Using Orientation Information for Qualitative Spatial Reasoning

Christian Freksa, 1992

presented by Amenity Applewhite
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Outline

- Introduction
- Motivation
- Previous approaches
- Argument for qualitative orientation
- Directional orientation in 2D
- Augmenting qualitative relations
- Conceptual neighborhood theory
- Using the orientation-based framework
- Applications
- Further work

Introduction

An approach to represent ***spatial knowledge*** using qualitative, neighborhood-oriented spatial information.

Motivation: Why qualitative?

Quantitative knowledge obtained by ***measuring***:

Motivation: Why qualitative?

Quantitative knowledge obtained by ***measuring***:

"thirteen centimeters"

Motivation: Why qualitative?

Quantitative knowledge obtained by ***measuring***:

"thirteen centimeters"

- Requires mapping between object domain and scale domain
- Mapping can produce distortions

Motivation: Why qualitative?

Qualitative knowledge obtained by ***comparison*** rather than ***measuring***:

Motivation: Why qualitative?

Qualitative knowledge obtained by ***comparison*** rather than ***measuring***:

"longer"

Motivation: Why qualitative?

Qualitative knowledge obtained by ***comparison*** rather than ***measuring***:

"longer"

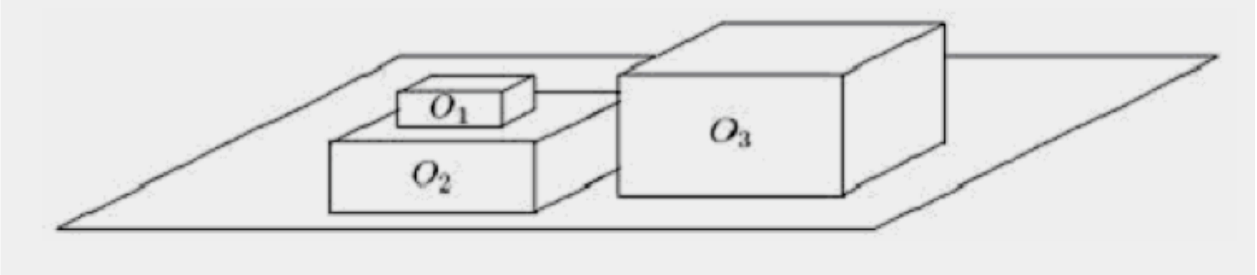
- Direct evaluation entirely within object domain
- Focuses knowledge processing on information relevant to decision making

Motivation: Why spatial?

- Spatial reasoning is essential to numerous actions and decisions
- Arguably, physical space is more fundamental than logical reason:
  - Spatial reasoning more "primitive" in nature
  - Logic as an abstraction of spatial reasoning

Previous approaches to qualitative spatial reasoning

Cartesian framework Güsgen, 1989



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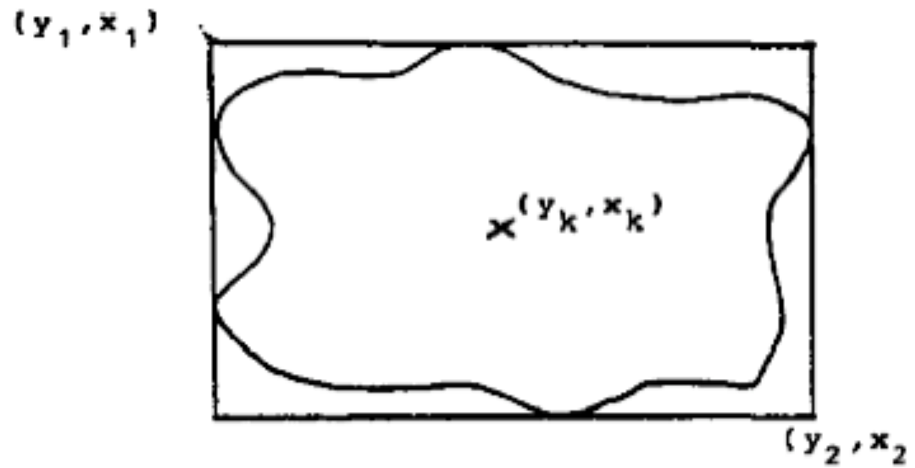

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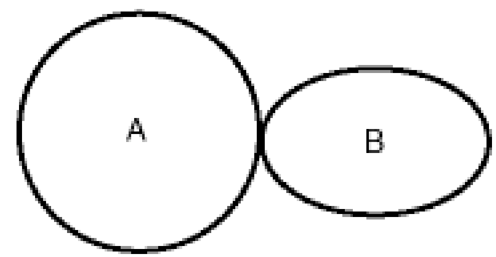
Object-boundary and interior intersections
Egenhofer & Franzosa, 1991



A TOUCH B

Previous approaches to qualitative spatial reasoning

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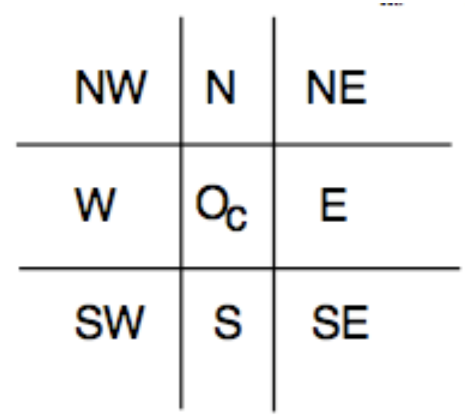
Cardinal direction grids Frank, 1991



Why qualitative orientation?

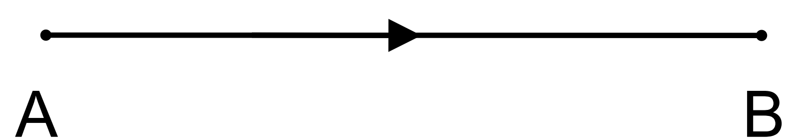
Availability of spatial information:

- Qualitative orientation is available through ***pure perception***
- Other representations, such as Cartesian coordinates or cardinal orientation, refer to ***extra-perceptual*** information

Directional orientation in 2D

Directional orientation a 1D feature determined by an oriented line

Oriented line specified by an ordered set of two points



orientation ab

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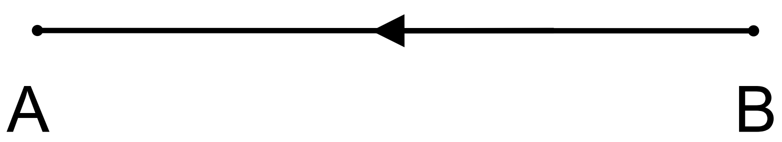
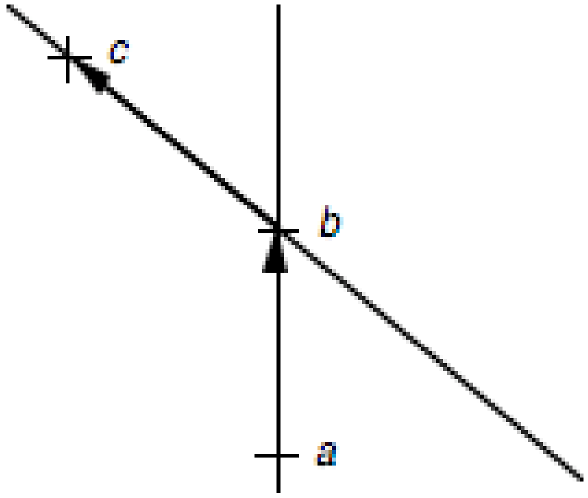


orientation ba

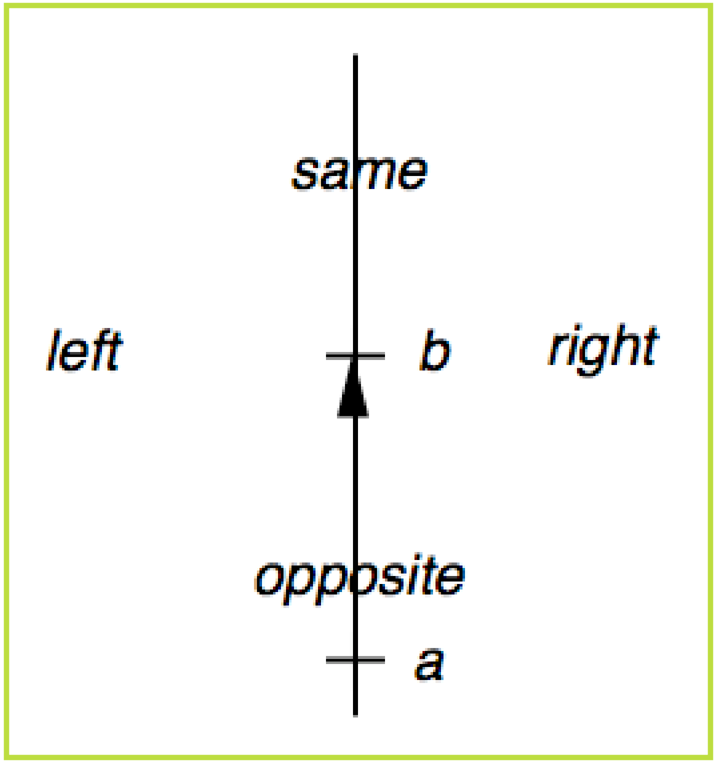
Directional orientation in 2D

Relative Orientation specified by two oriented lines



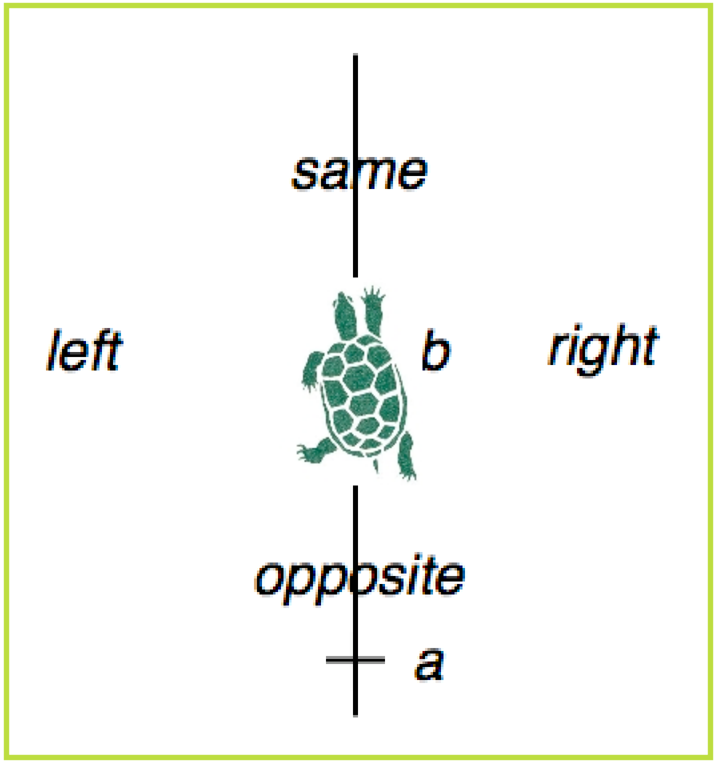
Orientation of line bc relative to line ab

Properties of qualitative orientation



wrt. location b and orientation ab

Properties of qualitative orientation



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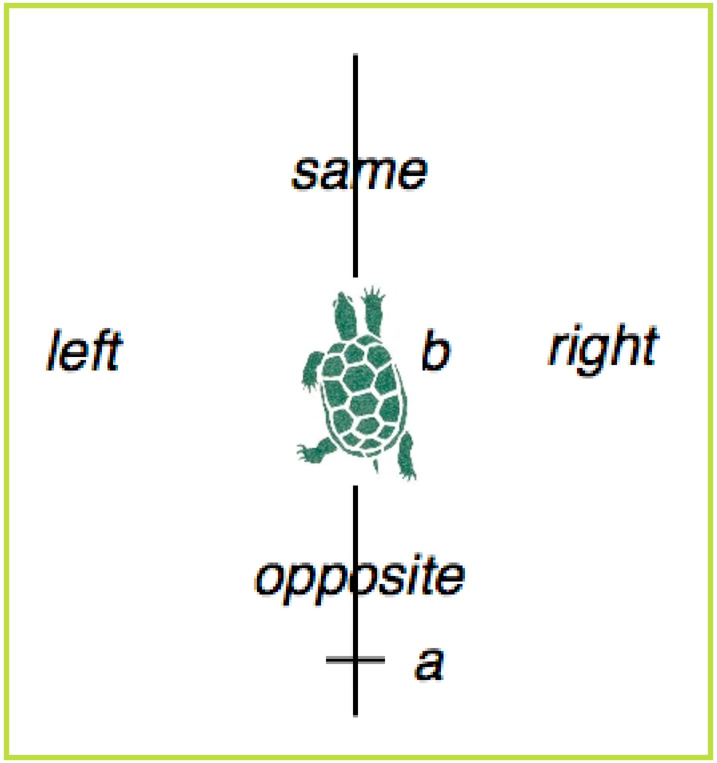
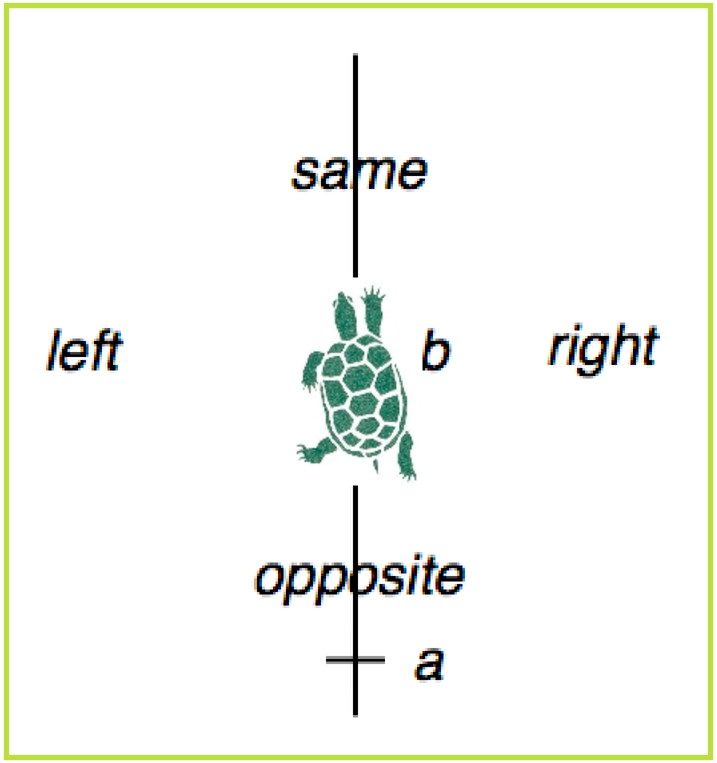


wrt. location b and orientation ab

Same transitive

if ab=bc and bc=cd then ab=cd

Properties of qualitative orientation



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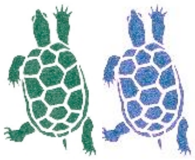

