A Qualitative Framework for Deriving a Terrain Feature

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Abstract

This paper proposes a qualitative treatment of a two-dimensional figure with height information. We give a symbolic representation to a terrain, a topographic surface of a landscape, and we can get its abstract feature by reasoning on the representation. A target terrain viewed from above is modeled as a closed rectangle divided into multiple regions. For each pair of adjacent regions, we represent their connection patterns with regard to height. We can derive the relative grade of a slope and/or its direction, as well as the existence of a height gap between regions. We can apply this method for the route finding in a given terrain, considering gradients and gaps. We illustrate an application to an actual landscape.

1 Introduction

Qualitative Spatial Reasoning (QSR) is a method that treats figures or images qualitatively, by extracting the information necessary for a user's purpose [18; 4; 13]. Various formalizations have been proposed to date including RCC [15], 9-intersection model [7], PLCA [20], and so on. It is useful in identifying the feature of a terrain or understanding construction of spatial data at an abstract level. One of natural qualitative representations for a terrain is given using the relationship of attributed regions. Regions such as fields, lakes, buildings or such an area that is affected by a pollution are defined and their relative spatial relationships are expressed using mereological relations, relative size, relative directions, and so on. Assertions such as "The field is tangentially connected to the lake" or "The residential area is in the north of the polluted area" can be handled in these frameworks. However, the answer to the queries regarding height such as "Is there an ascending slope in a specific route?" or "From which area is damaged when a flood occurs?" cannot be derived.

Consider the object shown in Figure 1(a). It is viewed from above and can be represented qualitatively, for example, "Two areas are connected by one line." If we consider the heights of the areas, multiple possible cases are considered. Some of them are shown in Figure 1(b)∼(f). They are the shapes of the object viewed from the point VP in Figure 1(a). We cannot distinguish between these shapes without height information.

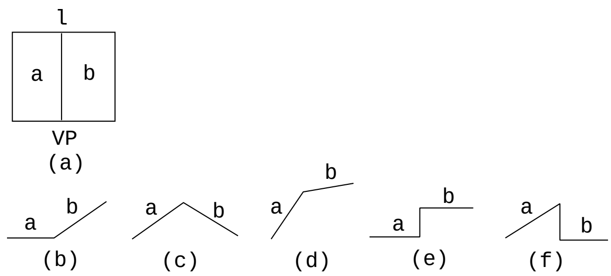

Figure 1: Figures in different heights

Most of works on QSR handle only figures on a two-dimensional (2D) plane. But if we reason about a terrain feature, we have to add some information on relative height to this figure.

One method for handling height information is adding relative height to each region in a 2D plane. But this is not enough since we cannot express the fact that a region is inclined or that there is a height gap between adjacent regions. Another method is adding relative height to several points. However, the representation would be complicated. For a point in a region, it is hard to determine which point should be selected. For a vertex, it is hard to determine which set of target vertices to be compared since most of vertices are contained in multiple regions.

In this paper, we focus on the connection of regions as a yet another method. We propose a method such that for each pair of adjacent regions, we represent their connection patterns with regard to height. It can provide information specific to height such as the relative grade of a slope and/or its direction.

We show the outline of the method.

We assume that the target terrain is within a finite range. First, we project the target terrain onto a 2D plane, and divide it into multiple regions by extracting objects such as fields, lakes, buildings and so on. Make a qualitative representation for this 2D figure using PLCA expression [19; 20]. PLCA uses points(P), lines(L), circuits(C) and areas(A) as primitive objects and represents a figure symbolically by the membership relations and connections of these primitive objects.

Next, we add height information on this expression. Each line is shared by a pair of areas. We express direction of a slope of these areas with respect to the line, that is, ascending, descending, horizontal, or the characteristics of the connection. For example, in Figure 1(c), a is ascending and b is descending with respect to line l. There are two kinds of the connection patterns of the areas, the one by a line (e.g., Figure 1(b)(c)(d)) and the other by a vertical area (e.g., Figure 1(e)(f)). As for the latter, the line observable from above is unique, actually it is a superposition of two lines. These patterns can be distinguished by the representation and in addition, the relative grade of slopes can be derived in some cases.

On this symbolic representation, we can reason about the feature of a path from one area to another, that is, to derive the number of ascending and descending and that of climbing gaps. In this paper, we represent a terrain around our university and present the result of finding the route considering gradients and gaps.

This paper is organized as follows. In section 2, we describe our target terrain and present a description language. In section 3, we show the reasoning on this representation. In section 4, we show an application. In section 5, we compare our work to related works. Finally, in section 6, we present our conclusions.

