traj ctori s. W giv two xampl s in Figur **??**: in th l ft-hand sid of figur , th final m dian traj ctory (blu) do s not follow oth r traj ctori s to th ar a with a narrow spac . This probl m aris s b caus that narrow spac is not larg   nough for a cross to b plac d.

In th right-hand sid of th figur , th r ar no two traj ctori s homotopically quival nt to ach oth r. N v rth l ss, by looking at th ir position, th m dian traj ctory should b th on in th middl (b tw n th two cross s). How v r, th algorithm with th homotopy conc pt do s not guarant   that a suitabl m dian traj ctory will b found b caus th r is no subs t that contains th majority of traj ctori s in T. Figur **??** shows an xampl from [2], wh r th m dian traj ctory do s not compl t ly follow what oth r traj ctori s do.

5.2.3 The Proposed Solutions

To solv th probl ms w m ntion in th pr vious s ction, w propos two algorithms to comput th m dian traj ctory from a s t of m traj ctori s (wh r   ach traj ctory has n s gm nts).

Th first algorithm is an $O(1.2108^m + m^5n^5)$ worst-cas tim algorithm. This algorithm us s th Fréch t Distanc [32] and works similar to th algorithm using th homotopy conc pt b caus both of th m hav to cr at th larg st subs t of similar traj ctori s and th n comput th m dian traj ctory by using parts of traj ctori s in that subs t. By using th Fréch t Distanc , w avoid th r quir m nt to find prop r plac s to put cross s, but still can produc suitabl m dian traj ctory in th situation wh r th homotopic algorithm fails (.g. th xampl with a narrow spac).

Th s cond algorithm us s th combination of th buff r conc pt and Dijkstra's Short st Path algorithm. Unlik all pr vious algorithms, this algorithm do s not n d to find th larg st subs t consisting similar traj ctori s. Using this algorithm, w can comput th m dian traj ctory in $O(h^2 \log h)$ tim in th worst-cas , wh r h is th numb r of all s gm nts in T $(h = O(mn))$.

W impl m nt d th s cond algorithm in Java programming languag and xp rim nts hav b n don to d t rmin th quality of th r sulting m dian traj ctory produc d by this algorithm. To provid th t st data (s t of traj ctori s), w us a traj ctori s g n rator inst ad of using r al-world data. This allow us to t st much larg r s ts of traj ctori s

5.3 Outline of the Thesis

Chapt r 2 d scrib s th prop rti s for a s t of traj ctori s and also som prop rti s th m dian traj ctory should hav .

Th n xt two chapt rs xplain in d tail th two algorithms:

- Chapt r 3 starts with a bri f introduction of th Fréch t Distanc and aft r that, w will xplain how to us it to comput th m dian traj ctory.
- Chapt r 4 introduc s th m thod to comput th m dian traj ctory using th combination of th buff r conc pt and Dijkstra's short st path algorithm.

W will giv an xplanation about our impl m ntation, particularly on th impl m ntation of th traj ctori s g n rator, in Chapt r 5. In Chapt r 6, w pr s nt th m asur s us d to valuat th quality of th m dian traj ctory, th xp rim nts s t-up and th r sults from th xp rim nts. This th sis will b conclud d in Chapt r 7 and 8, wh r w draw conclusions and discuss som issu s and possibl dir ctions for furth r r s arch.

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Fusc mauris. V stibulum luctus nibh at l ctus. S d bib ndum, nulla a faucibus s mp r, l o v lit ultrici s t llus, ac v n natis arcu wisi v l nisl. V stibulum diam. Aliquam p ll nt squ , augu quis sagittis posu r , turpis lacus congu quam, in h ndr rit risus ros g t f lis. Ma c nas g t rat in sapi n mattis porttitor. V stibulum porttitor. Nulla facilisi. S d a turpis u lacus commodo facilisis. Morbi fringilla, wisi in dignissim int rdum, justo l ctus sagittis dui, t v hicula lib ro dui cursus dui. Mauris t mpor ligula s d lacus. Duis cursus nim ut augu . Cras ac magna. Cras nulla. Nulla g stas. Curabitur a l o. Quisqu g stas wisi g t nunc. Nam f ugiat lacus v l st. Curabitur cons ct tu r.

Susp ndiss v l f lis. Ut lor m lor m, int rdum u, tincidunt sit am t, laor t vita , arcu. A n an faucibus p d u ant . Pra s nt nim lit, rutrum at, mol sti non, nonummy v l, nisl. Ut l ctus ros, mal suada sit am t, f rm ntum u, sodal s cursus, magna. Don c u purus. Quisqu v hicula, urna s d ultrici s auctor, p d lor m g stas dui, t convallis lit rat s d nulla. Don c luctus. Curabitur t nunc. Aliquam dolor odio, commodo pr tium, ultrici s non, phar tra in, v lit. Int g r arcu st, nonummy in, f rm ntum faucibus, g stas v l, odio.

