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Qualitative Spatial Representation in Video Processing: A Survey

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Abstract: *Representation and reasoning about spatial data is a key problem in artificial intelligence, and has wide applications in the fields of geographic information system, computer vision, autonomous robot navigation, scene understanding, human action recognition, and so on. The reason for this increasing interest in using Qualitative Spatial Relations as formalism to abstract large amounts of video data is to obtain high level conceptualisations and cognition. This paper summarizes the use of key spatial calculi representing different types of spatial relationships between objects in video processing.*

Keywords: *Qualitative spatial reasoning, topology, orientation, direction of motion,distance.*

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I. Introduction

Due to the tremendous growth of image capturing devices and video sharing services over the World Wide Web, the human centered handling of these huge volumes of visual data is becoming impossible now a days. To overcome this problem, some machine supported counterpart has been used to replace with the human. These artificial counterparts must have cognitive abilities like human being. Humans in day-to-day non-technical communication use spatial reasoning to accomplish routine tasks and make decisions in a timely and efficient manner. Though the quantitative description is more appropriate than a qualitative description, practically in some situations it is not possible to express each and every entity quantitatively. While representing the relation between any two entities people normally use qualitative expressions like "the pen is near the water bottle", instead of expressing it quantitatively like "the pen is one foot away from the water bottle". These types of qualitative representations are introduced by Cohn et al. [1] as qualitative spatial reasoning (QSR) which becomes promising nowadays. It is an approach that deals with common sense knowledge, which is a central topic of artificial intelligence (AI). It is almost closer to the representation and reasoning of a human being about common sense knowledge.

This paper is devoted largely to present the use of qualitative spatial reasoning methods to attain the cognition of scenes in video processing. Video is a sequence of images. It captures real-world events that occur in space over time. The objects or the part of objects in a video scene are perceived as moving in space over time. This change of state is called event that may be a moving part of an object or an interaction between multiple objects. The period within which an event occurs is called the temporal extent of the event whereas the location within which the event is taking place is called the spatial extent of the event.

Spatial relationships between objects in video change over time. Time and space are two important aspects of commonsense knowledge. Time is a scalar quantity and can be represented using qualitative temporal reasoning, which is a subfield of qualitative reasoning. The basic aspects of spatial reasoning are topology, orientation, and distance. There are many other spatial aspects which include size, shape, morphology, and spatial change (motion). Points and spatial regions are the basic entities used to represent spatial relations.

The rest of the paper is organized as follows. Section 2 introduces some basic notions and terminologies of qualitative spatial reasoning. Section 3 provides a survey of representative spatial relationship formalisms used in video processing. Section 4 summarizes the objectives, spatial calculi used as well as the application domains of the surveyed papers. Finally section 5 concludes by mentioning some domain specific spatial calculi obtained by analyzing our survey.

II. Qualitative Spatial Reasoning

The term Qualitative Spatial Reasoning (QSR) is concerned with some methods and techniques which allow to reason about spatial knowledge and thus helps in developing efficient algorithms. Qualitative Spatial Reasoning includes both the sub-fields of representation and reasoning. Representation is concerned with various types of spatial knowledge. It also shows the formalizations and how these can be represented in a computational framework. Reasoning deals with the methods and techniques for decision-making. It provides calculus to a machine for representation and reasoning with spatial entities instead of dealing with traditional

quantitative techniques.There are many different aspects of space and its representation. In the following sections, we will introduce some methods to represent different aspects of qualitative spatial knowledge.

Topology

The topological approach in QSR defines the relationship between spatial regions, which are the subsets of some topological space. The most well-known approach in this domain is Region Connection Calculus (RCC-8), which was given by Randell, Cui and Cohn [2]. Region connection calculus defines that "two regions are connected if their topological closures share a common point". Some approaches distinguish between parthood relation and connected relation [3]. The parthood relation is a mereological primitive whereas connected relation is a topological primitive. Asher and Vieu [4] distinguish between strong contact and weak contact, where strong contact is the case where two regions have points in common and weak contact means two regions are disjoint but their topological closures share common points. Some approaches distinguish between open and closed regions.