2 Description Language

2.1 Target terrains

A target terrain viewed from above is modeled as a closed rectangle divided into a finite number of polygons in the following manner: (i) Each polygon corresponds to a plane with a specific height, or a slope in a specific direction with a specific degree of inclination. (ii) Each edge of a polygon is shared at most two other polygons.

Throughout the paper, figures use the rectangle as a polygon to simplify an explanation, but the method is available for any shape.

We also put the following constraints to our target terrain.

- Each edge should be either horizontal, monotonically increasing, or monotonically decreasing in height; that is, it does not have inflection points in its inner part.
- Each area is even; that is, it does not have protuberances or caves in its inner part.
- No area is overhanging.
- Slopes in different directions never cross at their connected lines (Figure 2(a)).
- At least one pair of the opposite edges of an area are both horizontal (Figure 2(b)).

2.2 PLCA expression for a figure in 2D

We proposed PLCA expression [20], the symbolic expression for the projection on a 2D plane.

PLCA comprises four kinds of objects: points, lines, circuits and areas.

A point is defined as a primitive p.

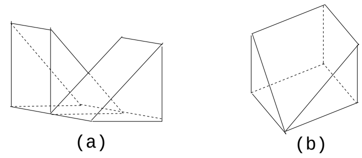

Figure 2: Not-allowed terrains

A line is defined as an object that connects two different points. $l = (p, p')$. We denote $p, p' \in l$. A line has an inherent orientation. When $l = (p, p')$, l^+ and l^- mean (p, p') and (p', p), respectively. l^* denotes either l^+ or l^-.

A circuit is defined as a sequence of lines. $c = [l_0^*, \dots, l_{n-1}^*]$ where $l_i^* = (p_i, p_{i+1})$ $(0 \leq i \leq n-1)$, $l_n = l_0$, $1 \leq n$. We denote $l_i^* \in c$ $(0 \leq i \leq n-1)$.

An area is defined as a set of circuits. $a = \{c_0, \dots, c_{n-1}\}$. We denote $c_i \in a$ $(0 \leq i \leq n-1)$.

In addition, we assume that there exists a circuit in the outermost side of the figure that is called $outermost$.

Then a figure in 2D plane is expressed as a quadruple (P, L, C, A), where P, L, C, A are sets of points, lines, circuits including $outermost$ and areas together with their relationships.

A PLCA expression $e = \{P, L, C, A\}$ corresponding to Figure 3 is shown below.

$e.points = \{p_0, p_1, p_2, p_3, p_4, p_5\}$ $\quad l_0.points = [p_0, p_0]$
$e.lines = \{l_0, l_1, l_2, l_3, l_4, l_5, l_6\}$ $\quad l_1.points = [p_1, p_2]$
$e.circuits = \{c_0, c_1\}$ $\quad l_2.points = [p_2, p_3]$
$e.areas = \{a_0, a_1\}$ $\quad l_3.points = [p_3, p_4]$
$a_0.circuits = \{c_0\}$ $\quad l_4.points = [p_4, p_5]$
$a_1.circuits = \{c_1\}$ $\quad l_5.points = [p_5, p_0]$
$c_0.lines = [l_0^-, l_5^-, l_4^-, l_6^-]$ $\quad l_6.points = [p_1, p_4]$
$c_1.lines = [l_1^-, l_6^+, l_3^-, l_2^-]$
$outermost.lines = [l_0^+, l_1^+, l_2^+, l_3^+, l_4^+, l_5^+]$

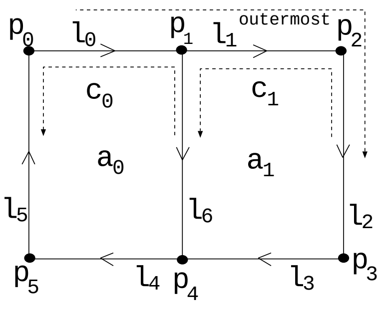

Figure 3: Example of PLCA

Intuitively, PLCA expression can be considered as a doubly-connected edge without coordinates which is used in computational geometry [14]. In doubly-connected edge, there exists only one figure corresponding to a symbolic expression, whereas we can draw infinite number of figures corresponding to a PLCA expression, since it determines no size nor coordinates.

For any line l, there exists circuits c, c' and areas a, b such that $l^+ \in c, c \in a$ and $l^- \in c', c' \in b$. A pair of areas a and b are said to be *adjacent areas* and l is said to be *a c-line of a and b*. The lines l^+ and l^-, denoted by l_a and l_b, are said to be a's c-line and b's c-line, respectively, to make it clear which area a line belongs to. For example, in Figure 3, l_6 is a c-line of a_0 and a_1, l_6^+ and l_6^- are denoted by l_{a_1} and l_{a_0}, respectively.