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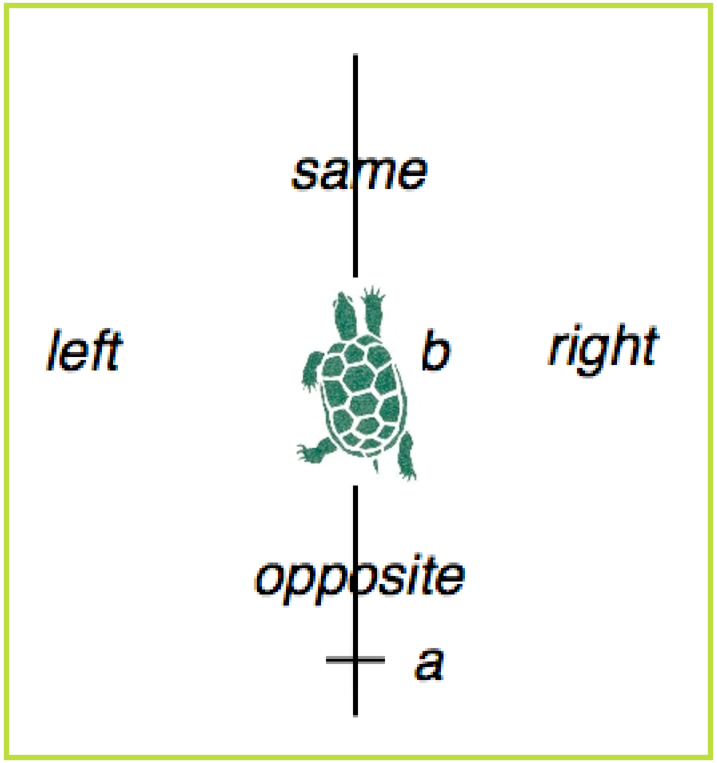

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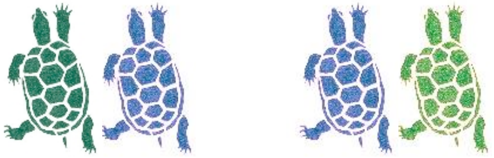

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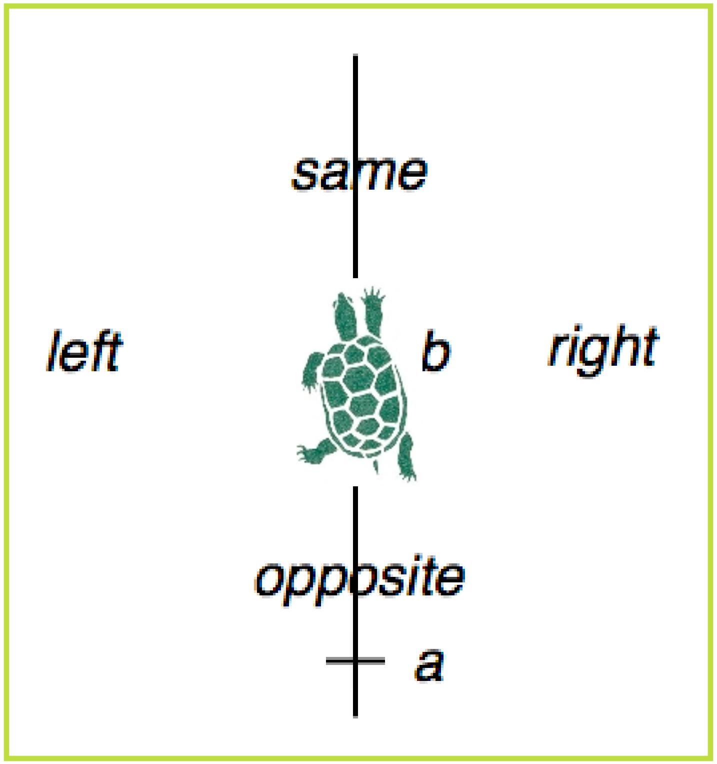

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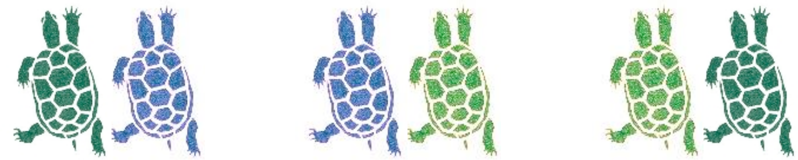

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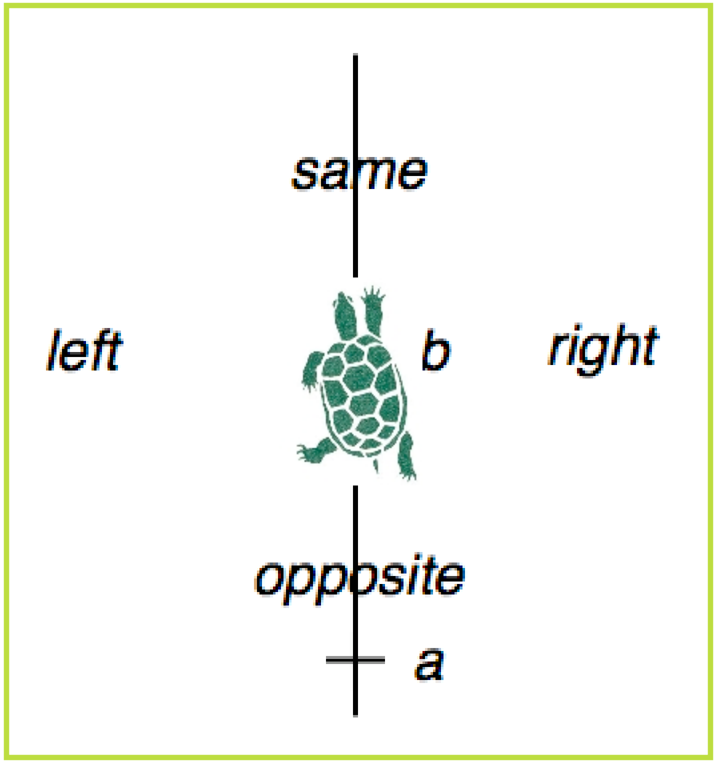

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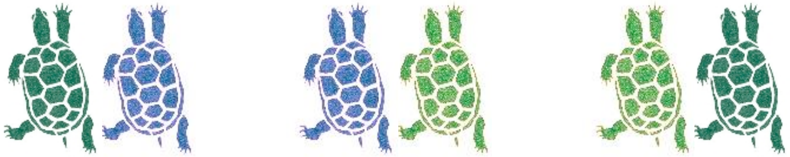
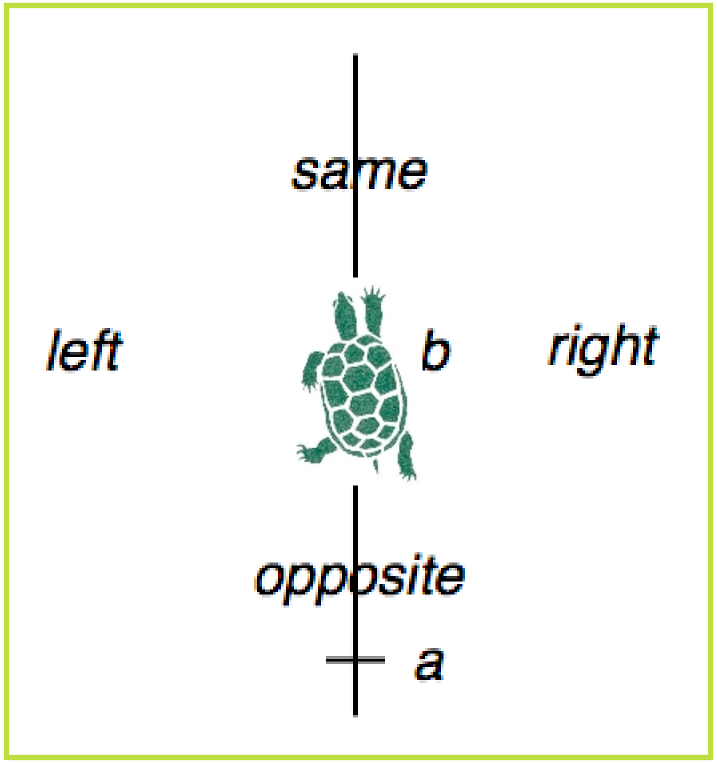


Opposite periodic

Properties of qualitative orientation



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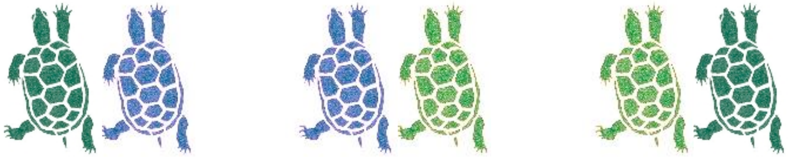
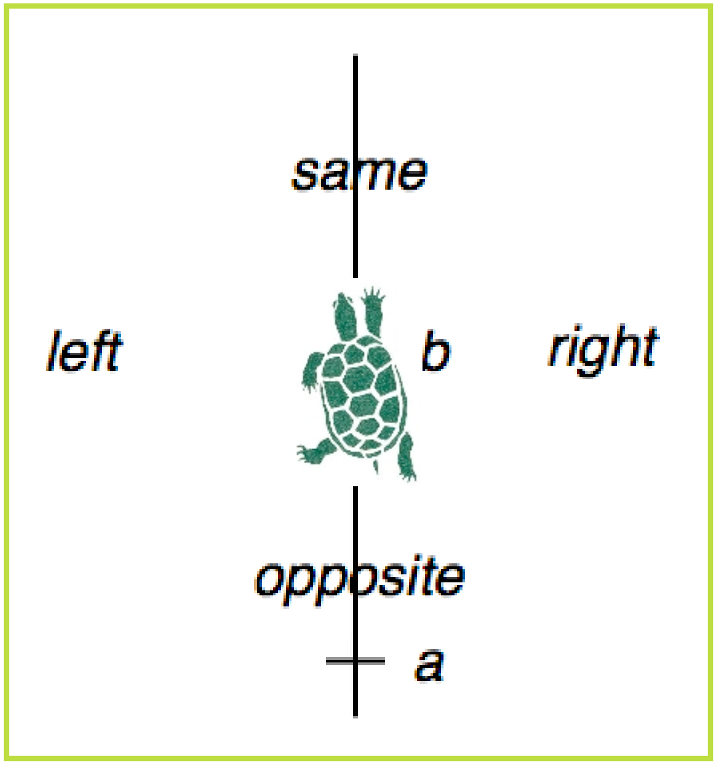


Opposite periodic

opposite ∞ *left* yields *right*

Properties of qualitative orientation



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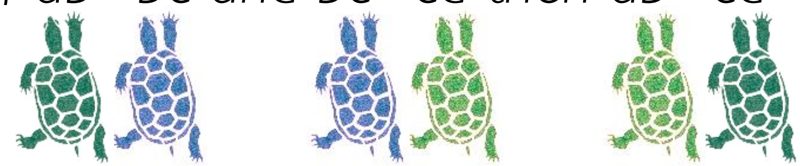

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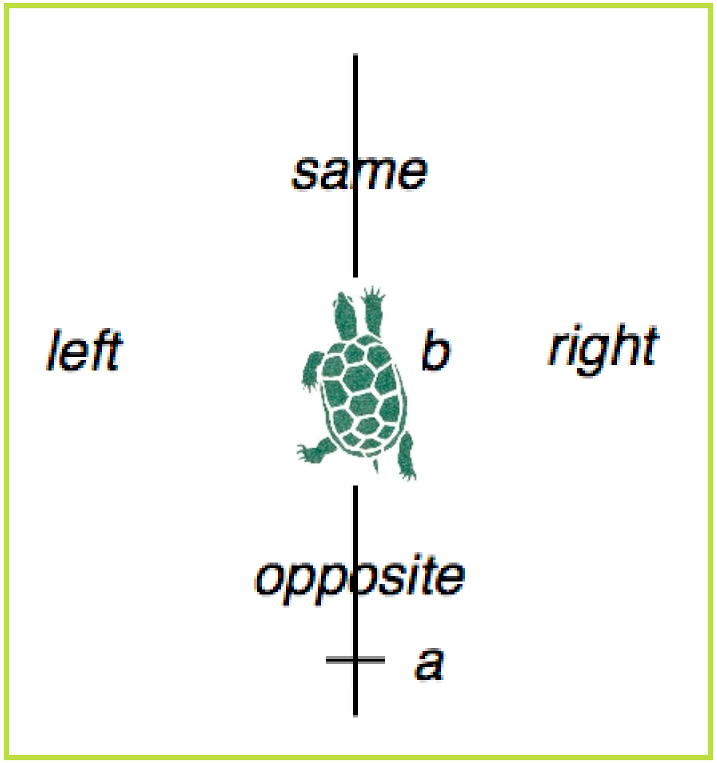