Direction and Orientation

Direction relation can be defined as the direction of one entity with respect to another one. The direction relation can be represented in terms of the primary object, the reference object and the frame of reference. The frame of reference may be a third object or a given direction. The three different types of frames of reference are extrinsic, intrinsic and deictic. When the primary object has intrinsic front, orientation calculi is used. If the orientation of the reference object is imposed by some external factors then the frame of reference is termed as extrinsic. If some inherent property of the reference object gives the orientation, then it is called intrinsic and if the orientation is given with respect to the point of view from which the reference object is seen, then the frame of reference is called deictic. Orientation calculi are the special case of a direction calculus. It is the most commonly used qualitative approach. In technical communication, numerical expressions like "53 degrees", "1 foot", etc. are commonly used terms to refer an entity with respect to another one, but in day-to-day non-technical communication, orientation of a spatial entity with respect to another one is normally given as "to the left of", "northeast of", etc. The orientation of spatial entities is a ternary relationship as it depends on the located object, the reference object and the frame of reference. The orientation can be represented in terms of binary relationship with respect to the given frame of reference if the frame of reference is given. According to Frank [5], if in a local space, the cardinal direction of a point with respect to a reference point is expressed as "front", "right", "back" and "left", then in a geographic space, the same can be represented as "north", "east", "south" and "west", depending on granularity. Frank [5] defines "cone-based method" and "project-based method", where the project-based approach represents nine different relations (n,ne,e,se,s,sw,w,nw,eq) in terms of point algebra. The project-based approach is also called "cardinal algebra" which was used by Ligozat [6].

Distance and size

Distance is a scalar entity. In communication, distance can be expressed as "A is close to B", "A is closer to B than to C" or using some numerical values like "A is about one meter away from B". Distance relations can be categorized into absolute distance relation and relative distance relation. Absolute distance is the distance between two spatial entities whereas relative distance is the distance between two spatial entities as compared to the distance to a third entity. Relative distance is qualitative but absolute distance may be either qualitative or quantitative. Sometimes distance and orientation are combined to get the spatial information of an entity. This combination is called positional information. This approach was adopted by Clementini et al. [7] to develop position calculus. Clementini et al. combines a cone-based orientation approach with absolute distance relations.

Shape

The shape is a very important characteristic of an entity, but it is very difficult to describe it qualitatively. It is a visual feature. It is an absolute property which depends only on the region itself.

Region connection calculus

RCC [8] is the notion of connection between pairs of regions in space. There is a set of possible relations representing the connection between a pair of spatial regions. On the basis of the nature and number of connections between a pair of spatial regions, various types of RCC systems can be derived, out of which RCC8 is most widely used. RCC-8 defines eight jointly exhaustive and pairwise disjoint (JEPD) relations between two regions- disconnected (DC), externally connected (EC), equal (EQ), partially overlapping (PO), tangential proper part (TPP), tangential proper part inverse (TPPi), non-tangential proper part (NTPP) and non-tangential proper part inverse (NTPPi). All these relationships are symmetrical except for TPP and NTPP which are anti-symmetrical.

Ternary Point Configuration Calculus

Ternary Point Configuration Calculus (TPCC) is derived from the single cross calculus. It describes the spatial arrangement of a point, relative to two other points. It has the ability to make finer distinctions than any other calculi.

Qualitative Trajectory Calculus

Qualitative Trajectory Calculus (QTC) is used to represent and reason about moving objects in two dimensions. It represents the relative motion of two points with respect to a reference line, which connects the two points. It is computed over consecutive time-points. it was introduced by Van de Weghe in 2004.

Allen's Interval Algebra

Allen's interval algebra contains relations and operations on thirteen basic relations between time intervals which are distinct, exhaustive, and qualitative. The relations are distinct in the sense that no pair of definite intervals can be related by more than one of the relationships, exhaustive in the sense that any pair of definite intervals is described by one of the relations and qualitative as no numeric time spans are considered. Allen's thirteen basic relations are precedes, meets, overlaps, finished by, contains, starts, equals, started by, during, finishes, overlapped by, met by and preceded by.