Originally, a shape of an object is ignored and curved lines are allowed as a PLCA expression. In this paper, we consider a subset of PLCA in which only a straight line is used, a circuit consists of exactly four lines and an area consists of a single circuit.

2.3 Expression for relative height

We add information on height to the PLCA expression, assuming that PLCA expression is already given.

Let F be a target terrain in a 3D space and F_0 be its projection onto a 2D plane. There are two characteristics of an area: plane and slope. A vertical area in F does not appear in F_0. Thus, some lines and points in F_0 are superpositions of two lines or points, respectively. Superposition means that the objects are in the same position in F_0 but have different heights in F. Consider a terrain in Figure 4(a) whose projection onto a 2D plane is Figure 4(b). A line $l = (p, p')$ in Figure 4(b) is a superposition of l_a and l_b in Figure 4(a). Point p in Figure 4(b) is a superposition of p_a and p_b in Figure 4(a), and point p' in Figure 4(b) is a superposition of p'_a and p'_b in Figure 4(a) where $l_a = (p_a, p'_a)$ and $l_b = (p_b, p'_b)$.

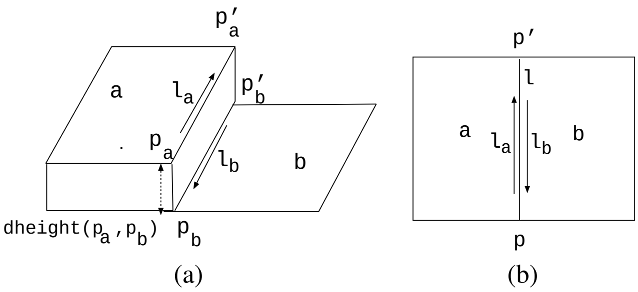

Figure 4: Superposed points and lines

For a point p, $h(p)$ denotes the height of p. For points p_1 and p_2, $dheight(p_1, p_2)$ denotes a difference of $h(p_1)$ and $h(p_2)$. For example, the dotted line in Figure 4(a) shows $dheight(p_a, p_b)$.

For a line $l = (p_1, p_2)$, if $dheight(p_1, p_2) = 0$, then it is said that l is *horizontal*. In this case, $h(l)$ is defined as $h(p_1)$. If l is not horizontal, $h(l)$ is undefined.

Defintion 1 *For a pair of adjacent areas, if c-line is a superposition of two lines, then it is said that the areas are* inclining connected (i-connected)*; otherwise, it is said that they are* horizontally connected (h-connected).

If areas are h-connected, all c-lines are horizontal. If areas are i-connected, at least one of them is not horizontal.

h-connected

The h-connection pattern with regard to height is expressed in the form of $\alpha \mathcal{R}_h \beta$. α and β are pairs of $area$ with $height$, where $area$ is a corresponding area, and $height$ is a relative height of the $area$'s c-line. The value of $height$ is either $high$, low or hl. $high$ means that it is higher than the line in the opposite side of $area$. low means that it is lower than the line in the opposite side of $area$. And hl means all the lines in $area$ are the same height. $\mathcal{R}_h = \{<_h, =_h\}$ is a binary relation. It represents a relative height between c-lines of the connected areas.

Defintion 2 *For area x, let l_x be an x's c-line. Then, $c(l_x)$, the qualitative height of l_x in x, is defined as follows:*

- $c(l_x) = x\_low$ *if* $\exists l'_x \in x$, $l'_x \neq l_x$ *s.t.* $h(l_x) < h(l'_x)$.
- $c(l_x) = x\_high$ *if* $\exists l'_x \in x$, $l'_x \neq l_x$ *s.t.*$h(l'_x) < h(l_x)$.
- $c(l_x) = x\_hl$ *if* $\forall l'_x \in x$, $h(l'_x) = h(l_x)$.

Let l_a and l_b be a's c-line and b's c-line, respectively. $\mathcal{R}_h$ is defined as follows.

- $c(l_a) <_h c(l_b)$ if $h(l_a) < h(l_b)$.
- $c(l_a) =_h c(l_b)$ if $h(l_a) = h(l_b)$.