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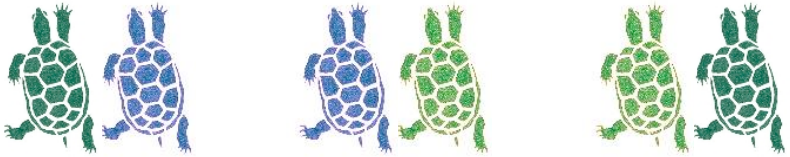

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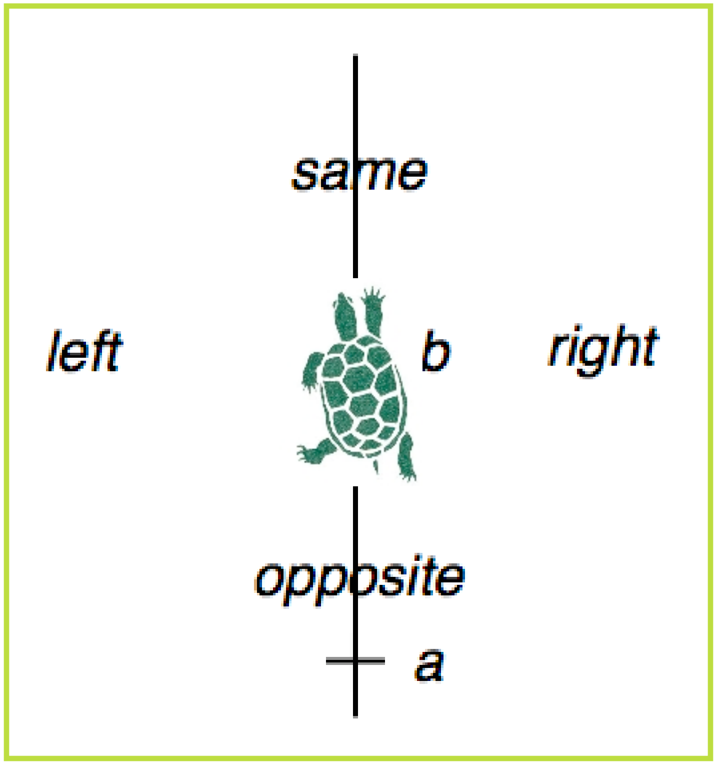

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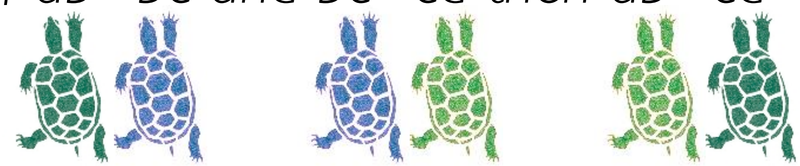

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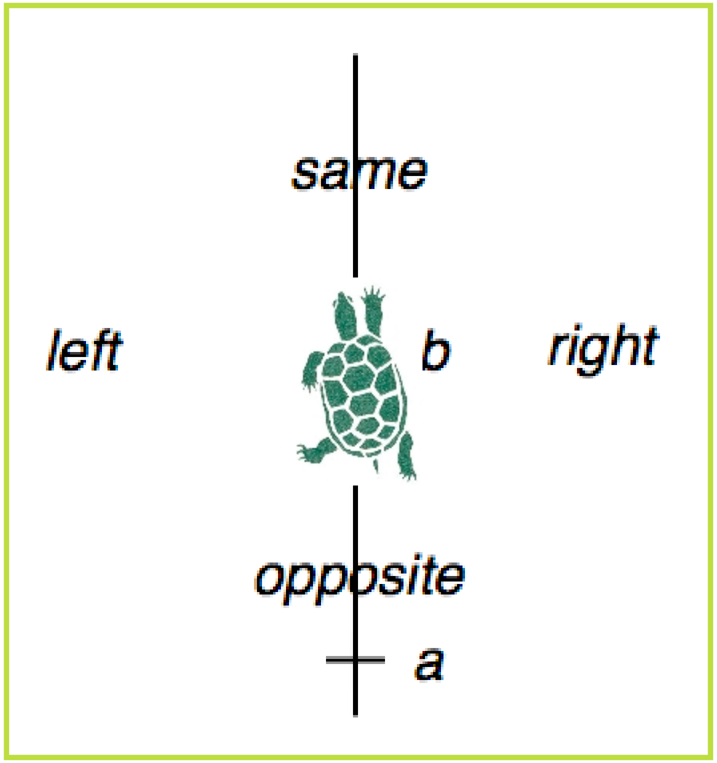

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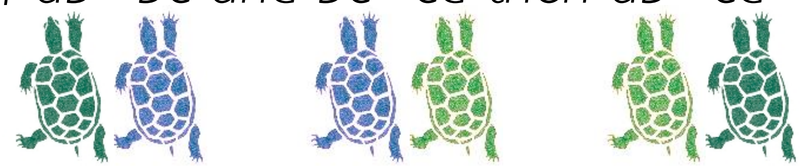

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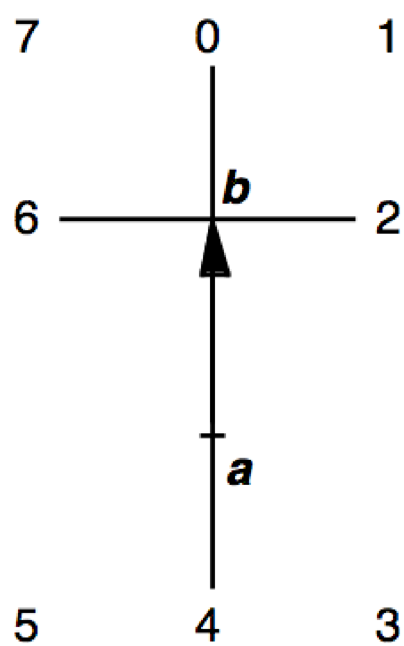
Orientation is a circular dimension

Augmenting qualitative relations

Front-back segmentation

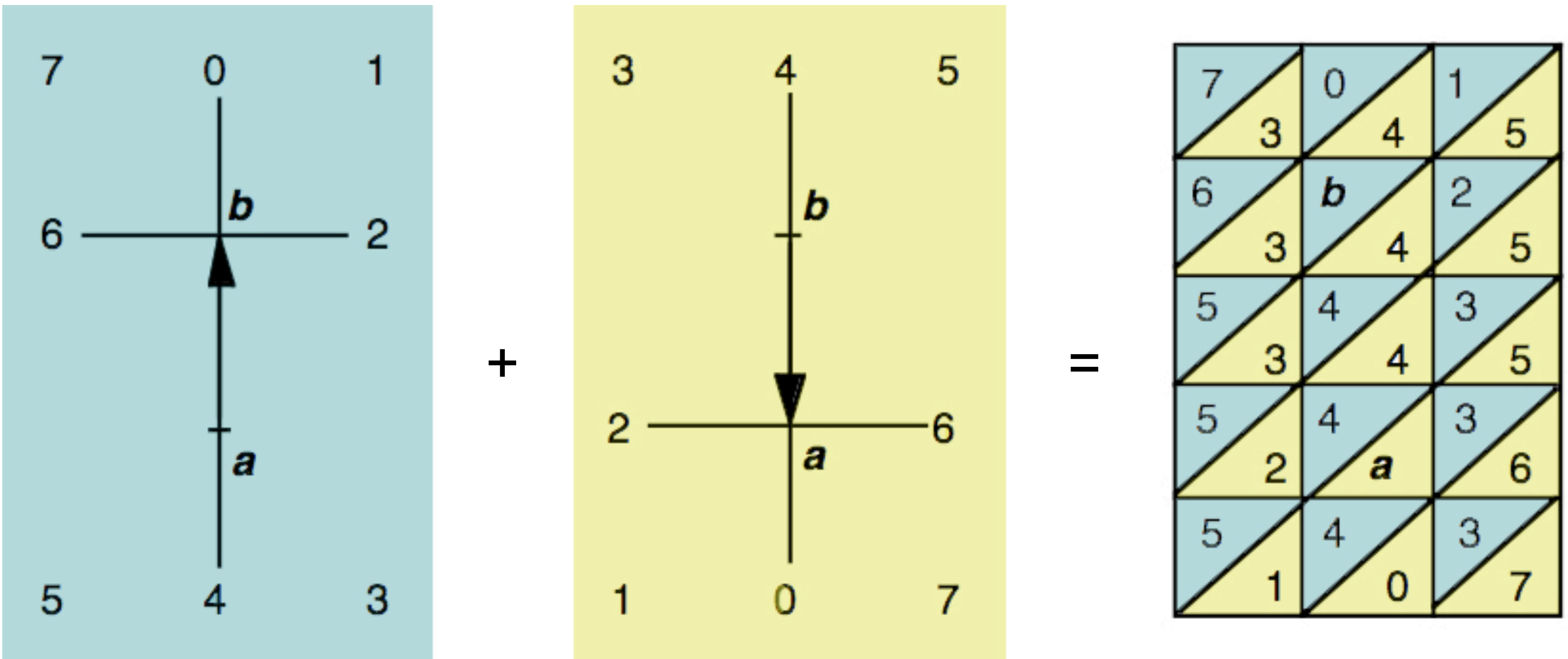
- cognitively meaningful to people and animals
- most objects have this implicit dichotomy



8 disjoint orientation relations

0 straight-front	*4 straight-back*
1 right-front	*5 left-back*
2 right-neutral	*6 left-neutral*
3 right- back	*7 left-front*

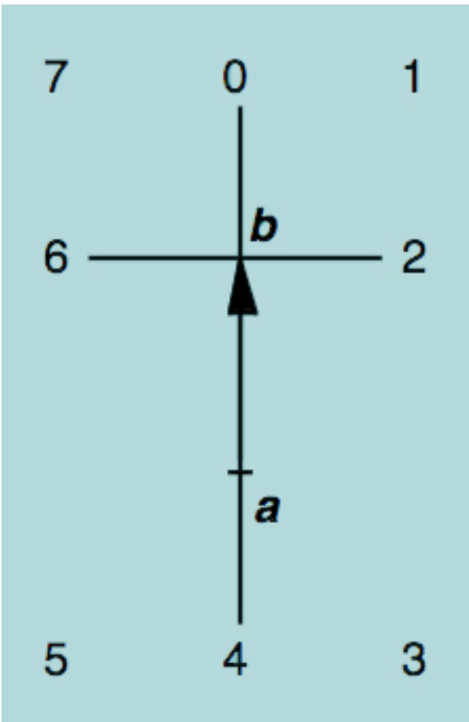
Orientation-based qualitative location



front-back dichotomy wrt. ab in b

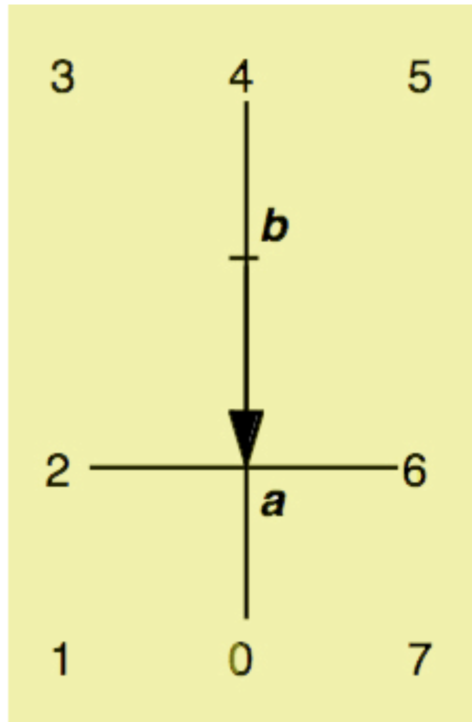
front-back dichotomy wrt. ba in a

Orientation-based qualitative location



front-back dichotomy wrt. ab in b

+



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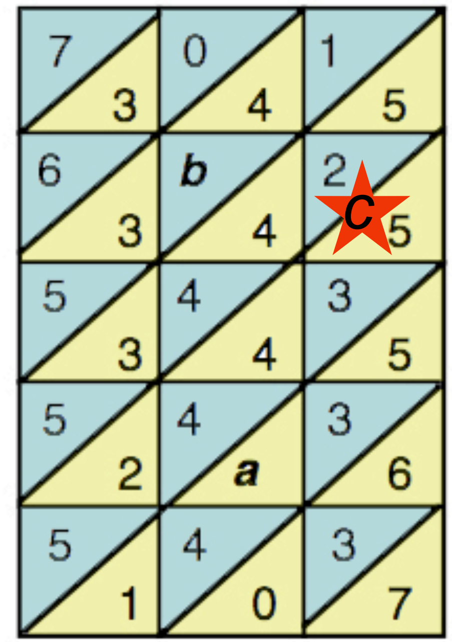
=