III. Survey of Representative Spatial Relationship Formalisms

Due to the recent advancement of intelligent mobile robots, the understanding of human activities in daily living environment becomes easier. For the understanding of an observed scene, a set of qualitative spatial- temporal representations can be used to capture the various relations between human and their environment. In [9], various movements of the human body are detected and tracked by using the embedded sensors of a single mobile robot. Also from the environment, the location of the key objects is also learned by the sensors. Qualitative distance calculus and qualitative trajectory calculus are used to represent the various movements of a human body. In [10], qualitative spatial and temporal reasoning (QSTR) and Diagrammatic reasoning (DR) are combined to recognise activities of individual and group of human actors performed in video clips of CAVIAR dataset. Relative position, direction, displacement, distance, Allen's interval relation and angular relation are used as spatial calculi to represent various activities of human actors. Cohn, Renz and Sridhar [11], developed a comprehensive representation of spatial information such as topology, direction, size, distance and motion between two rectangular regions. [12] uses traffic domain where the direction of movement and relative orientation are basically used to represent vehicles qualitatively. Zia UI- Qayyum and A.G. Cohn [13] adopted Vogel et al's semantic modelling framework for image categorization and retrieval [14] for qualitative image description. Images are described qualitatively by relative size, Allen relations [15], Chord patterns [16], and a binary touching relationship. [17] proposed a model for pass prediction over a real world soccer dataset. Basically, four categories of QSRs namely distance, direction, mereotopology and movement are considered in this paper. To define the predicates, this paper defines three categories of features namely static qualitative relationships, dynamic relationship and transition features. In static qualitative relationship, two calculi are employed i.e., cone- shaped direction calculus, which describes the relative position of players with respect to some reference frame and double-cross calculus to describe position of players relative to each possible pass line. Dynamic relationship maps the relative motion between two players like moving towards each other, moving away from each other, and maintaining the same distance using qualitative trajectory calculus (QTC). In transition features, a new predicate is derived to describe the transition from one predicate to another. Very high resolution remote sensing images are analysed in [18] to identify complex objects. In order to describe the relationship between the segmented regions of an image, a spatial reasoning technique called Region Connection Calculus (RCC8) is used.

Typical bottom up approaches allow a robot to recognize objects, but in [19], along with the bottom up object class recognition, a top- down spatial relational reasoning is combined to improve the performance of the perception system. The qualitative description of a scene is constructed from ternary point calculus and four types of predicates, viz. Directional, distance, size and projective connectivity. In [20], the positions of the objects are represented in egocentric frame of reference and the qualitative information about the position of an object is considered. An object which is 'close' to a reference object is qualitatively represented in [21] by its relative position and relative direction with respect to the reference object. The description of the shape of a moving object can be obtained by some tracking process.

The main focus of [22] is to analyze the spatiotemporal structure. The analysis is performed in one spatial dimension plus time. The spatial dimensions considered here are unstructured, static, flicker, coherent motion, incoherent motion and scintillation. Two neighboring objects in [23] are represented qualitatively by their relative position and relative direction of movement. The relative directions considered here are same, opposing, towards and away. [24] is tested on a traffic domain, where the vehicles which move along the same

direction with different speeds are identified. Event models for two neighboring objects (vehicles) are built using QSR calculi for relative direction and relative orientation (e.g., following, overtaking, etc.).

In order to obtain visual and spatial description of the objects in an image, qualitative models of shape, colour, topology and fixed and relative orientation are applied in [25]. Image shape and colour are visual features whereas topology and orientation of regions or objects are the spatial features. They have adopted the qualitative models of topology [26] and orientation [27, 28] to describe the spatial features of the regions.