For example, compare the figures in Figure 5. In case (a), since c-line of area a is higher than the line in the opposite side of a, that of b is higher than the line in the opposite side of b, and their heights are equivalent, the connection pattern with regard to height is represented as $a\_high =_h b\_high$; in case (b), since c-line of area b is equivalent to the line in the opposite side of b, $a\_high =_h b\_hl$; and in case (c), since c-line of area a is higher than that of b, $b\_hl <_h a\_high$.

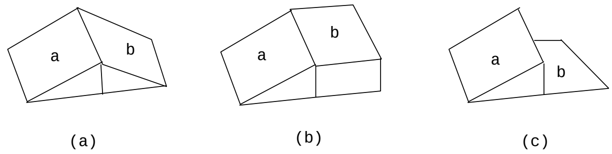

Figure 5: Difference of expressions (h-connected)

i-connected

First, we define *base-point* of a c-line.

For a superposed point p, $f_x(p)$ denotes a point belonging to area x.

Defintion 3 *Let $l = (p_1, p_2)$ be a superposed c-line of a and b. A point $dminp$ that satisfies $dheight(f_a(dminp), f_b(dminp)) < dheight(f_a(p'), f_b(p'))$ for all $p' \in l$, $p' \neq dminp$, is said to be the* base-point *of l.*

The base-point of l is either p_1 or p_2, since the line does not have inflection points in its inner part. The other end of the line is set to be $dmaxp$. $f_x(dminp)$ and $f_x(dmaxp)$ are denoted by $dminp_x$ and $dmaxp_x$, respectively. Note that if a's c-line and b's c-line are in parallel, or coincide with each other, their base-points are not defined, since for all $p \in l$, $dheight(f_a(p), f_b(p))$ are equivalent.

The i-connection pattern with regard to height is expressed in the form of $\alpha \mathcal{R}_i \beta$. α and β are pairs of $area$ with $height$, where $area$ is the corresponding area, and $height$ is a relative height of the $area$'s base-point in its c-line. The value of $height$ is either $high$, low, hl or all. $high$ means that the base-point is higher than the other end point in the c-line. low means that it is lower than the other end point in the c-line. hl means that the c-line is horizontal. And all means the c-line does not have a base-point. $\mathcal{R}_i = \{<_i, \leq_i, =_i\}$ is a binary relation. It represents a relative height between the base-points in the c-lines.

Defintion 4 *For an area x, let p_x be x's $dminp_x$, and l_x be x's c-line. Then $c(p_x)$ is a connection pattern of an area x with regard to height, and is defined as follows:*

- *$c(p_x)$ is x_high if $h(dmaxp_x) < h(dminp_x)$.*
- *$c(p_x)$ is x_low if $h(dminp_x) < h(dmaxp_x)$.*
- *$c(p_x)$ is x_hl if $h(dminp_x) = h(dmaxp_x)$.*
- *$c(p_x)$ is x_all otherwise.*

Let l_a and l_b be a's c-line and b's c-line, respectively. $\mathcal{R}_i$ is defined as follows.

- $c(l_a) <_i c(l_b)$ if both $h(f_a(p_1)) < h(f_b(p_1))$ and $h(f_a(p_2)) < h(f_b(p_2))$ hold.
- $c(l_a) \leq_i c(l_b)$ if both $h(f_a(p_1)) < h(f_b(p_1))$ and $h(f_a(p_2)) = h(f_b(p_2))$ hold, or both $h(f_a(p_1)) = h(f_b(p_1))$ and $h(f_a(p_2)) < h(f_b(p_2))$ hold.
- $c(l_a) =_i c(l_b)$ if $dheight(f_a(p_1), f_b(p_1)) = dheight(f_a(p_2), f_b(p_2))$ holds.

The last one shows the case that a and b are slopes in the same direction with the same degree of inclination.

In Figure 6, (a) is a 3D figure, (b) and (c) are its shapes viewed from above and side, respectively. a and b are adjacent areas, a's c-line is $l_a = (f_a(p_1), f_a(p_2))$. b's c-line is $l_b = (f_b(p_1), f_b(p_2))$. In this case, $dminp = p_1$, $dmaxp = p_2$. Since $h(f_a(p_1)) < h(f_a(p_2))$ holds, $c(p_a)$ is a_low. Since $h(f_b(p_1)) < h(f_b(p_2))$ holds, $c(p_b)$ is b_low. And since $h(f_b(p_1)) < h(f_a(p_1))$ and $h(f_b(p_2)) < h(f_a(p_2))$ hold, their i-connection pattern is $b\_low <_i a\_low$.

