Reasoning on the Patterns of Spatial Arrangements between a Path and a Region-Like Landmark

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INTRODUCTION

RfDL (*Region-in-the-frame-of-Directed-Line*) is a series of spatial models that distinguish the patterns of spatial arrangements between a path and a region-like landmark at different levels of granuralities (Kurata and Shi 2008). These models are useful for capturing path-centric concepts of motions, such as "*go toward*", "*pass … on the right*", and "*go across*". Each RfDL model adopts a specific frame of reference (Levinson 1996), which partitions the space on/around the path into a set of *fields*. Each pattern of path-landmark arrangements is defined as the set of fields over which the landmark extends. Among the eight models proposed by Kurata and Shi (2008), the finest model $\text{RfDL}_{3\text{-}12}$ corresponds to Double Cross (Freksa 1992), since both models adopt the same ‡-shaped intrinsic frame that combines left-right, front-side-back, and entry-interior-exit distinctions (Fig. 1a). The aim of this work is to develop a foundation of spatial reasoning on the patterns of path-landmark arrangements modeled by $\text{RfDL}_{3\text{-}12}$, making use of the correspondence between $\text{RfDL}_{3\text{-}12}$ and Double Cross. The developed reasoning methods can be applied, for instance, to the mobile robots that interpret human route instructions. For visualization, path-landmark arrangement patterns modeled by Double Cross and $\text{RfDL}_{3\text{-}12}$, called *DC-patterns* and *$\text{RfDL}_{3\text{-}12}$-patterns*, are represented by icons, whose black cells indicate the fields over which the landmark extends (Fig. 1b).

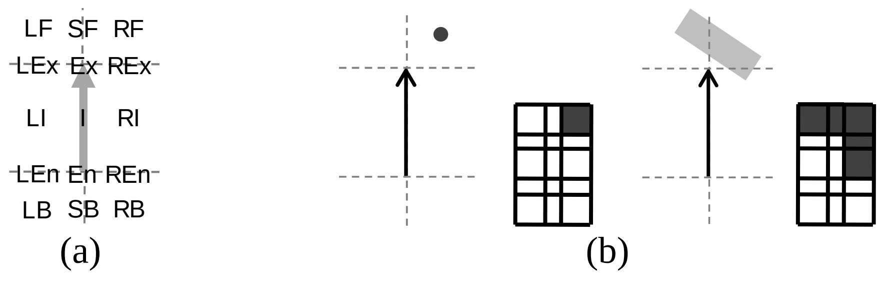


Fig. 1: (a) The frame of reference adopted by Double Cross and $\text{RfDL}_{3\text{-}12}$, and (b) icons of DC- and $\text{RfDL}_{3\text{-}12}$-patterns.

INVERSION, HOMEING, AND SHORTCUT

In Double Cross, *inversion* (*INV*), *homing* (*HM*), and *shortcut* (*SC*) are the operations that map a DC-pattern $\overrightarrow{ab}:c$ to $\overrightarrow{ba}:c$, $\overrightarrow{bc}:a$, and $\overrightarrow{ac}:b$, respectively (Zimmermann and Freksa 1996). In a practical sense, if we know the direction of a location *c* as seen from a path $\overrightarrow{ab}$, $INV\left(\overrightarrow{ab}:c\right)$ gives *c*'s direction as seen from the reversed path $\overrightarrow{ba}$, $HM\left(\overrightarrow{ab}:c\right)$ gives all possible directions of the origin *a* as seen from $\overrightarrow{bc}$, and $SC\left(\overrightarrow{ab}:c\right)$ gives all possible directions of *b* as seen from the shortcutting path $\overrightarrow{ac}$ (Fig. 2a). Thus, considering similar perspective changes (Figs. 2a-b), we defined the inversion, homing, and shortcut of an $RfDL_{3\text{-}12}$-pattern $\overrightarrow{ab}:R$ (*R*: a region) as $INV\left(\overrightarrow{ab}:R\right)=\overrightarrow{ba}:R$, $HM\left(\overrightarrow{ab}:R\right)=\bigcup_{x\in R}\overrightarrow{bx}:a$, and $SC\left(\overrightarrow{ab}:R\right)=\bigcup_{x\in R}\overrightarrow{ax}:b$.

