Qualitative Spatial and Temporal Representation and Reasoning: Efficiency in Time and Space

by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student

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a°	Interior of a point set a	21
$\overline{a}$	Closure of a point set a	21
$a_1 R a_2$, $(a_1, a_2) \in R$	(a_1, a_2) satisfies the relation R	16
$\mathsf{adj}(v)$	Adjacency set of vertex v in a graph	28
α, α_i, β, β_j	some basic relations	18
$\alpha_{i_1} \cup \ldots \cup \alpha_{i_k}$	A relation that is the union of some basic relations	18
$\alpha \diamond \beta$, $R \diamond S$	Weak composition of two relations	31
$\alpha \otimes \beta$, $R \otimes S$	Cartesian product of two relations	19
$\mathcal{R} \otimes \mathcal{S}$	Cartesian product of two subclasses	20
$\alpha \in R$	A basic relation α is contained in a relation R	18
$S \subseteq R$	A relation S is contained in a relation R	18
BA(n,m)	Barabási-Albert model with preferential attachment value m and n vertices	89
$\mathsf{id}_{\mathcal{U}}$	Identity relation	16
$\mathsf{B}_{\mathcal{M}}$	The set of basic relation in a qualitative calculus $\mathcal{M}$	17
$\mathcal{C}$	A set of constraint	25
c_i	A constraint	69
$\bar{d}$	Average intersection degree	133
$\delta(a, b)$	A CDC relation	23

F_k	$\{v_j \in \mathsf{adj}(v_k) : j > k\}$	29
$G = (V, E)$	An undirected graph, with vertices V and edges E	27
$G_{\mathcal{N}}$	Constraint graph	27
$\mathcal{M}$	A qualitative calculus	17
$\mathsf{mbr}(a)$	The MBR of a	21
$\mathcal{N}$, $\mathcal{N}'$	Qualitative constraint network	25
$\mathcal{N}_{\mathrm{c}}$	Core of $\mathcal{N}$	103
$\mathcal{N}_{\mathrm{m}}$	Minimal subnetwork of $\mathcal{N}$	42
$\mathcal{N}_{\mathrm{p}}$	A-closure of $\mathcal{N}$	70
$\mathcal{N}_{\mathrm{p}}^{G}$	partially path consistent subnetwork of $\mathcal{N}$ w.r.t. G	35
$\mathcal{N}\|_{V_0}$	The restriction of $\mathcal{N}$ on $V_0 \subseteq V$	27
$\mathcal{N} \models (uRv)$	$\mathcal{N}$ entails (uRv)	47
o_i	Spatial object or region	122
$\mathbf{O}_5$, $\mathbf{O}_8$	Specific sets of relations in RCC5/8	73
π, $(c_1, \ldots, c_s)$	A path in a QCN	69
$\pi_{<i}$, $\pi_{>i}$	$(c_1, \ldots, c_{i-1})$ and $(c_{i+1}, \ldots, c_s)$	69
$\mathrm{CT}(\pi)$	The composition of a path π in a QCN	70
$\|\pi\|$	The length of a path π in a QCN	69
$\mathcal{P}_{xy}^{\mathcal{N}}$	The set of all paths from x to y in a QCN $\mathcal{N}$	70
R, S, T	A relation	16
R_{ij}, S_{ij}, T_{ij}	A relation between v_i and v_j	16
R^{-1}, S^{-1}, T^{-1}	Converse of a relation	16
$\mathcal{R}, \mathcal{S}, \mathcal{T}$, $\mathcal{X}$	Subclass of relations or subalgebra	18
$\widehat{\mathcal{R}}$, $\widehat{\mathcal{S}}$, $\widehat{\mathcal{T}}$, $\widehat{\mathcal{X}}$	Closure of a subclass of relations	60

$\mathbf{Rel}(\mathcal{U})$	The power set of $\mathcal{U} \times \mathcal{U}$	17
σ	A solution of a network	37
t, t_j	Spatial clustering index tile	122
$\mathcal{U}$	Universe, domain	16
(uRv)	A constraint	25
$\star$	Universal relation	16
V	A set of variables or vertices	25
v, w, u	Variable, vertex	25
W	The intersection of the weak compositions of all paths from x to y in $\mathcal{N} \setminus \{(xRy)\}$	74
x_a^-, y_a^-, x_a^+, y_a^+	Lower (upper) bound of the projection of point set a on x/y-axis	21
$I_x(a)$, $[x_a^-, x_a^+]$, $I_y(a)$, $[y_a^-, y_a^+]$	The projection of point set a on x/y-axis	21
$\mathcal{C}_{\mathrm{PA}}$, $\mathcal{S}_{\mathrm{PA}}$	Maximal distributive subalgebras of PA	207
$\mathcal{C}_{\mathrm{IA}}$, $\mathcal{S}_{\mathrm{IA}}$	Maximal distributive subalgebras of IA	208
$\mathcal{D}^5_{14}$, $\mathcal{D}^5_{20}$	Maximal distributive subalgebras of RCC5	210
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ABSTRACT

Qualitative Spatial and Temporal Reasoning (QSTR) provides a human-friendly abstract way to describe and to interpret spatial and temporal information. To describe the qualitative information, QSTR makes use of qualitative relations between entities and usually stores them in a qualitative constraint network (QCN). The QCNs are then used as the basis to process qualitative spatial and temporal information, including qualitative reasoning and query answering.

Time efficiency of reasoning techniques in QSTR is critical for applications to deal with qualitative spatial and temporal information in large-scale datasets. In this thesis, we present a special family of tractable subclasses of relations, called distributive subalgebras. We show that several efficient algorithms are applicable to the QCNs over distributive subalgebras for solving important reasoning problems. We also identify maximal distributive subalgebras for popular relation models in QSTR and point out their connections with several previously identified important subclasses.

Regarding the network representation in QSTR, there are two important problems, which in turn affect the time efficiency of other applications.

First, the network representation can have redundant relations, which will significantly increase the efforts needed for tasks whose efficiency is strongly related to the number of relations in a network. Fortunately, for any QCN over distributive subalgebras of qualitative calculi PA, RCC5, and RCC8, we show that essentially it has a unique subset consisting of non-redundant relations, which expresses the same qualitative information as the original QCN. We also devise an efficient algorithm to construct such subsets.

Second, the network representation sometimes requires a large storage space when encoding large-scale data. This could severely limit the ability of relation retrieval for any two given spatial entities. In fact, when the size of a QCN becomes large, it might be too costly or even infeasible to fit the QCN into fast accessible storage and relation retrieval will become inefficient. We propose two alternative representation techniques to compactly encode qualitative spatial relations between regions. For this purpose, the first technique uses minimum bounding rectangles (MBRs) to encode both topological relations and directional relations, while the second technique focuses on encoding topological relations by generating axis-aligned rectangles for spatial entities. We show that for large real-world datasets of regions, these two techniques can significantly reduce the storage size of qualitative spatial information and in the meantime the relations between regions can be efficiently inferred from those simple geometric shapes.