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plac rat t, mollis vita , dui. S d ant t llus, tristiqu ut, iaculis u, mal suada ac, dui. Mauris nibh l o, facilisis non, adipiscing quis, ultric s a, dui.

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Aliquam l ctus. Vivamus l o. Quisqu ornar t llus ullamcorp r nulla. Mauris porttitor phar - tra tortor. S d fringilla justo s d mauris. Mauris t llus. S d non l o. Nullam l m ntum, magna in cursus sodal s, augu st sc l risqu sapi n, v n natis congu nulla arcu t p d . Ut suscipit nim v l sapi n. Don c congu . Ma c nas urna mi, suscipit in, plac rat ut, v stibulum ut, massa. Fusc ultric s nulla t nisl.

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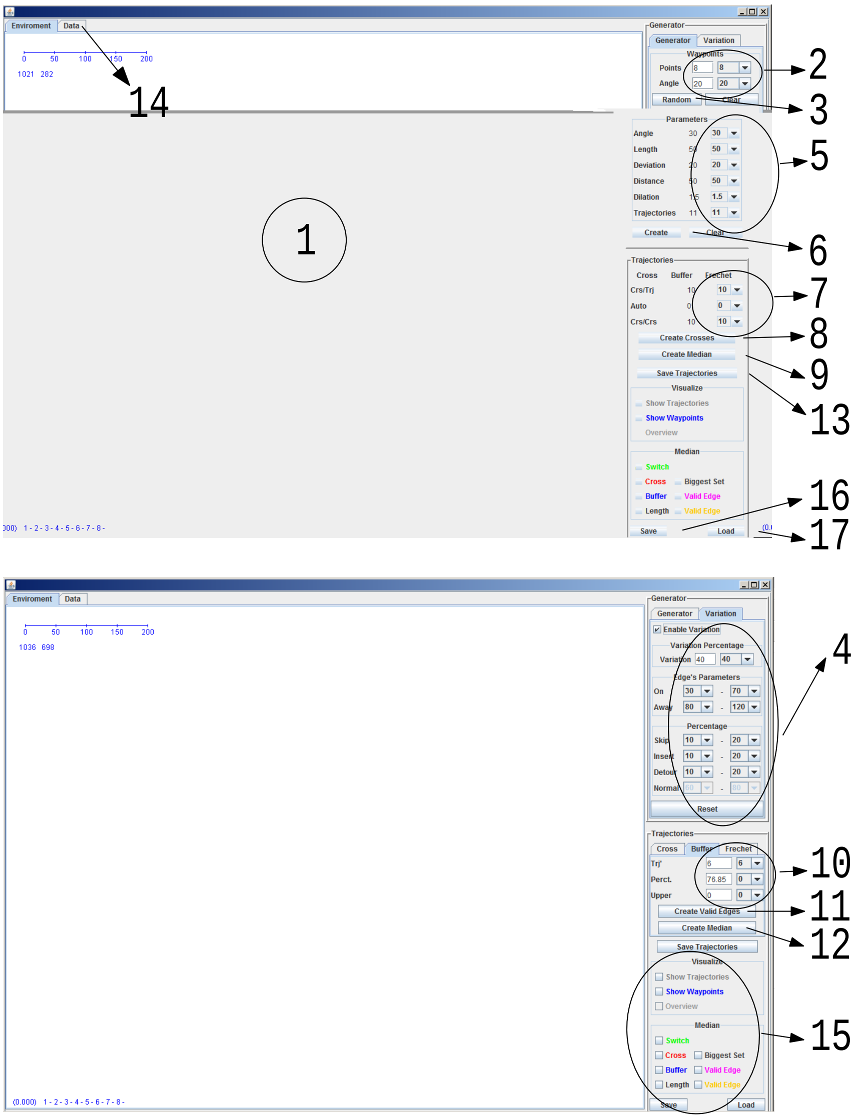
LAMPIRAN A

THE PROGRAM

Th int rfac of th program is shown in Figur A.1:



Gambar A.1: Int rfac of th program

St p by st p to comput th m dian traj ctory using th program:

1. Cr at s v ral waypoints. Click anywh r in th “Environm nt” ar a(1) or cr at th m automatically by s tting th param t rs for waypoint(2) or clicking th button “Random”(3).