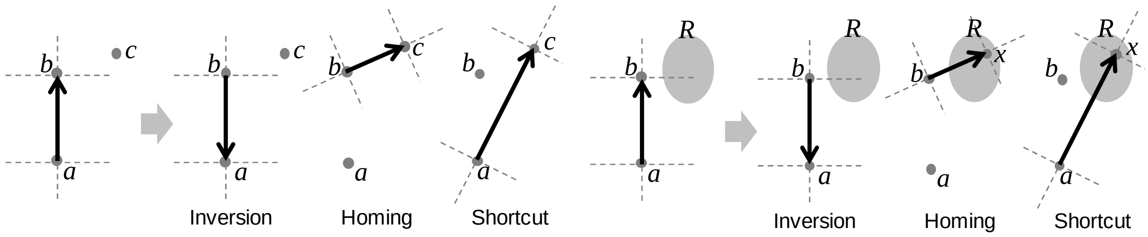
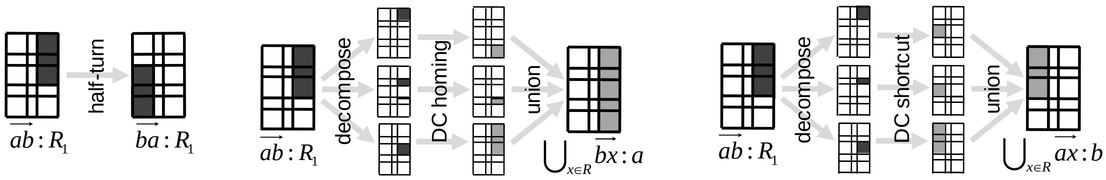


Fig. 2: Perspective changes in inversion, homing, and shortcut operations.

$INV\left(\overrightarrow{ab}:R\right)$ gives *R*'s direction as seen from the reversed path $\overrightarrow{ba}$. It is easily derived by the icon's half-turn (Fig. 3a). $HM\left(\overrightarrow{ab}:R\right)$ gives all possible directions of the origin *a* as seen from a path $\overrightarrow{bx}$ where *x* is somewhere in *R*. It is derived as the union of the results of DC-homing $HM\left(\overrightarrow{ab}:x\right)$ where $x\in R$ (Fig. 3b). Finally, $SC\left(\overrightarrow{ab}:R\right)$ gives all possible directions of *b* as seen from a shortcutting path from $\overrightarrow{ax}$ where *x* is somewhere in *R*. It is derived similarly by union operation (Fig. 3c). Note the results of $RfDL_{3\text{-}12}$-homing and $RfDL_{3\text{-}12}$-shortcut are a set of DC-patterns. Thus, $RfDL_{3\text{-}12}$-homing and $RfDL_{3\text{-}12}$-shortcut cannot be applied repeatedly to $RfDL_{3\text{-}12}$-patterns, unlike DC-homing and DC-shortcut that can be applied repeatedly to DC-patterns. This limitation stems from the heterogeneity of $RfDL_{3\text{-}12}$-patterns, which are established by two points and a region, instead of three points.



(a) inversion (b) homing (c) shortcut

Fig. 3: Derivation of inversion, homing, and shortcut of the RfDL$_{3\text{-}12}$-pattern $\overrightarrow{ab}:R$ in Fig. 2b. Icons with gray cells represent a set of DC-patterns, each with only one black cell among the gray cells.