In [29], quasi-topological relations, cardinal direction relations and qualitative distance relations are considered as a region based spatial relations. The relations between two areal objects of an image are represented by six quasi-topological relations- disjoint, surrounded-by, surround, invade, invaded by and s-meet. In order to find the similarities between regions of a scene, common motion patterns are used in [30]. The spatial regions are grouped on the basis of proximity, direction and local motion similarity of the regions. [31] considers the four spatial relations- partonomic, distance, topological and directional along with the effect of their combinations.

In order to recognize human actions, [32] uses a new 3D qualitative trajectory calculus (QTC_{3D}) [33] to capture the spatio- temporal interaction between different joints of a human skeleton. Spatial and temporal relations are used in [34] to represent interactions of objects. The three spatial relations used in this paper are 'discrete', 'inside' and 'touch'. These set of three topological relations are the abstracted version of RCC8 [35]. They have also used qualitative trajectory calculus QTC_{L1} [36] and some domain specific relations. For temporal interval relations, Allen's interval algebra [37] is used to define the temporal relations between time intervals

In [38], an approach called qualitative image description logic (QIDL) is used to extract the qualitative descriptors. The qualitative descriptors of image considered here are shape, colour, topology and location. [39] presents a modern library named QSRlib which contains QSRs based on Qualitative Distance Calculus, Probabilistic Qualitative Distance Calculus, Cardinal Directions, Moving or Stationary Qualitative Trajectory Calculus, Rectangle/Block Algebra, Region Connection Calculus, Ternary Point Configuration Calculus and combination of direction- topology. In [40], topological, directional, distance information, size of objects and CORE9, Extended CORE9 are used for each activity sequence of a video scene.

In [41], the special aspects of a web document, a combination of RCC8, qualitative distances and directions are used to describe the relationship between each pair of objects. The set of qualitative features used in [42] are cardinal direction, moving or static, qualitative distance calculus and qualitative trajectory calculus.

The qualitative spatial and temporal relational information used in [43] between each pair of polygons are Allen's interval relation, relative position, relative distance, basic displacement relations and relative displacement direction relations derived from QD_8 [44]. In [45], the human poses are abstracted using ternary point configuration calculus (TPCC) [46, 47], qualitative trajectory calculus (QTC) [48] and qualitative distance calculus (QDC). This set of three QSR s is computed by using a publicly available ROS library.

The topological and cardinal direction relations are extracted in [49] using RCC-8 algebra, the rectangle algebra and cardinal direction calculus. In [50], spatial information for human activity recognition is obtained by using spatial calculiExt$CORE9_C$, Ext$CORE9_W$ and $CORE9_W$. The topological relationships between Boolean combinations of regions in [51] are obtained using mereological and qualitative spatial relations. In [52], the spatial relations between active visual objects of real world image can be obtained by using Gaussian mixture models and ternary point calculus.

IV. Summary of the Survey

Table no 1: Summary of the survey

Year	Title of the paper	Objective of the paper	Spatial calculi used in the paper	Application domain
1997	Event recognition using qualitative reasoning on automatically generated spatio-temporal models from visual input. [23]	To generate event models automatically using QSR a statistical analysis of video	Relative Position, Relative direction of motion, Object history/ event database	Traffic
1998	Integrating Vision and Spatial Reasoning for Assistive Navigation [20]	To provide substantial assistance to people with severe mobility Impairments, by enabling wheelchairs with active vision, sensing modes and spatial knowledge representation and reasoning,	Allocentric spatial reference frame and Qualitative position	Intelligent wheelchair project
2000	Constructing qualitative event models automatically from video input. [21]	To generate event models automatically using QSR a statistical analysis of video	Relative Position, Relative direction of motion, object history/ event database	Traffic