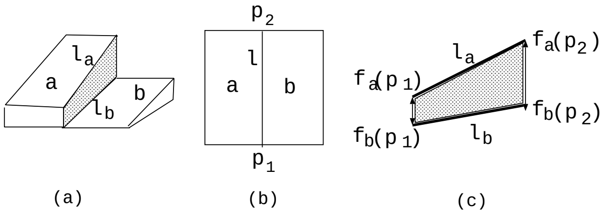

Figure 6: Expression for i-connected pattern

We show other examples of i-connected patterns of areas a and b in Figure 7. These figures show the shape of the connected part from the side viewpoint. The i-connected patterns of a and b are represented as follows: (a) $b\_high <_i a\_high$, (b) $b\_high \leq_i a\_hl$, and (c) $b\_all <_i a\_all$.

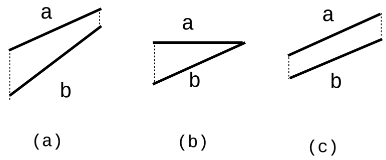

Figure 7: Examples for i-connected patterns

2.4 Validity of expression

Let H be a set of connection patterns for each pair of adjacent areas. There are several necessary conditions that H should fulfill for the existence of the corresponding 3D terrain.

1. For each line, connection patterns with regard to height is uniquely defined.
2. For an area a appearing in H, a_hl does not appear iff a_high or a_low appear.
3. Properties of relative height relation, e.g., transitivity of $<_h$, are not violated.

Consider the following sets of connection patterns. There exists the 3D figure that satisfies H_1 (Figure 8(a)) and H_2 (Figure 8(b)), but there is not for H_3.

$H_1 = \{\ a\_hl =_h b\_high,\ c\_hl <_h a\_hl,\ c\_hl \leq_i b\_low\ \}$

$H_2 = \{\ a\_high =_h b\_high,\ c\_hl \leq_i a\_low,\ c\_hl \leq_i b\_low$
$\}$

$H_3 = \{\ a\_hl =_h b\_high,\ c\_hl \leq_i a\_low,\ c\_hl \leq_i b\_low\ \}$

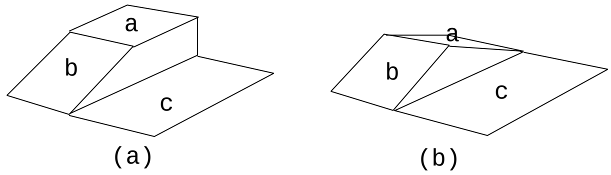

Figure 8: Terrains for given sets of relations of connection patterns

3 Reasoning on degree of slope

We show several reasoning on PLCA with height expression.

Gap between adjacent areas

We can determine whether there is a gap between adjacent areas.

For any pair of adjacent areas a and b, if they are i-connected with a pattern $a\_all =_i b\_all$, or if they are h-connected with a pattern $a\_* =_h b\_*$ where $*$ denotes either $high$, low or hl, then there is no gap between a and b. Otherwise, there is a gap.

For example, in Figure 8(a), there are gaps between areas a and c, b and c, but not between a and b.

Direction of slopes

When areas are h-connected, we can determine the direction of slopes for both areas. On the other hand, when areas are i-connected, we cannot always determine it.

Let x be h-connected with some area, and let $c(l_x)$ be a qualitative height l_x in x. If $c(l_x)$ is x_high, then x is ascending slope towards its c-line. If $c(l_x)$ is x_low, then x is descending slope towards its c-line. If $c(l_x)$ is x_hl, then x is a plane.

Degree of slopes

When areas are h-connected, we cannot determine the degree of slopes. When areas are i-connected, we can determine it when they are inclined in the same direction.

Let a and b be adjacent areas. If the connection pattern with regard to height is $a\_all\mathcal{R}_i b\_all$, then degrees of inclination of a and b are the same. Otherwise, if $a\_high\mathcal{R}_i b\_high$, then a is steeper than b; if $b\_low\mathcal{R}_i a\_low$, then b is steeper than a.

4 Application

In this section, we show an application of the proposed method for an actual landscape.

4.1 Expression

Figure 9 shows a map of Kobe Sanda Campus of Kwansei Gakuin University, and Figure 10 is its qualitative model which is obtained manually. Kobe Sanda Campus is located on the hill and there are lots of slopes or gaps.