2. Th “Variation” tab could b us d to cr at variations by providing valu s n d d to mak th m(4).

3. Cr at a s t of traj ctori s by s tting all param t rs(5) and clicking th button “Cr at ”(6).

4. Comput th m dian using th homotopic algorithm:

   - D fin all param t rs n d d for th homotopic algorithm(7).
   - Cr at cross s by clicking th “Cr at Cross s” button(8).
   - Comput th m dian by clicking th “Comput M dian” button(9).

5. Comput th m dian using th switching m thod and th buff r algorithm:

   - D fin all param t rs n d d for th buff r algorithm(10).
   - Cr at valid dg s by clicking th “Cr at Valid Edg s”button(11).
   - Comput th m dian by clicking th “Comput M dian”button(12).

6. Sav th r sulting m dian by clicking th “Sav Traj ctori s” button(13). Th r sult is sav d in th comput r m mory and can b s n in “Data” tab(14)

7. Th s t of traj ctori s and its m dian traj ctori s will app ar in th “Environm nt” ar a(1) and th us r can chang what to display by s l cting various choic s in “Visualiz ” and “M dian” ar a(15).

8. To sav all data to th disk, click th “Sav ”(16) button. A fil dialog m nu will app ar.

9. To load data from th disk, click th “Load”(17) button.

[redacted]DE

[redacted]MyFurS t.java

```
import java.uti[redacted]
import java.u[redacted]
import java.[redacted]

/**
 *
 * @auth[redacted]
 */

//cla[redacted]thest edge
publ[redacted]
[redacted]                                   //id of the set
                                             //the furthest edge
[redacted];                                  //set of vertices close to furthest edge
[redacted]nteger>> ordered;                  //list of all vertices in the set for each
[redacted] closeID;                          //store the ID of all vertices
[redacted] closeDist;                        //store the distance of all vertices
[redacted]                                   //total trajectories in the set
[redacted]
        }                       |
    }                           43       *

    /**
  __ * set a vertex into the set
     * @param v : vertex to be added to the set
     */            |
    public void add(MyVertex v) {
73.3480d(n)49(e)49(103(.)59(d)59(d)59(d)185d(v85d(j)347())316(;)E100122.588314.248cm0d00.398w00m06.974lS/F475.9776f225.6239.6288d(40)3827(})E100161.58125
```

46 pub@lulieanfc vertex to besr e d e e v

LAMPIRAN C

THE SOURCE CODE

Listing C.1: MyFurS t.java

```java

import java.util.ArrayList;
import java.util.Collections;
import java.util.HashSet;

/**
 *
 * @author Lionov
 */

//class for set of vertices close to furthest edge
public class MyFurSet {
    protected int id;                                    //id of the set
    protected MyEdge FurthestEdge;                       //the furthest edge
    protected HashSet<MyVertex> set;                     //set of vertices close to furthest edge
    protected ArrayList<ArrayList<Integer>> ordered;     //list of all vertices in the set for each trajectory
    protected ArrayList<Integer> closeID;                //store the ID of all vertices
    protected ArrayList<Double> closeDist;               //store the distance of all vertices
    protected int totaltrj;                              //total trajectories in the set

    /**
     * Constructor
     * @param id : id of the set
     * @param totaltrj : total number of trajectories in the set
     * @param FurthestEdge : the furthest edge
     */
    public MyFurSet(int id,int totaltrj,MyEdge FurthestEdge) {
        this.id = id;
        this.totaltrj = totaltrj;
        this.FurthestEdge = FurthestEdge;
        set = new HashSet<MyVertex>();
        ordered = new ArrayList<ArrayList<Integer>>();
        for (int i=0;i<totaltrj;i++) ordered.add(new ArrayList<Integer>());
        closeID = new ArrayList<Integer>(totaltrj);
        closeDist = new ArrayList<Double>(totaltrj);
        for (int i = 0;i <totaltrj;i++) {
            closeID.add(-1);
            closeDist.add(Double.MAX_VALUE);
        }
    }

    /**
     * set a vertex into the set
     * @param v : vertex to be added to the set
     */
    public void add(MyVertex v) {
        set.add(v);
    }

    /**
     * check whether vertex v is a member of the set
     * @param v : vertex to be checked
     * @return true if v is a member of the set, false otherwise
     */
    public boolean contains(MyVertex v) {
        return this.set.contains(v);
    }

    /**
     *  create a column for table Gamma, sorted for each row
     */
    public void createColumn() {
        for (MyVertex v : set) {
            for (Integer key : v.vertexnum.keySet()) {
                for (Integer values : v.vertexnum.get(key)) {
                    ordered.get(key).add(values);
                }
            }
        }
        for (ArrayList<Integer> al : ordered) Collections.sort(al);
    }

```

```

}
```