2000	Qualitative Spatiotemporal Analysis Using an Oriented Energy Representation [22]	to represent and analyze spatiotemporal information for making qualitative and semantically meaningful distinctions of objects.	one spatial dimension plus time dimensions of the adduced categories: unstructured, static, flicker, coherent motion, incoherent motion and scintillation.	natural imagery
2002	Modeling Interaction Using Learnt Qualitative Spatio-Temporal Relations and Variable Length Markov Models. [12]	To automatically infer object interaction models for interpretation of observed behavior within a scene.	Direction of movement and Relative orientation	Traffic
2007	Image Retrieval through Qualitative Representations over Semantic Features [13]	To bridge the semantic gap between a human user and that of CBIR systems by using qualitative relations over local semantic concepts of images	relative size, Allen relations, Chord patterns and a binary touching relationship	Natural scene images
2008	Towards an Architecture for Cognitive Vision Using Qualitative Spatio-temporal Representations and Abduction. [24]	To construct cognitive vision systems using qualitative spatial-temporal representations	Direction of movement and Relative orientation	Traffic
2008	A framework of region-based spatial relations for non-overlapping features and its application in object based image analysis [26]	To develop a framework of binary spatial relations between segmented objects to aid in object classification.	topological relations, cardinal direction relations and qualitative distance relations.	aerial photo-high resolution remot sensing imagery
2008	Modelling Scenes Using the Activity within Them [30]	To develop a method for building visual maps from video data using quantized descriptions of motion	Direction and motion	an indoor room scenario, an underground station and an outdoor scene .
2009	Qualitative Spatial Reasoning for High-Resolution Remote Sensing Image Analysis [18]	To present the use spatial reasoning techniques in order to describe complex objects	RCC 8	High resolution remote-sensing image
2011	Qualitative spatial representation and reasoning for data integration of ocean observing systems [31]	To develop a framework for qualitative spatial representation and reasoning for data integration of ocean observing systems.	partonomic, topological, distance, and directional relations.	In situ ocean observing stations
2011	Describing Images Using Qualitative Models and Description Logics [25]	To obtain visual and spatial description of all the characteristic regions or objects contained in an image.	shape, colour, topology and fixed and relative orientation	Image of interior of a building
2012	Thinking Inside the Box: A Comprehensive Spatial Representation for Video Analysis [11]	To represent uniform and comprehensive spatial representation of moving objects and to demonstrate the suitability for video analysis	topology, direction, size, distance, and motion	Video input
2014	Reasoning about Topological and Cardinal Direction Relations Between 2-Dimensional Spatial Objects [49]	to present the important combination of topological and directional information for extended spatial objects	RCC8 algebra, the Rectangle Algebra, and Cardinal Direction Calculus	Angry Birds domain
2014	Combining Top-down Spatial Reasoning and Bottom-up Object Class Recognition for Scene Understanding [19]	To develop a framework for combining 3D object class recognition system with learned, spatial models of object relations.	ternary point calculus , Directional, qualitative distance, relative size, Projective connectivity	scene of an office desk
2014	Declarative Spatial Reasoning with Boolean Combinations of Axis- Aligned Rectangular Polytopes [51]	To develop a framework for declarative spatial representation and reasoning about the topological relationships between boolean combinations of regions (i.e., union,intersection, difference, xor).	mereological and qualitative spatial relations.	Any domain such as design, geography, robotics, and cognitive vision.
2014	Bootstrapping Probabilistic Models of Qualitative Spatial Relations for Active Visual Object	To investigate how probabilistic models of qualitative spatial relations can improve the performance object search.	Gaussian Mixture Models, ternary point calculus,	real-world image