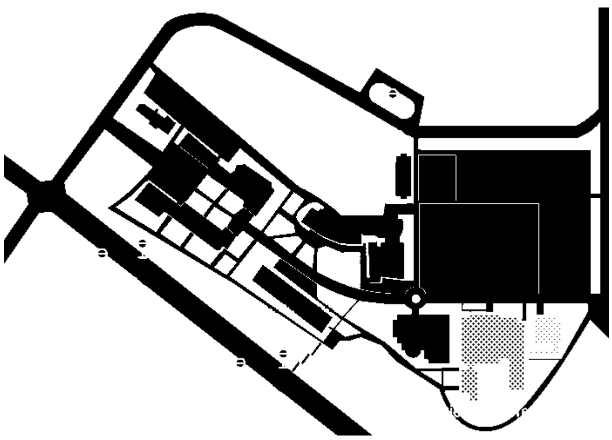

Figure 9: A map of Kobe Sanda Campus

In Figure 10, an arrow indicates the slope in descending direction, a bold line indicates a gap, and an area placed between dotted lines indicates stairways.

For stairways, it is possible to consider them as a sequence of small areas. In this case, we need a refined statement that requires much memory. Here, we use alternative modeling in which the entire stairway is considered a slope. We add an attribute to each area to distinguish a stairway and a real slope. This method can be used not only for stairways, but also areas that we may want to avoid passing, such as an area under construction or a dangerous area.

The followings is a part of elements of the relation of connection patterns.

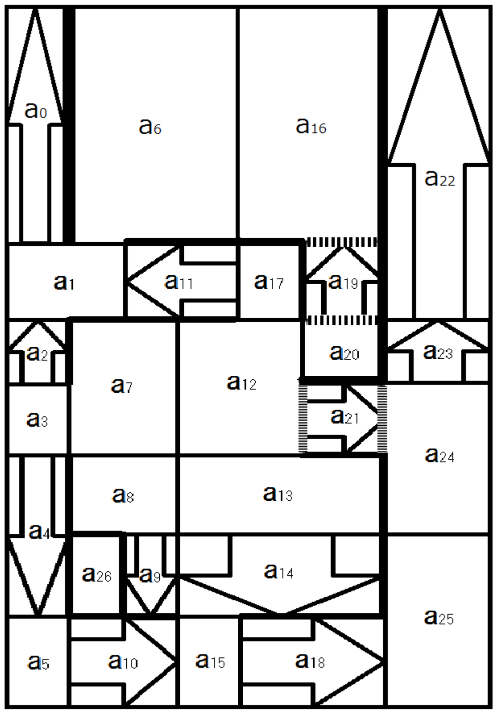

Figure 10: A model for Figure 9

(1) $a_0\_high =_h a_1\_hl$. (2) $a_0\_high \leq_i a_6\_hl$.
(3) $a_1\_hl =_h a_6\_hl$. (4) $a_1\_hl =_h a_{11}\_low$.
(5) $a_6\_hl \leq_i a_{11}\_low$. (6) $a_1\_hl =_h a_2\_low$.
(7) $a_1\_hl <_h a_7\_hl$. (8) $a_2\_high =_h a_3\_hl$.
(9) $a_2\_high \leq_i a_7\_hl$. (10) $a_3\_hl =_h a_7\_hl$.

They are consistent in the sense that there exists a terrain that satisfies these relationships.

Conversely, we can derive the relation (5) from (3) and (4) if we know that a_6 and a_{11} are i-connected. Similarly, we can derive that a_7 is relatively higher than a_1, that is, $a_1\_hl <_h a_7\_hl$ holds from (6),(8) and (10), unless (7) is represented explicitly.

As a result of judging the slopes from this expression, $a_0, a_2, a_4, a_9, a_{10}, a_{11}, a_{14}, a_{18}, a_{19}, a_{21}, a_{22}, a_{23}$ are judged as slopes. This result is consistent with the shape of the actual landscape.

4.2 Route finding

For the PLCA expression with height, we take areas as nodes and lines as edges in a graph, where connection patterns is added to each edge, and apply search algorithms on the graph.

We have implemented the search algorithm and applied it to find a specific route from the entrance of a playground (a_0) to a convenience store (a_{25}) in Figure 10. First, we search for a route that avoids a gap including a stairway as far as possible. The system generates 28 routes that may contain a gap, and 12 of them without a gap. For example, route

(r2) $a_0 \to a_1 \to a_{11} \to a_{17} \to a_{12} \to a_{21} \to a_{24} \to a_{25}$ is a route that passes a stairway a_{21}, whereas route **(r1)** $a_0 \to a_1 \to a_{11} \to a_{17} \to a_{12} \to a_{13} \to a_{14} \to a_{15} \to a_{18} \to a_{25}$ is a route that does not contain a gap. It makes a detour instead of passing a_{21}. **(r1)** is suitable for a user who is searching for a gap-free path.