Composition

The composition of DC-patterns $\overrightarrow{ab}:c$ and $\overrightarrow{bc}:d$, denoted as $\overrightarrow{ab}:c\,;\overrightarrow{bc}:d$, gives all possible patterns of $\overrightarrow{ab}:d$ (Freksa 1992). Similarly, we can consider the composition of a DC-pattern $\overrightarrow{ab}:c$ and an RfDL$_{3\text{-}12}$-pattern $\overrightarrow{bc}:R$, denoted as $\overrightarrow{ab}:c\,;\overrightarrow{bc}:R$, which gives all possible patterns of $\overrightarrow{ab}:R$. For instance, if c is located at the right front of $\overrightarrow{ab}$ and R extends over the left front to the right front of $\overrightarrow{bc}$ (Fig. 4), there are 15 possible patterns of $\overrightarrow{ab}:R$. Basically, this composition is derived as the union of the results of the DC-composition $\overrightarrow{ab}:c\,;\overrightarrow{bc}:x$, considering a point x that moves in R (Fig. 4). From Freksa's (1992) composition table, we can determine $\overrightarrow{ab}:c\,;\overrightarrow{bc}:x$ when x is located at $\overrightarrow{bc}$'s left-front, straight-front, and right-front, respectively. Each of the three results of $\overrightarrow{ab}:c\,;\overrightarrow{bc}:x$ specifies the fields where x can be located with respect to $\overrightarrow{ab}$. Since R contains x, R extends over at least one of the fields that each of the three results specifies (Condition 1). In addition, R extends over no field other than the union of the three results (Condition 2). Among all RfDL$_{3\text{-}12}$-patterns, only 15

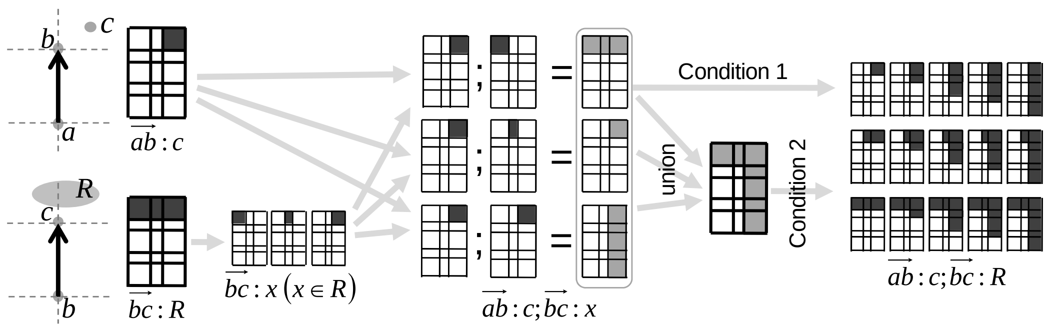


Fig. 4: Derivation process of the composition $\overrightarrow{ab}:c;\overrightarrow{bc}:R$.

patterns satisfy these two conditions (Fig. 4). Thus, these 15 patterns are the result of the composition $\overrightarrow{ab}:c\,;\overrightarrow{bc}:R$.

We can also define another type of composition, which combines two RfDL$_{3\text{-}12}$-patterns—say, $\overrightarrow{ab}:R_1\,;\overrightarrow{bx}:R_2\,(x\in R_1)$. This composition gives all possible $\overrightarrow{ab}:R_2$ after a two-step movement from *a* via *b* to somewhere *x* in R_1, during which $\overrightarrow{ab}:R_1$ and $\overrightarrow{bx}:R_2$ are observed. Similarly, this composition is derived as the union of the results of DC-composition $\overrightarrow{ab}:x\,;\overrightarrow{bx}:y$, considering two points *x* and *y* that move in R_1 and R_2, respectively.

CONCLUSIONS AND FUTURE WORK

RfDL models are useful for characterizing path-landmark arrangements in a qualitative way, because the spatial patterns of RfDL models highlight where and how the landmark extends as seen from a moving agent. Indeed, Kurata and Shi (2008) applied RfDL$_{3\text{-}12}$ model to associating path-landmark arrangements with a number of human concepts of motions. In this paper, we developed a foundation of qualitative spatial reasoning on the pattern of the RfDL$_{3\text{-}12}$ model. Reasoning on the patterns of the other coarser RfDL models is also possible by assuming all potentially corresponding RfDL$_{3\text{-}12}$-patterns and integrating the results of reasoning on these patterns. In our current work, we are developing a set-theoretic computational approach to realize the operations discussed in this paper.

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