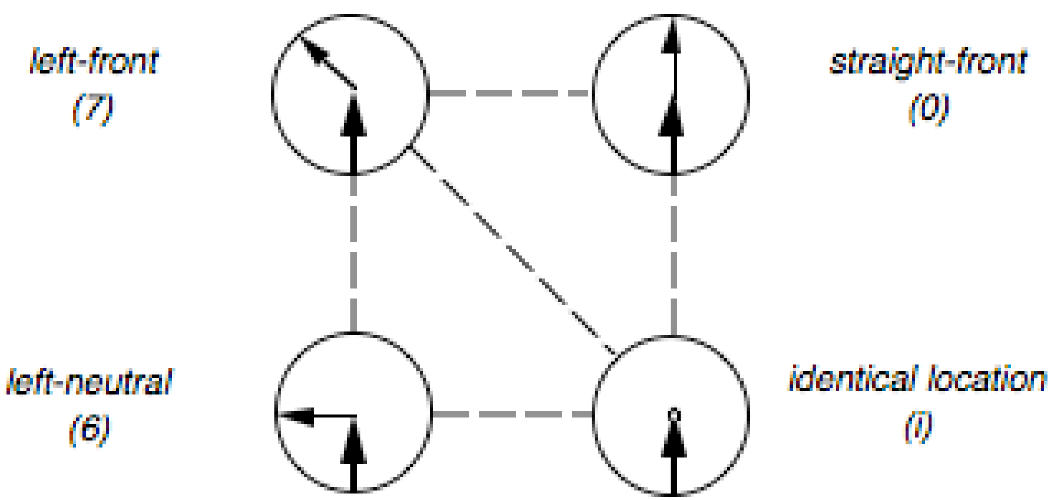
Conceptual neighborhood

Conceptual neighbor a relation that represents a direct transition in the object domain from the initial relation

- Based on studies of temporal cognition
- Cognitive & computational advantages

Conceptual neighborhood

- ***Conceptual neighbor*** a relation that represents a direct transition in the object domain from the initial relation



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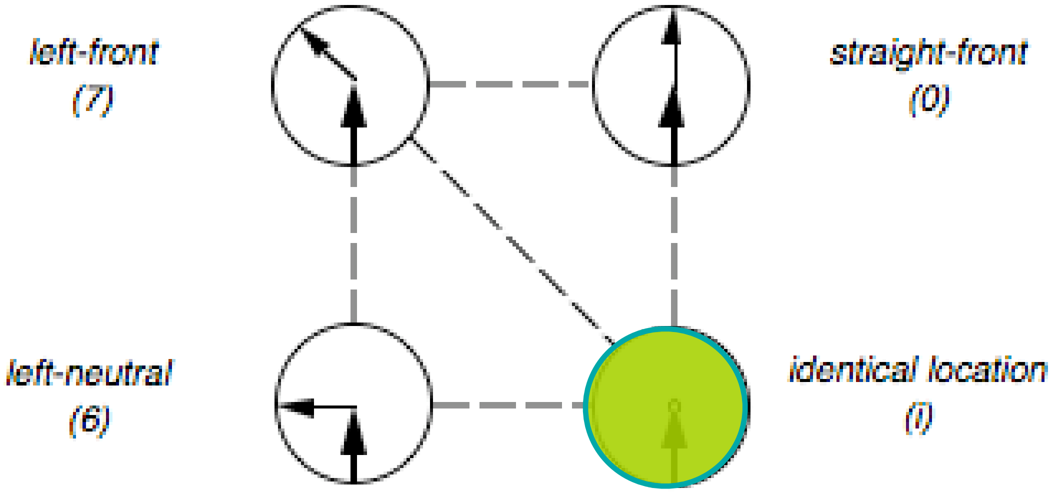

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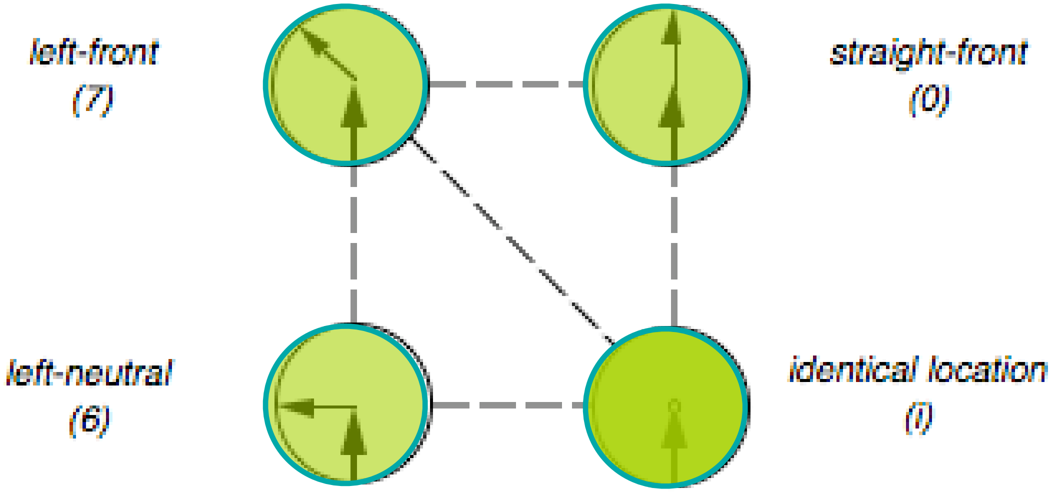


Conceptual neighbors:

i and 6

i and 7

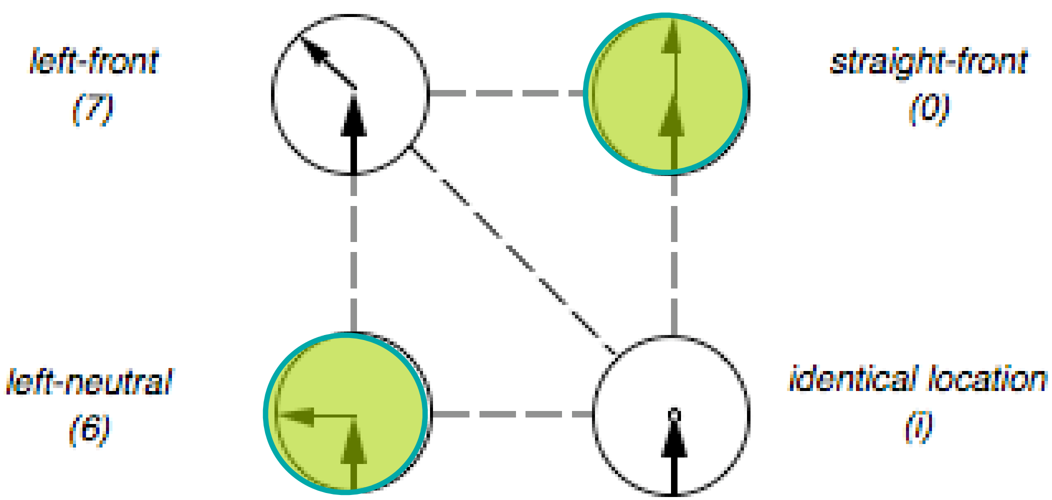
i and 0

6 and 7

7 and 0

Conceptual neighborhood

- ***Conceptual neighbor*** a relation that represents a direct transition in the object domain from the initial relation



Conceptual neighbors:

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i and 7

i and 0

6 and 7

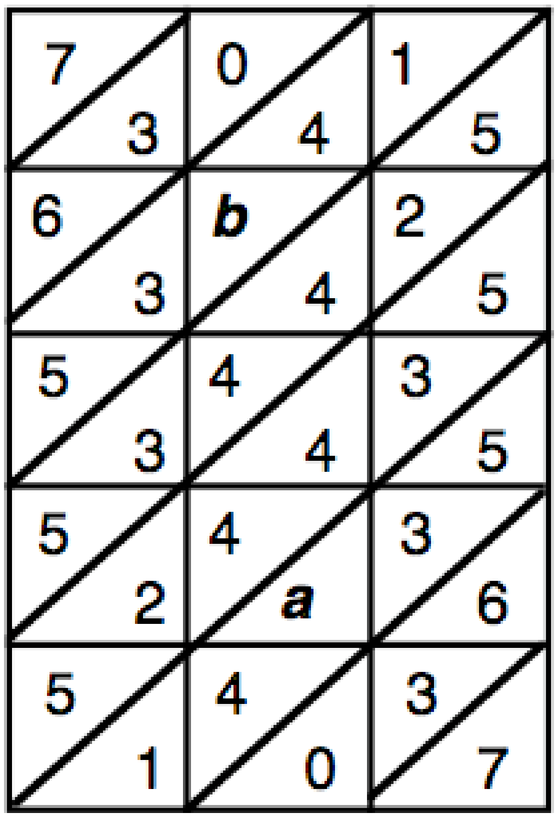
7 and 0

Not conceptual neighbors:

Require intermediate relations

6 and 0

Conceptual neigborhood in represented domain



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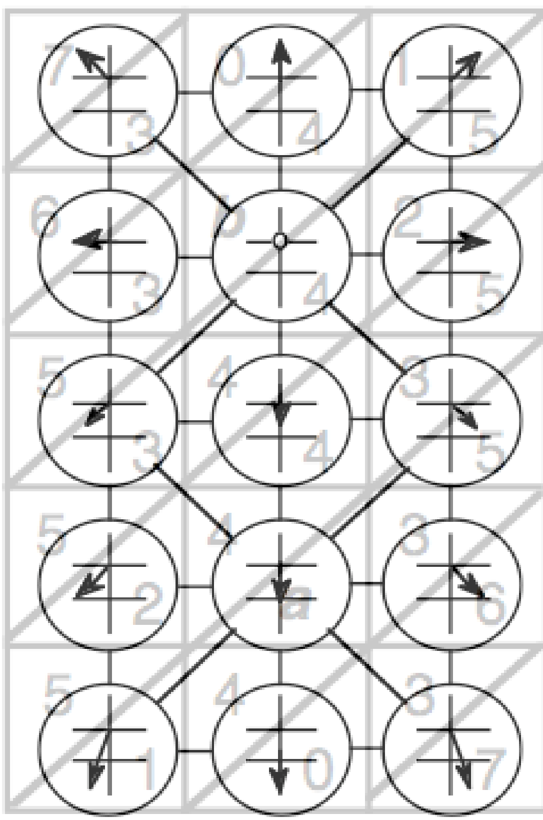

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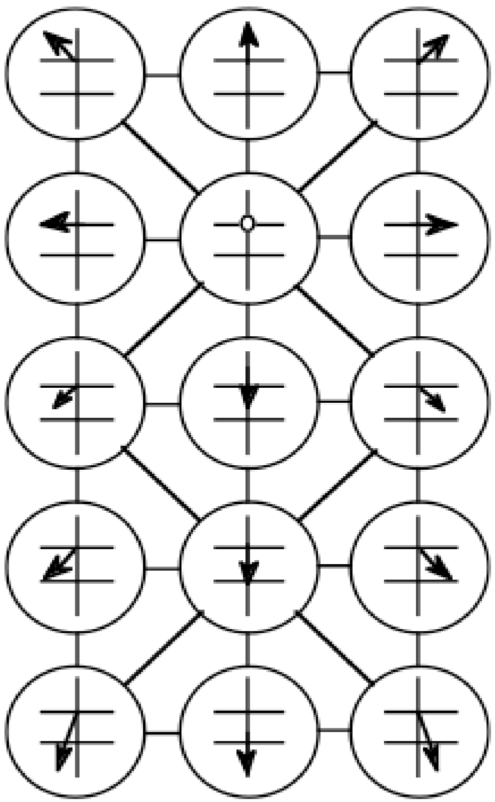
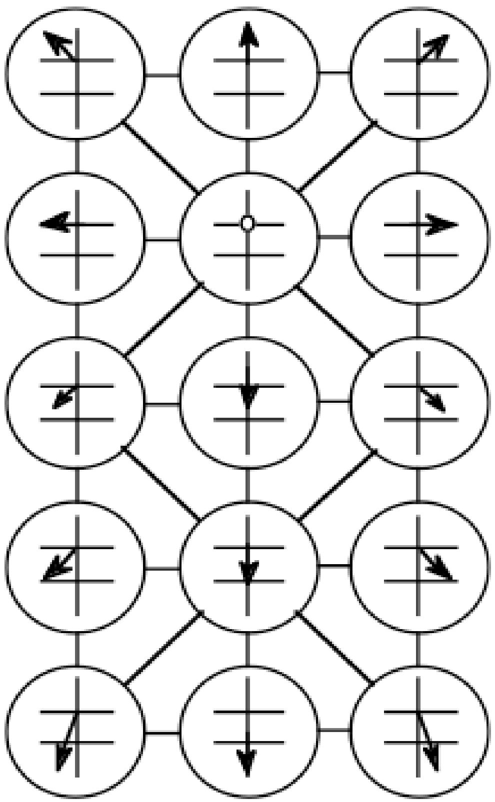


- *15 qualitative relations*
- *105 (unordered) pairs*
- *30 conceptual neighbors*

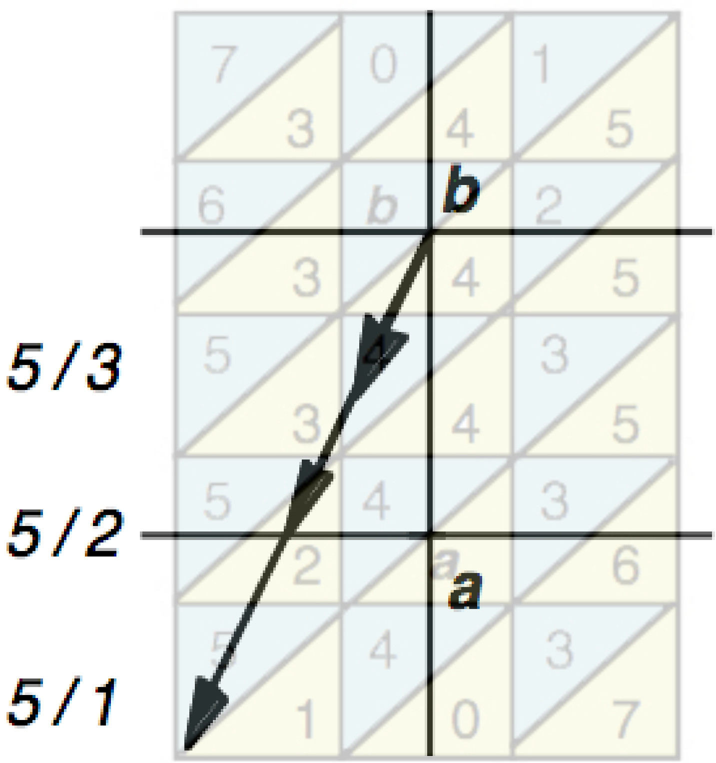
Conceptual neigborhood in represented domain