Next, we search for a route that contains the least number of gradients. Let a, b be adjacent areas. If $a\_high =_h b\_hl$, then transition from a to b is said to be *ascending*. If $a\_low =_h b\_hl$, then it is said to be *descending*. Otherwise, it is said to be *flat*. A route is a sequence of these elements. We deduce the number of gradients from the sequence by the algorithm shown below where the variable $count$ indicates the number of gradients.

[Algorithm for counting the gradients]

Let a_s be a start area and a_d be a destination area. Let $a_0, a_1, \ldots, a_n$ be a route from a_s to a_d without a gap. $check$ is a kind of a flag that shows the current state of ascending and descending.

1. Set $i = 0$, $a_0 = a_s$, $check = none$ and $count = 0$.
2. If $a_i = a_d$, then terminate.
   Otherwise,
   if transition from a_i to a_{i+1} is ascending
   if $check = down$,
   then increment $count$
   set $check = up$;
   if transition from a_i to a_{i+1} is descending
   if $check = up$,
   then increment $count$
   set $check = down$.
3. Increment i and go back to 2.

As a result, we find that 7 of the 28 routes have three gradients and the others have one. For example, route **(r25)** $a_0 \to a_1 \to a_6 \to a_{16} \to a_{19} \to a_{20} \to a_{12} \to a_{13} \to a_8 \to a_7 \to a_3 \to a_4 \to a_5 \to a_{10} \to a_{15} \to a_{18} \to a_{25}$ is a route that contains one gradients, whereas route **(r22)** $a_0 \to a_1 \to a_2 \to a_3 \to a_4 \to a_5 \to a_{10} \to a_{15} \to a_{14} \to a_{13} \to a_8 \to a_7 \to a_{12} \to a_{21} \to a_{24} \to a_{25}$ contains three. We conclude that **(r25)** is better than **(r22)** as a less burden route.

5 Discussion

Earlier research on deriving the feature of a terrain is a work by Frank et. al [8]. They formalized using a predicate calculus the extraction of the geomorphograhic feature from a set of predicates that expresses the positional relationships between objects such as edges or points. Guilbert proposed a method for extracting and analyzing terrain features from a contour map to give a qualitative description of a landscape [10]. They are not qualitative approaches and numerical data is used to derive the shape of a figure, although the essential idea is similar to ours. Kulik et al. formalized a method of deriving a feature of a terrain from its silhouette obtained by a fixed viewpoint [11]. They define qualitative representation such as ascending or descending for a line segment of a silhouette, and show a method for deriving a shape such as mountain and valley from a sequence of the segments. They also adopt the relative length of a segment. It is successful for the projection on one-dimension, but two-dimensional case is not handled. On the other hand, we show the treatment of two-dimensional case. Donlon et al. proposed a route-finding system with a concept of "trafficability" [6]. They add attributes such as vegetation and slope to terrains in Geographic Information Systems (GIS) and consider vehicular movements on that terrain depending on these values. Their purpose is to analyze trafficability and they do not adopt an idea of a relative height. On the other hand, our main purpose is to represent abstract features of a landscape with regard to height, and route-finding is one of the applications.

Basically, most studies on QSR have focused on 2D data including the projection of 3D data onto a 2D plane. Few attempts have been made to handle 3D data [1; 16], but they did not aim at the derivation of a feature of a terrain. As for a qualitative navigation, Freksa presented a framework in a 2D plane [9]. He proposed a method for representing an orientation using a reference point and a perspective point, and showed a navigation using their positional relationships. Qualitative treatment of 3D data that is projected onto a 2D plane is used as a robot navigation [17; 22], but symbolic approaches are not taken in these works.

There are lots of works on 3D models for a terrain in the field of GIS [12; 2; 3]. However, they use coordinates and take quantitative approach.

We have provided a method for deriving a feature of a terrain from a set of qualitative representation in a symbolic form.

6 Conclusion

We have presented a qualitative spatial representation based on connection patterns with relative height and reasoning on this representation. This method is a symbolic approach to understand the feature of a terrain. We have also shown the application of this method to route finding with height information of an actual landscape. In this paper, although we adopt a rectangle as a unit area, the method can be applicable to any shape of polygon, which involves triangulated irregular networks (TIN) model or regular square grid as a surface model.

This work is ongoing and there are lots of issues to be discussed. Among them, the most important ones that we currently think are the following three points.

1. To determine the method or rules to extract a terrain feature in a higher level, such as mountain and valley from the set of relations of connection patterns.
2. To find the condition that a set of relations of connection patterns should satisfy so that there exists a corresponding 3D figure.
3. To find a class of terrains that can be handled by this method, and how far the method can be extended.