	Search [52]			
2015	Applying a 3D Qualitative Trajectory Calculus to Human Action Recognition using Depth Cameras [32]	To develop an application for practical implementation of QTC3D to recognise human actions	3D Qualitative Trajectory Calculus (QTC3D),	skeleton representation of human body
2015	Learning Relational Event Models from Video [34]	to provide a supervised relational learning framework for recognition of events in video.	Qualitative Trajectory Calculus, topological relations-Discrete, Inside, touch; Allen's interval algebra.	an airport domain and a physical action verbs domain
2015	Logics based on Qualitative Descriptors for Scene Understanding [38]	To develop an approach for scene understanding based on qualitative descriptors, domain knowledge and Logic	shape, colour, topology and location	office environments
2016	QSRlib: a software library for online acquisition of Qualitative Spatial Relations from Video [39]	To present a software library that allows easy and fast computation of qualitative spatial and temporal relations from objects tracked in video data	Qualitative Distance Calculus, Probabilistic Qualitative Distance Calculus, Cardinal Directions, Moving or Stationary Qualitative Trajectory Calculus, Rectangle/Block Algebra, Region Connection Calculus, Ternary Point Configuration Calculus	Any domain
2016	Qualitative Spatial and Temporal Reasoning over Diagrams for Activity Recognition [10]	To develop a framework that combines QSTR and DR for activity detection in video.	Relative position, direction, displacement, distance, Allen's interval relation and angular relation.	videos from CAVIAR dataset
2016	Qualitative spatial reasoning for soccer pass prediction [17]	to explore the use of QSRs to extract various kinds of information from spatio-temporal data within the context of soccer pass prediction	Region connected calculus., qualitative trajectory calculus	real-world dataset consisting of 14 matches from a Belgian professional soccer club.
2017	Comprehensive Representation and Efficient Extraction of Spatial Information for Human Activity Recognition from Video Data [50]	To develop an efficient representation schema for extended objects along with a simple recursive algorithm to extract spatial information.	$ExtCORE9_C$, $ExtCORE9_W$ and $CORE9_W$	Human Activity Classification
2017	Efficient extraction of spatial relations for extended objects vis-`a-vis human activity recognition in video [40]	To represent a schema for interaction between rectangular entities.	topology, direction, distance, size, CORE9, Extended CORE9	Video data
2017	Latent Dirichlet Allocation for Unsupervised Activity Analysis on an Autonomous Mobile Robot [45]	To develop a method for unsupervised learning of common human movements and activities on an autonomous mobile Robot.	ternary point configuration calculus (TPCC) , qualitative trajectory calculus (QTC) and qualitative distance calculus (QDC).	publicly available dataset recorded from an autonomous mobile robot
2018	Unsupervised Human Activity Analysis for Intelligent Mobile Robot [9]	to understand human activities of real-world environments from long-term observation from an autonomous mobile robot	Qualitative distance calculus and qualitative trajectory calculus	Human activity video sequence
2018	Spatial reasoning about multimedia document for a profile based adaptation Combining distances, directions and topologies [41]	To present the use of spatial information present in XML document to adapt and modify the original document.	special aspects of a web document, a combination of RCC8, qualitative distances and directions	XML Multimedia
2018	Multimodal Interactive Learning of Primitive Actions [42]	To develop a framework to teach action concepts to machines, useing multimodal human-computer interaction.	cardinal direction, moving or static, qualitative distance calculus and qualitative trajectory calculus	VoxML/VoxSim platform [w,x]
2018	. 'Diagrams': A Hybrid Visual Information Representation and Reasoning Paradigm	To represent a video analysis combining qualitative reasoning with diagrammatic	Allen's interval relation, relative position, relative distance, basic	videos from J-HMDB dataset

	Towards Video Analysis [43]	reasoning	displacement relations and relative displacement direction relations derived from QD_8	

V. Conclusion

In this paper we have surveyed some of the representations of qualitative spatial reasoning. During our survey we have found that a large set of qualitative spatial reasoning calculi have been used in multiple aspects in different domains. The main objective of our survey is to outline a set of most frequently used spatial relationship calculi.

The most commonly used qualitative spatial calculi are topology, relative position, relative orientation, distance and direction. Relative direction of motion is the most widely used spatial calculi in traffic domain. In human activity analysis systems, qualitative trajectory calculus is used to identify physical action or human movements. In most of the video analysis works, Allen's interval calculus is used. In the domain of scene understanding, shape and colour are also used as spatial calculi along with topology and relative position.

Our survey will help the researchers to find a new way in representing qualitative spatial relations in a particular domain which has not been used by any other researcher in their work in the same domain.

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