Utility

- Reflects represented world
- Reasoning strategies entirely within the represented domain
- Assist domain visualization
- Computationally restrict problem space to feasible operations

Orientation-based qualitative distance



- Finer spatial resolution ***conveys distance***
- Does not increase orientation precision

Represented entities

Most approaches

- spatially extended objects
- convex or rectangular shapes

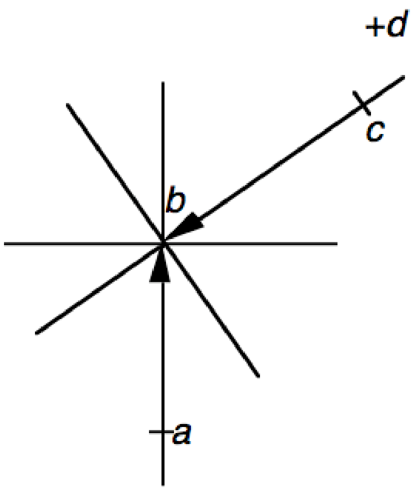
Points as basic entities, fundamental approach

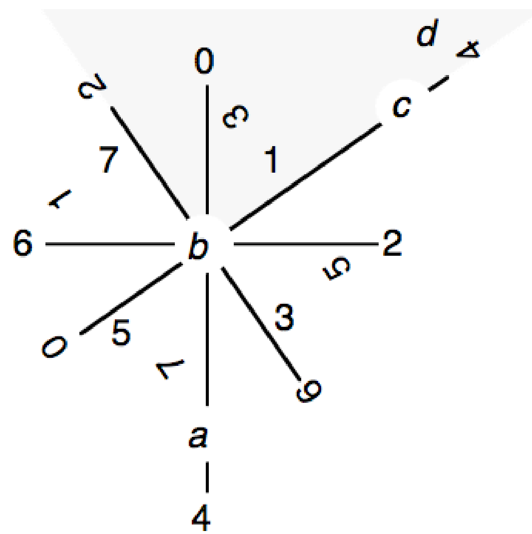
- Properties & relations hold for entire spatial domain
- Shapes can be described as points with various levels of abstraction and precision; flexible

0D point	city on wide area map
1D extension	length of a road
2D projection	area of a lake
3D constellation	shape or group of objects

Qualitative spatial reasoning

Using the orientation-based framework for inferences

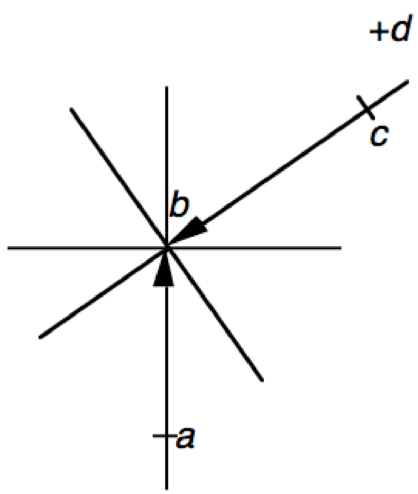


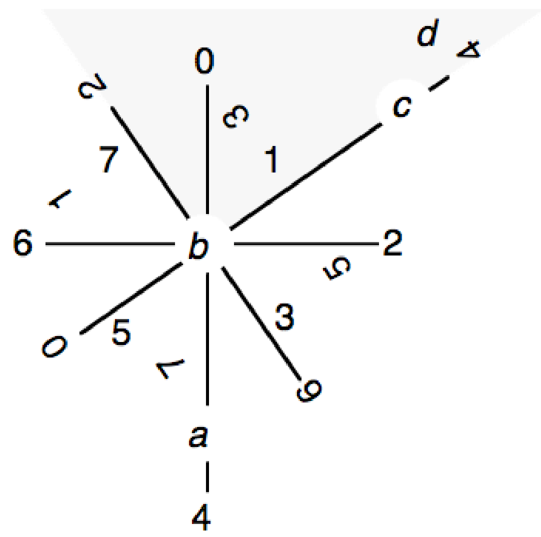


- Describe one spatial vector with relation to another
- Infer unknown vector relations based on known relations

Qualitative spatial reasoning

Using the orientation-based framework for inferences





Given

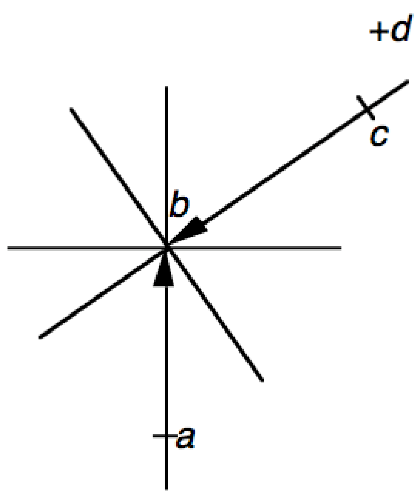
- relation of <u>vector ***bc***</u> to <u>vector ***ab***</u>
- relation of <u>vector ***cd***</u> to <u>vector ***bc***</u>

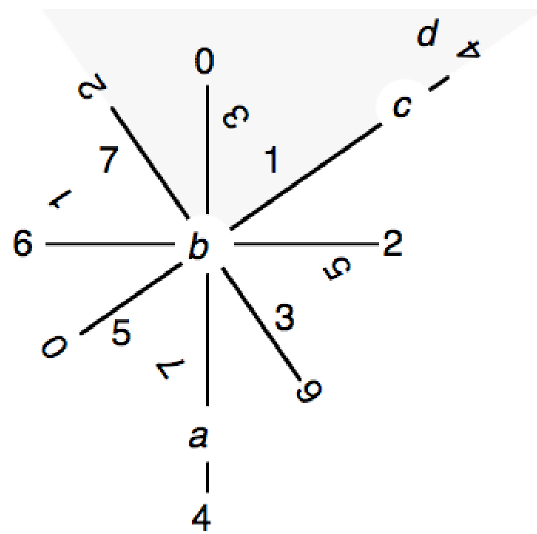
Infer

location of <u>***d***</u> to <u>vector ***ab***</u>

Qualitative spatial reasoning

Using the orientation-based framework for inferences

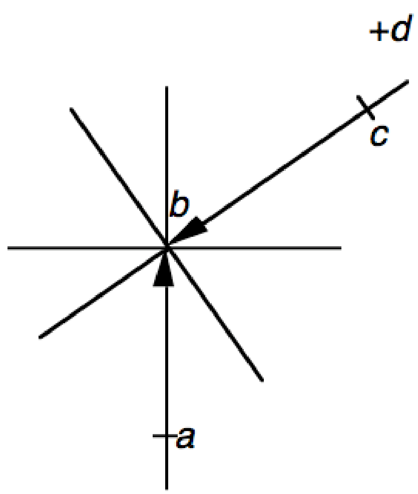


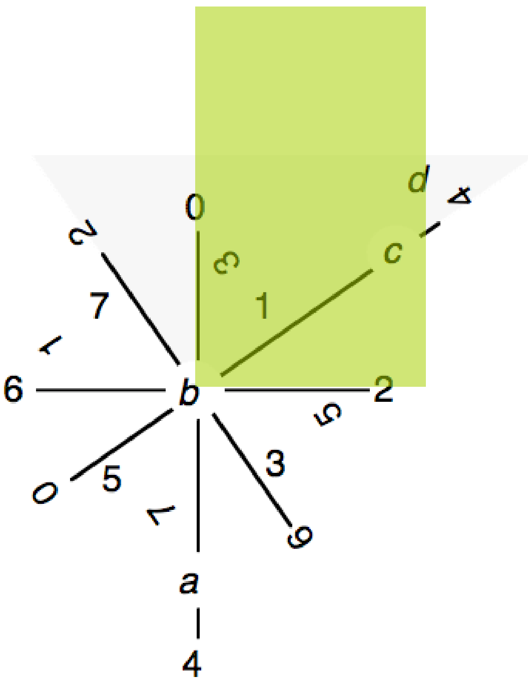


- Consider front-back dichotomies for known vectors

Qualitative spatial reasoning

Using the orientation-based framework for inferences

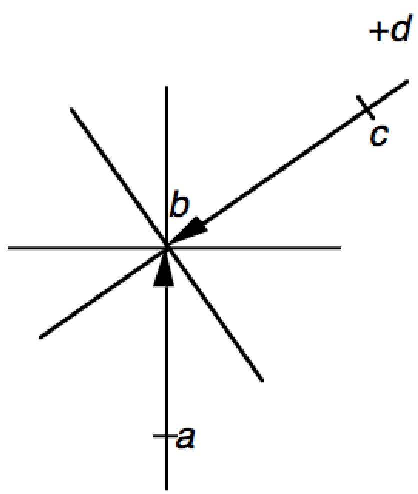


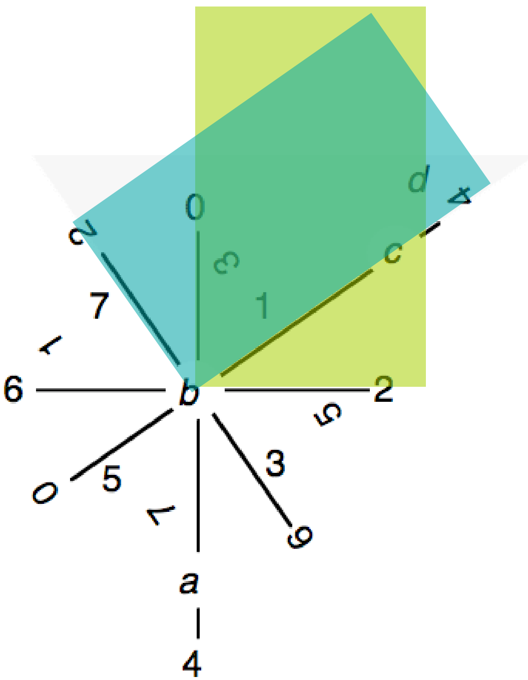


- Consider front-back dichotomies for known vectors
- *c right-front (1)* ***ab***

Qualitative spatial reasoning

Using the orientation-based framework for inferences

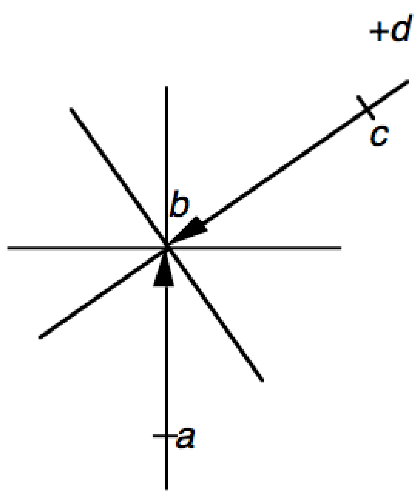


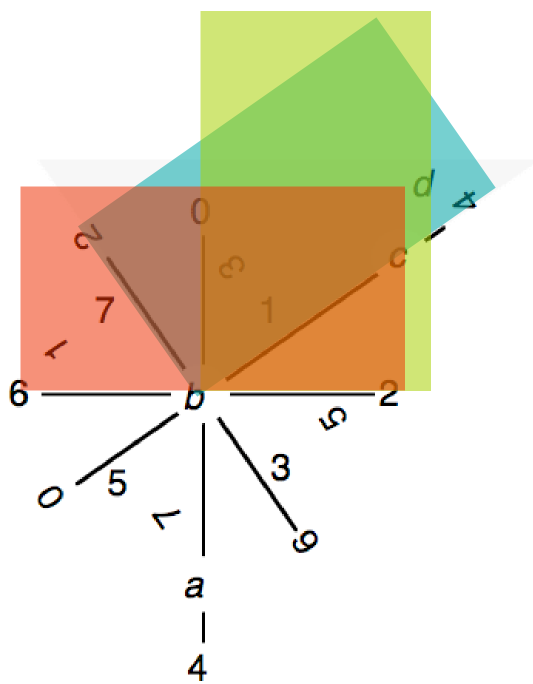


- Consider front-back dichotomies for known vectors
- *c right-front (1)* ***ab***
- *d right-back (3)* ***cb***