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References

[1] J. Albath, J. L. Leopold, C. L. Sabharwal, and K. Perry, 'Efficient reasoning with RCC-3D', in *Proceedings of Knowledge Science, Engineering and Management 2010*, pp. 470–481. Springer, (2010).

[2] B. Brugman, T. Tijssen and P. van Oosterom, 'Validating a 3D topological structure of a 3D space partition,' AGILE Confeferce pp.359-378 (2011).

[3] R. Billen and S.Zlatanova, '3D spatial relationships model: a useful concept for 3D cadastre?' in *Computers, Environment and Urban Systems* **27**(4): 411–425, (2003).

[4] A. G. Cohn and S. M. Hazarika, 'Qualitative spatial representation and reasoning: An overview.', *Fundamental Informaticae*, **46**(1-1), 1–29, (2001).

[5] A. Cohn and J. Renz, 'Qualitative spatial representation and reasoning', *Handbook of Knowledge Representation*, Chapt. 13, pp. 551-596, F. van Harmelen, V. Lifschitz, and B. Porter, Eds., Elsevier, (2008).

[6] CPT J. J. Donlon and K. D. Forbus, Using a Geographic Information System for Qualitative Spatial Reasoning about Trafficability in *Proceedings of 13th International Workshop on Qualitative Reasoning*, (1999).

[7] M. Egenhofer and J. Herring: 'Categorizing binary topological relations between regions, Lines, and Points in Geographic Databases', in *Department of Surveying Engineering*, University of Maine, (1990).

[8] A. U.Frank, B. Palmer and V. B. Robinson, 'Formal methods for accurate definitions of some fundamental terms in physical geography', in *Proceedings of Second International Symposium on Spatial Data Handling,* pp.583-599, (1986).

[9] C. Freksa, 'Using orientation information for qualitative spatial reasoning' in *Theories and methods of spatio-temporal reasoning in geographic space,* pp.162 - 178, Springer, (1992).

[10] E. Guilbert, 'Multi-level representation of terrain features on a contour map' in *GeoInformatica*, **17**:301-324, (2013).

[11] L. Kulik and M. J. Egenhofer, 'Linearized terrain: languages for silhouette representations' in *Spatial Information Theory (COSIT2003)*, pp. 118-135, (2003).

[12] C. Lemmen and P. van Oosterom, '3D cadastres,' in *Computers, Environment and Urban Systems*, **2**7(4): 337-343 (2003).

[13] G. Ligozat, *Qualitative Spatial and Temporal Reasoning*, Wiley, (2011).

[14] M. Overmars, M. de Berg, M. van Kreveld and O. Schwarzkopf. *Computational Geometry*, Springer-Verlag, (1997).

[15] D. A. Randell, Z. Cui, and A. G. Cohn, 'A spatial logic based on regions and connection', in *Proceedings of the Third International Conference on Principles of Knowledge Representation and Reasoning*, pp. 165–176. Morgan Kaufmann Publishers, (1992).

[16] C. Sabharwal, J. L. Leopold, and N. Eloe, 'A more expressive 3D region connection calculus', in *Proceedings of the 2011 International Workshop on Visual Languages and Computing*, pp. 307–311, (2011).

[17] N. M. Sgourosa, 'Qualitative navigation for mobile robots in indoor environments,' in *Applied Artificial Intelligence: An International Journal*, **15**(3):237-251, (2001).

[18] O. Stock, *Spatial and Temporal Reasoning*, Kluwer Academic Press, (1997).

[19] K. Takahashi, T. Sumitomo and I. Takeuti. 'On embedding a qualitative representation in a two-dimensional plane,' Spatial Cognition and Computation, **8**(1-2):4-26, (2008).

[20] K. Takahashi, 'PLCA: a framework for qualitative spatial reasoning based on connection patterns of regions,' Qualitative Spatio-Temporal Representation and Reasoning: Trends and Future Directions, S.Hazarika(ed.), Chapt 2, pp.63-96, IGI Publishers, (2012).

[21] M. Westphal, S. Wölfl, B. Nebel and J. Renz, 'On qualitative route descriptions: representation and computational complexity,' in *Proceedings of the twenty-second International Joint Conference on Artificial Intelligence*, pp.1120-1125, (2011).

[22] D. Wolter, F. Dylla and A. Kreutzmann, 'Rule-compliant navigation with qualitative spatial reasoning,' in *Proceedings of the 4th International Robotic Sailing Conference.*, Springer, (2011).