Qualitative spatial reasoning

Using the orientation-based framework for inferences





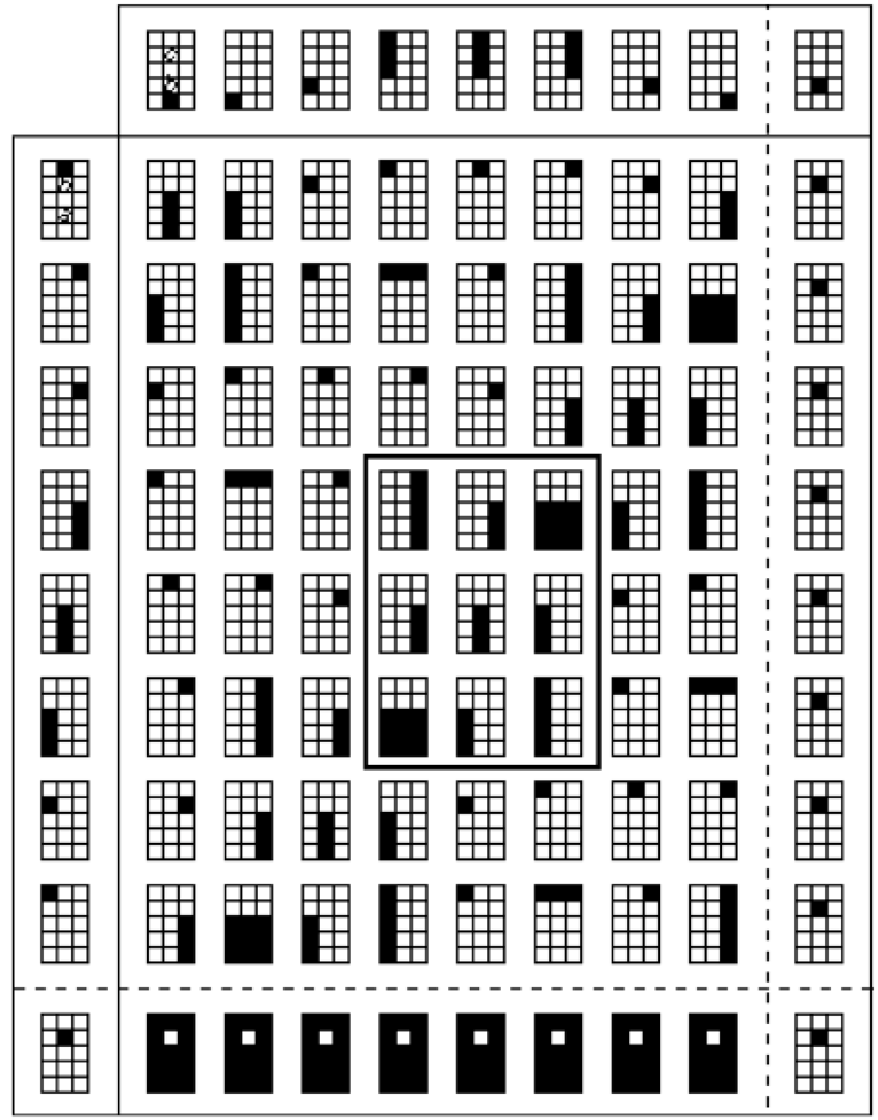
- Consider front-back dichotomies for known vectors

- *c right-front (1)* ***ab***
- *d right-back (3)* ***cb***

Wrt. to original <u>vector *ab*</u>, <u>vector *bd*</u> is either right-front (1), front (0), or left front (2)

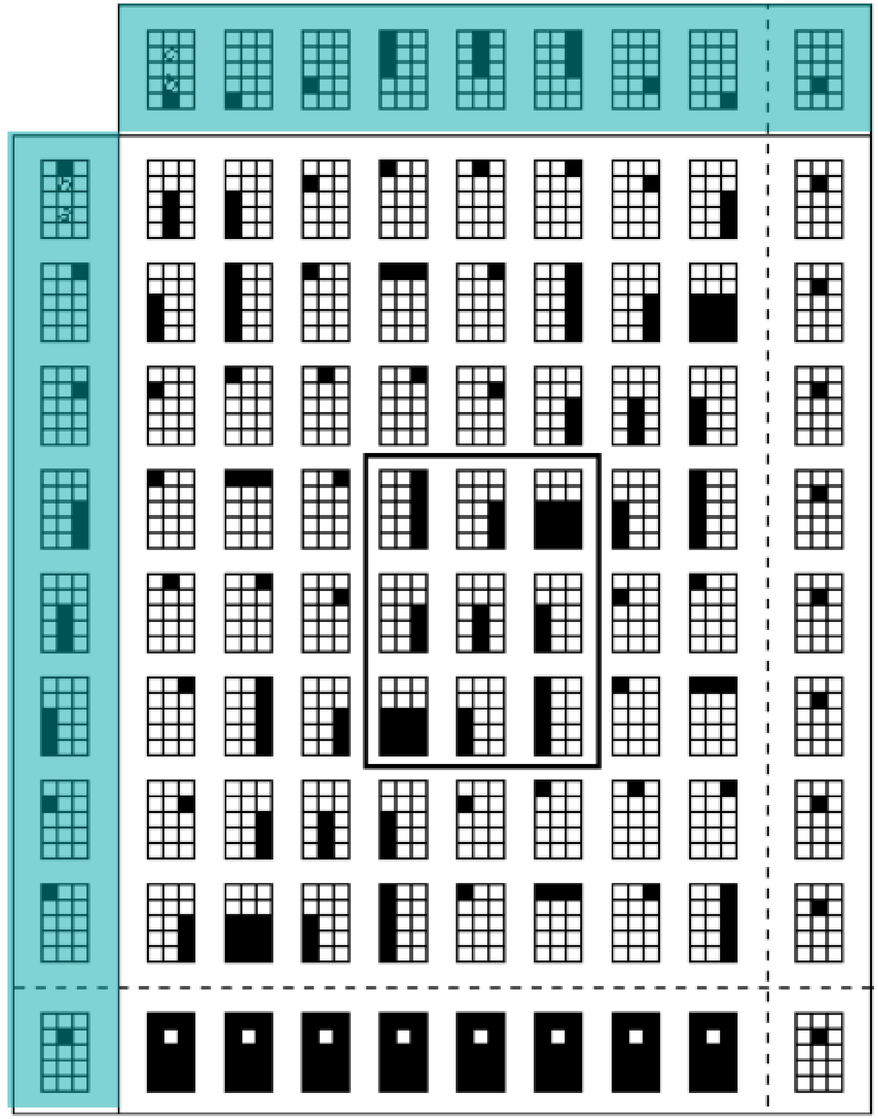
Composition table

- Organize qualitative orientation-based inferences
- Neighboring rows and columns show conceptual neighbors



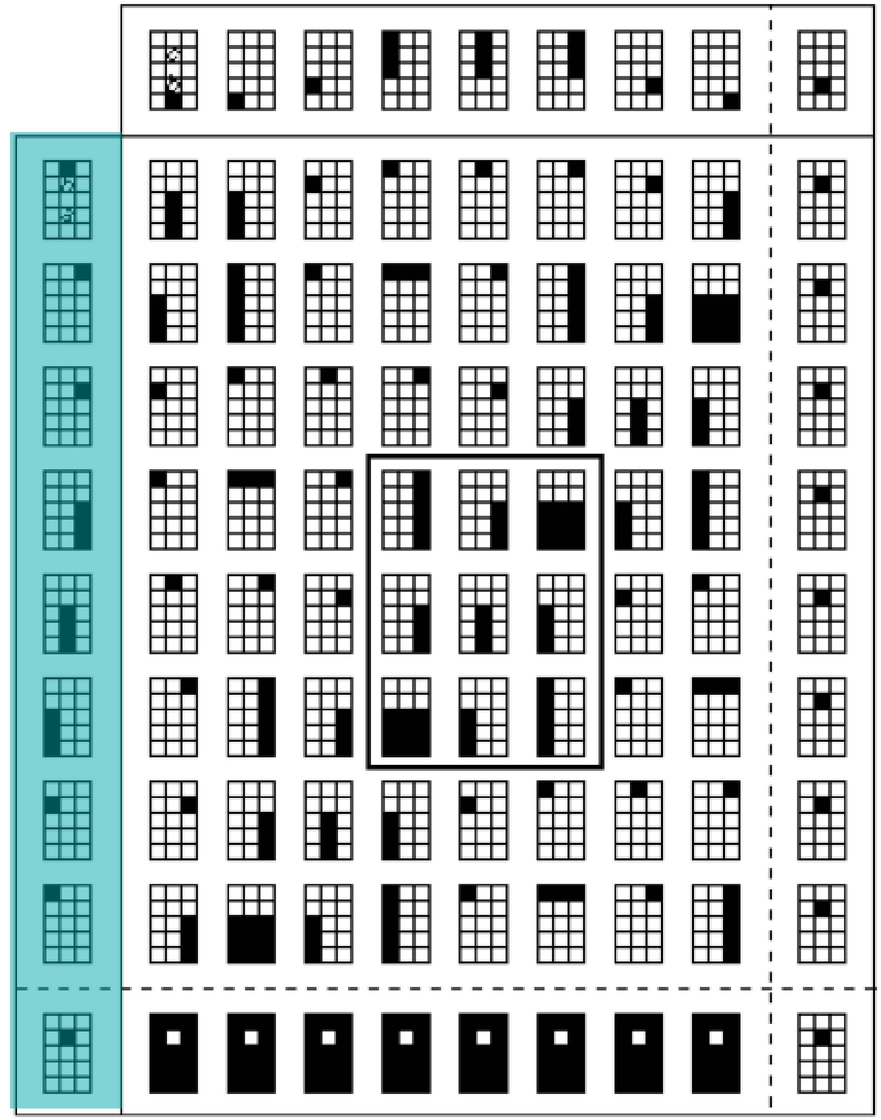
Composition table

- Initial conditions



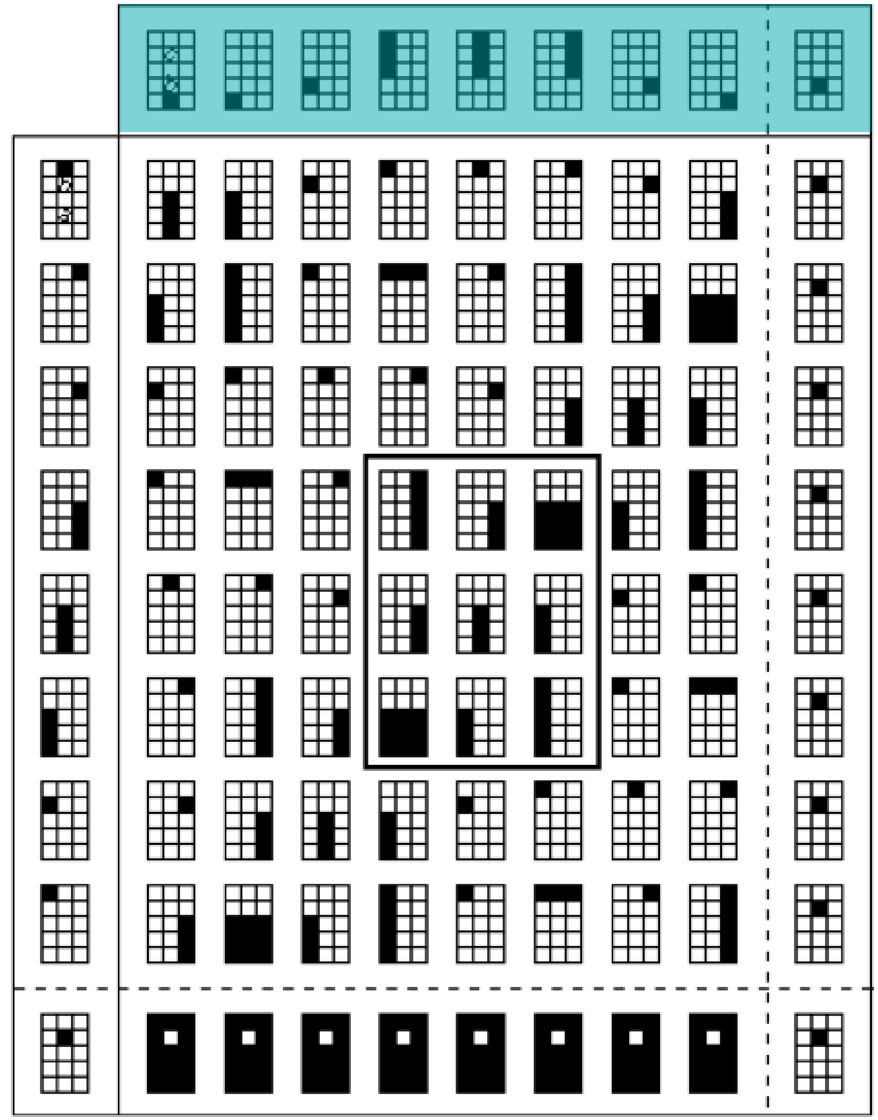
Composition table

- Possible locations of *c*



Composition table

- Possible locations of *d*

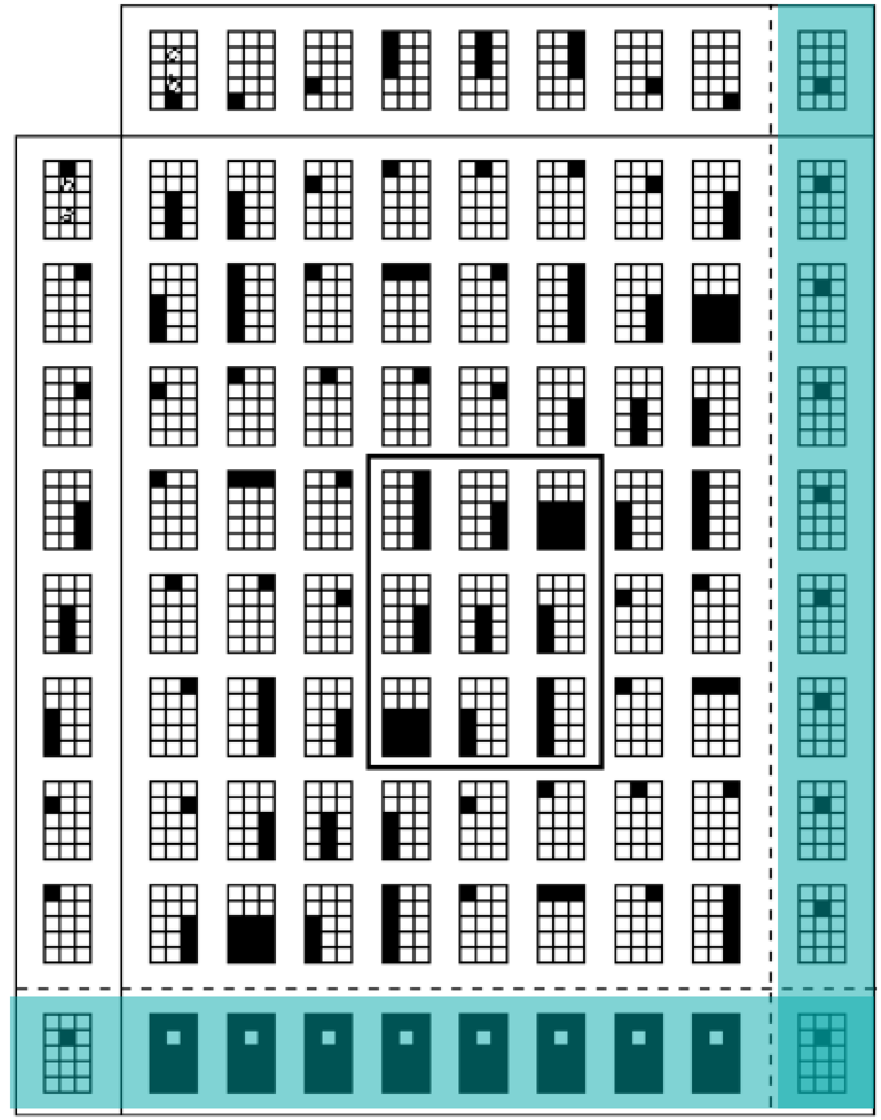


Composition table

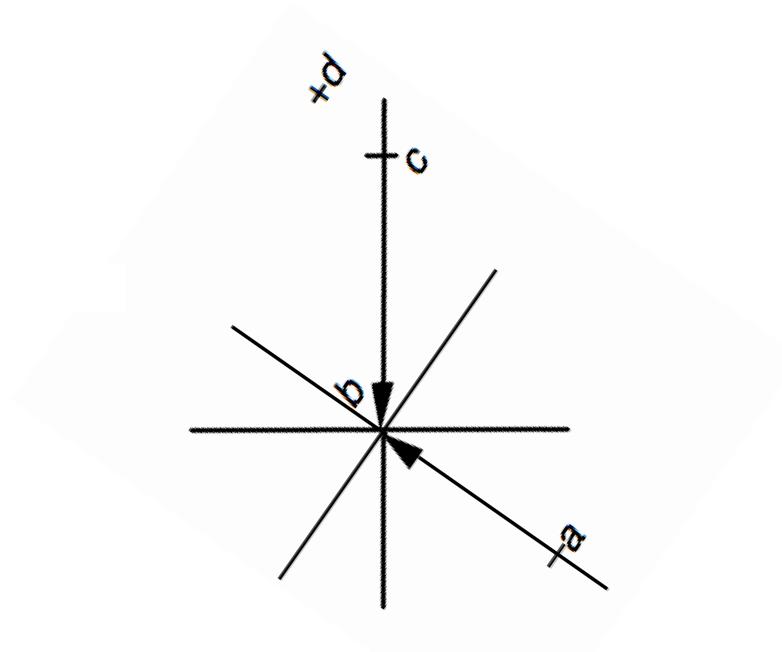
- Orientation-less

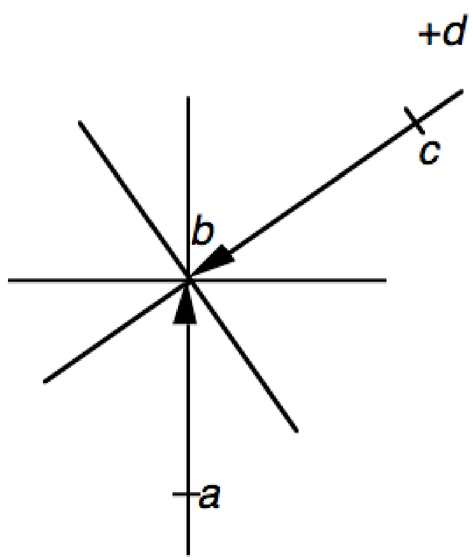
  $c=d$

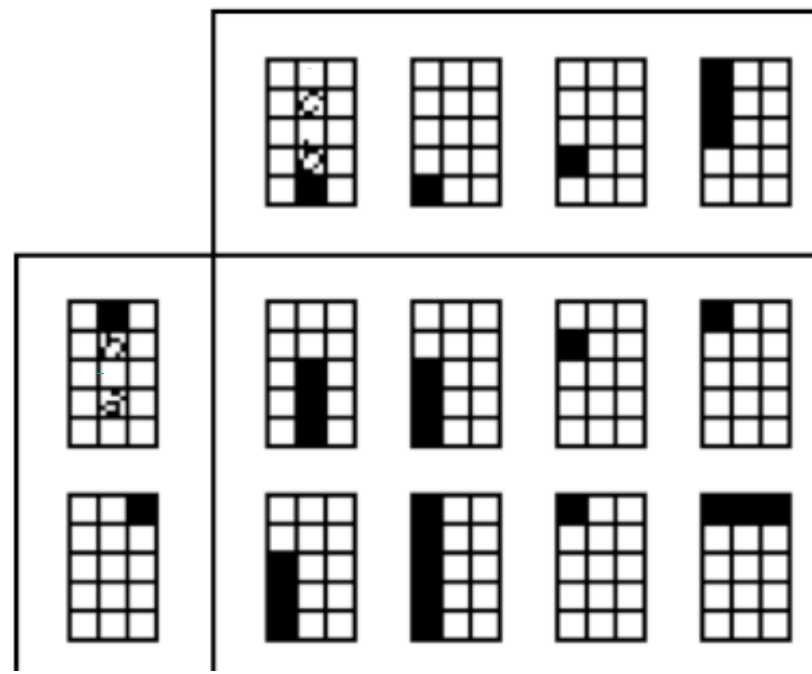
  $d=b$



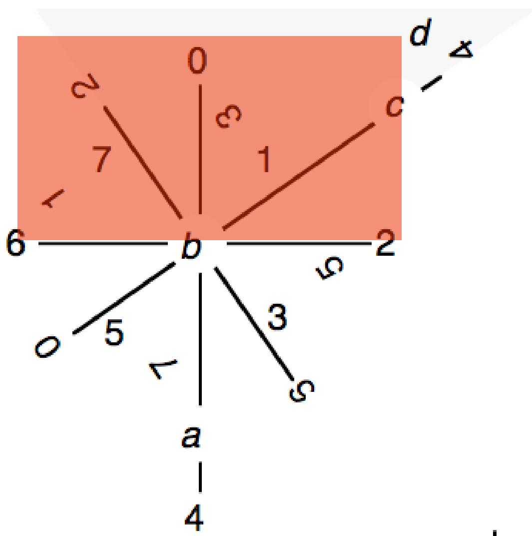
Composition table

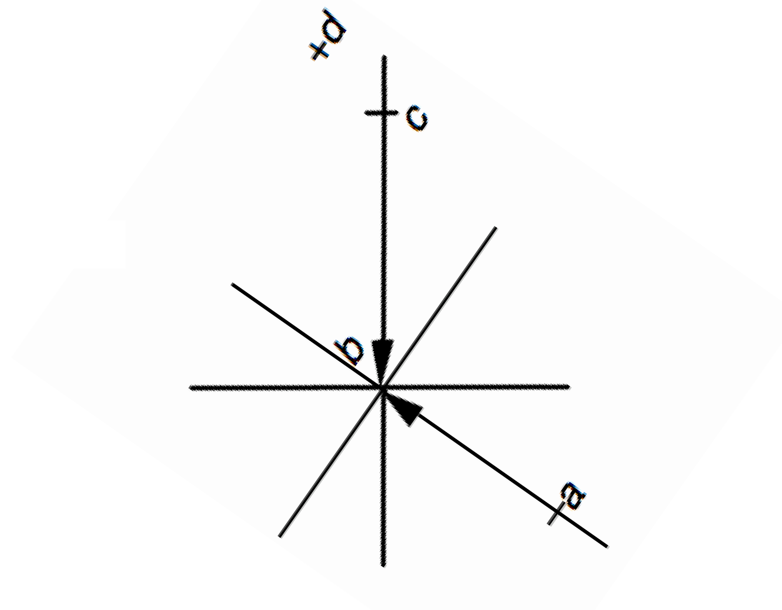


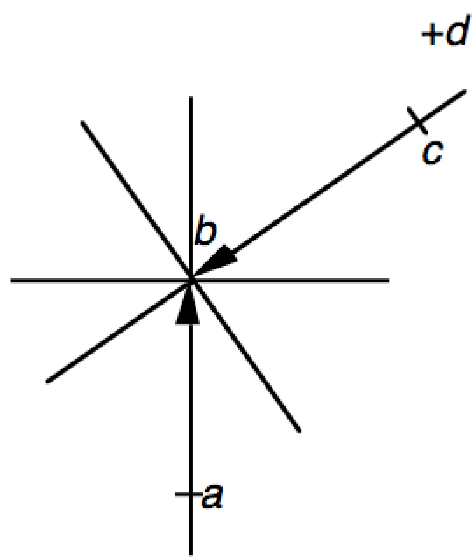


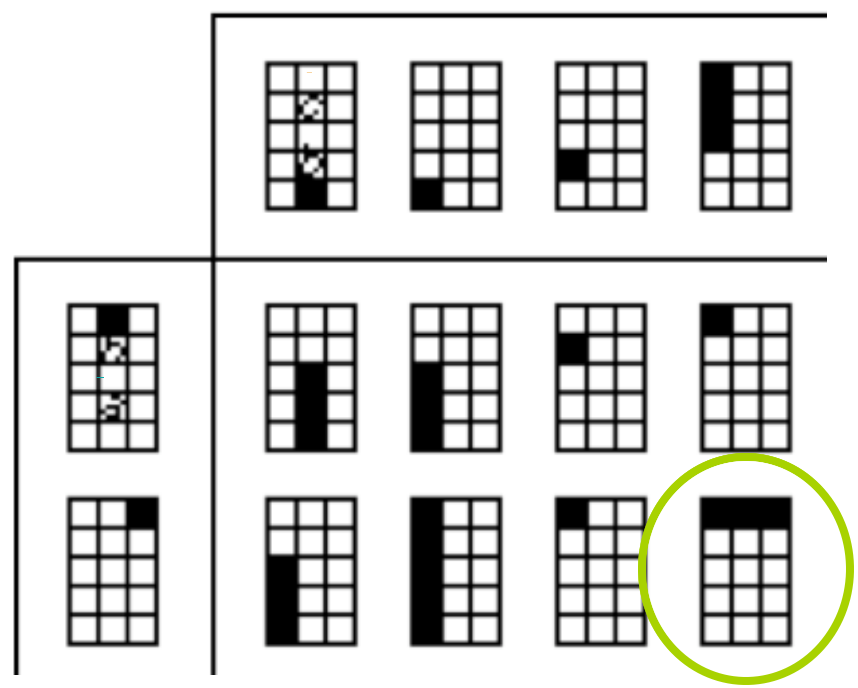


Composition table





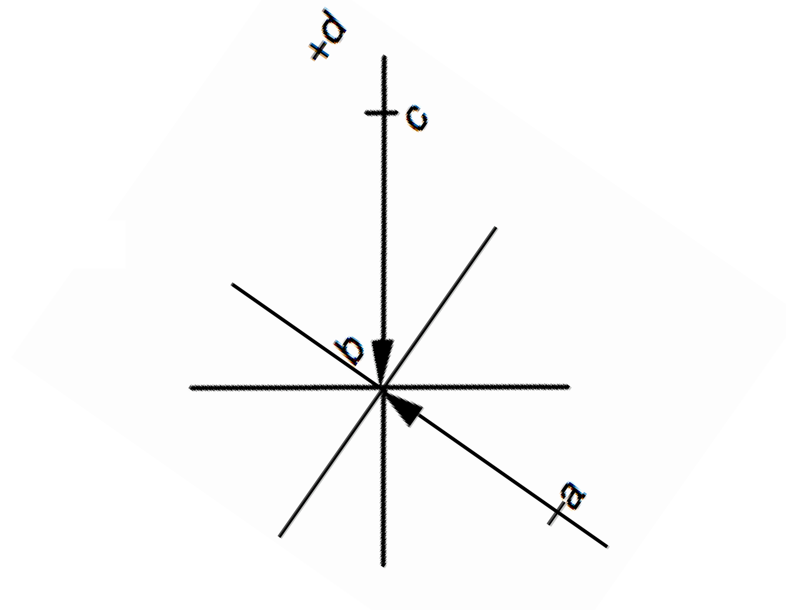


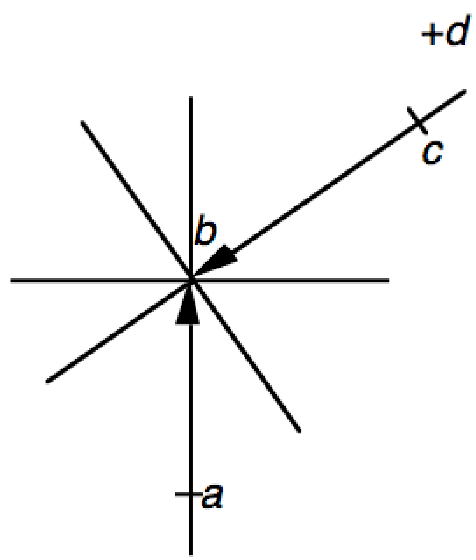


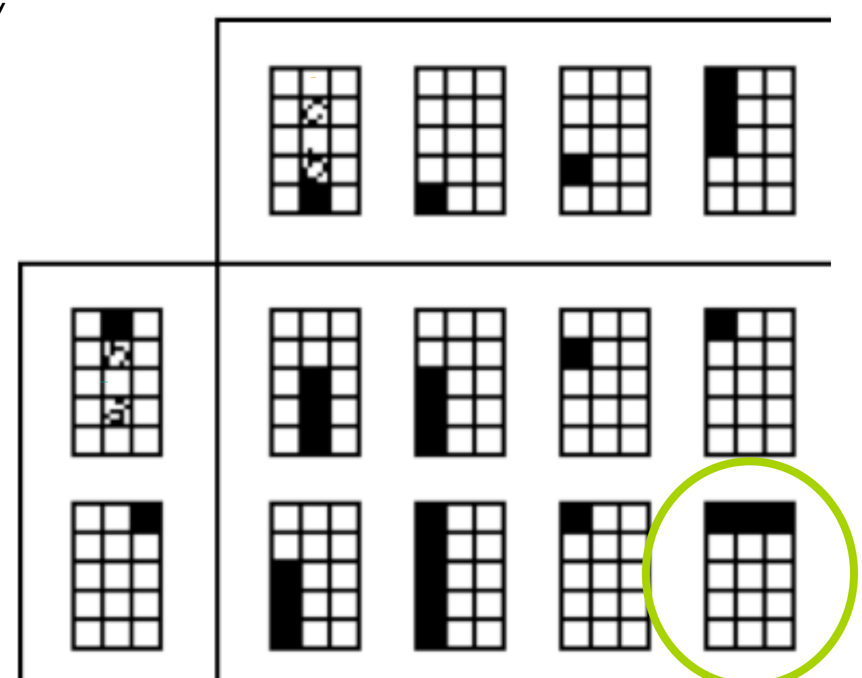
Composition table

25% of all cases hold uncertainty

- neighboring possibilities increase orientation angle up to 180°
- degree of uncertainty is precisely known







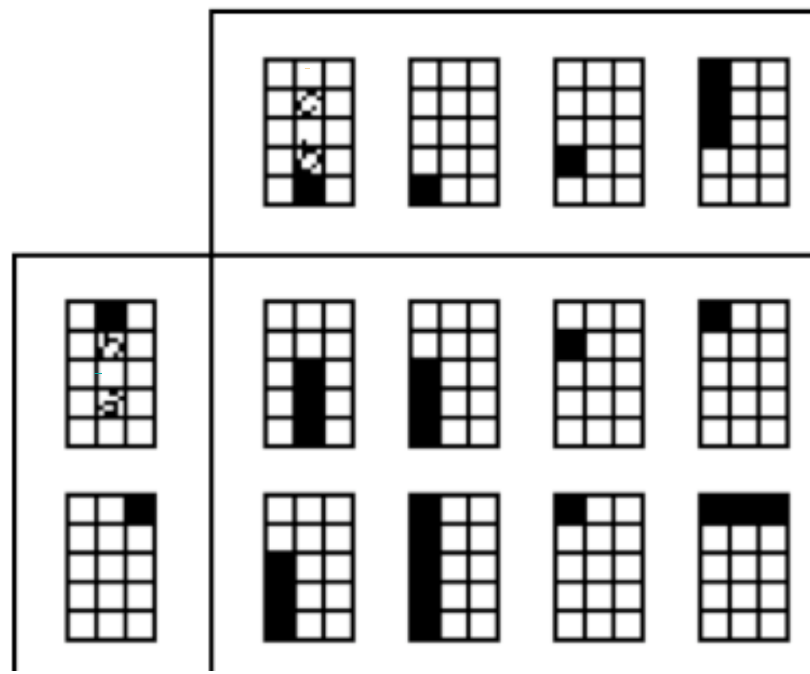
Composition table

$$t = \left\{ \begin{array}{ll} r + s & \text{for } r \text{ or } s \text{ even} \\ (r+s-1) \ldots (r+s+1) & \text{for } r \text{ and } s \text{ odd} \end{array} \right\} \text{mod } 8$$

r orientation of ***c*** wrt. ***ab***

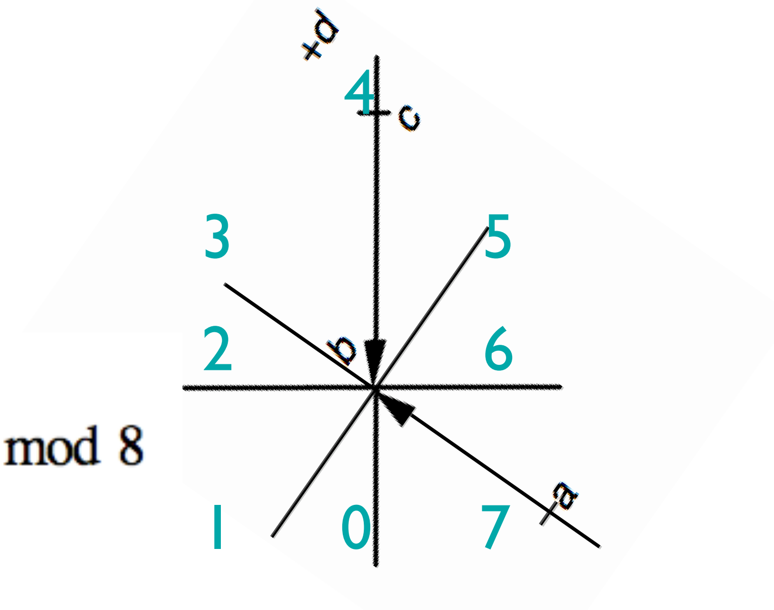
s the orientation of ***d*** wrt. ***bc***

t orientation of ***d*** wrt. ***ab***



Composition table

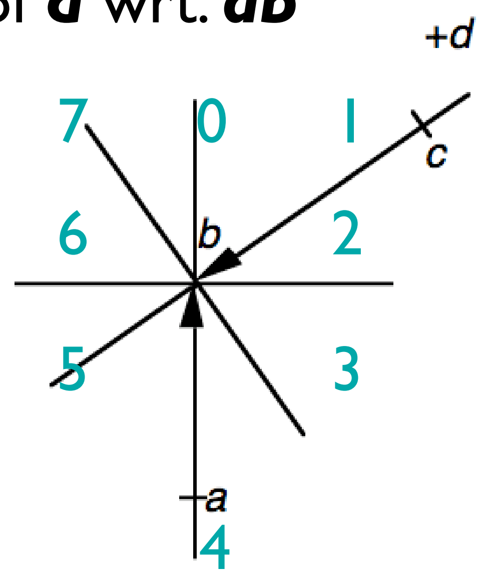
$$t = \left\{ \begin{array}{ll} r + s & \text{for } r \text{ or } s \text{ even} \\ (r+s-1) \ldots (r+s+1) & \text{for } r \text{ and } s \text{ odd} \end{array} \right\} \bmod 8$$

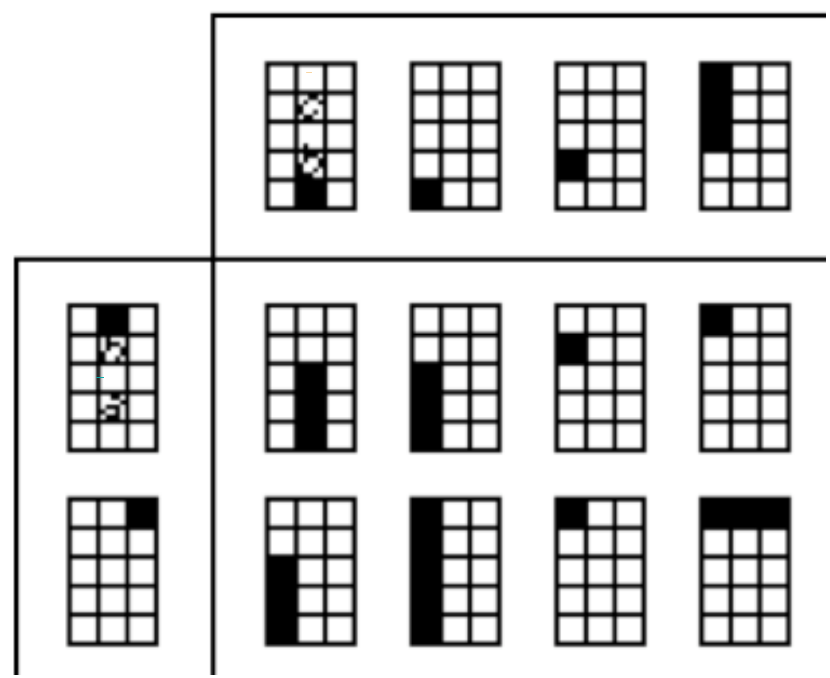


r orientation of ***c*** wrt. ***ab***

s the orientation of ***d*** wrt. ***bc***

t orientation of ***d*** wrt. ***ab***





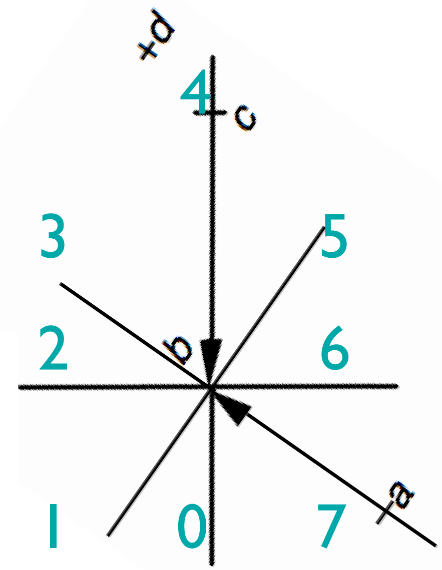
Composition table

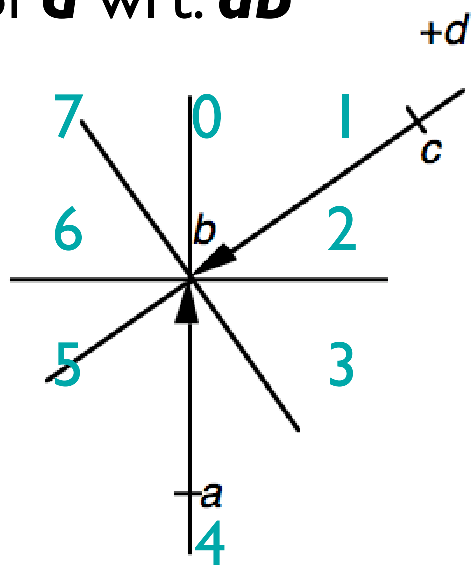
$$t = \left\{ \begin{array}{ll} r + s & \text{for } r \text{ or } s \text{ even} \\ (r+s-1) \ldots (r+s+1) & \text{for } r \text{ and } s \text{ odd} \end{array} \right\} \bmod 8$$

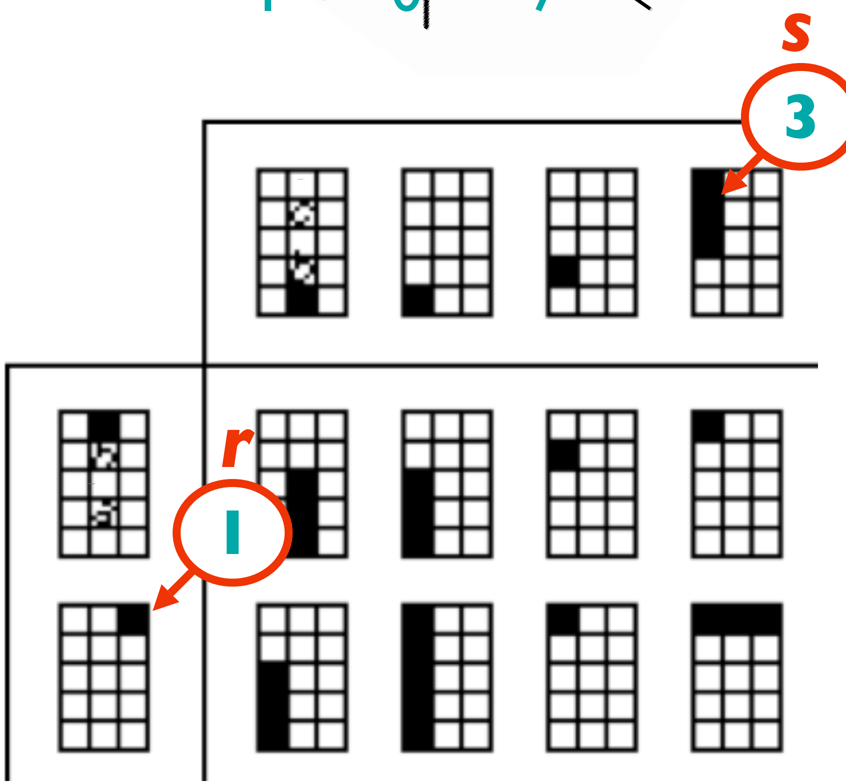
r orientation of ***c*** wrt. ***ab***

s the orientation of ***d*** wrt. ***bc***

t orientation of ***d*** wrt. ***ab***







Composition table

$$t = \left\{ \begin{array}{ll} r + s & \text{for } r \text{ or } s \text{ even} \\ (r+s\text{-}1) \ldots (r+s+1) & \text{for } r \text{ and } s \text{ odd} \end{array} \right\} \text{mod } 8$$

r orientation of ***c*** wrt. ***ab***

s the orientation of ***d*** wrt. ***bc***

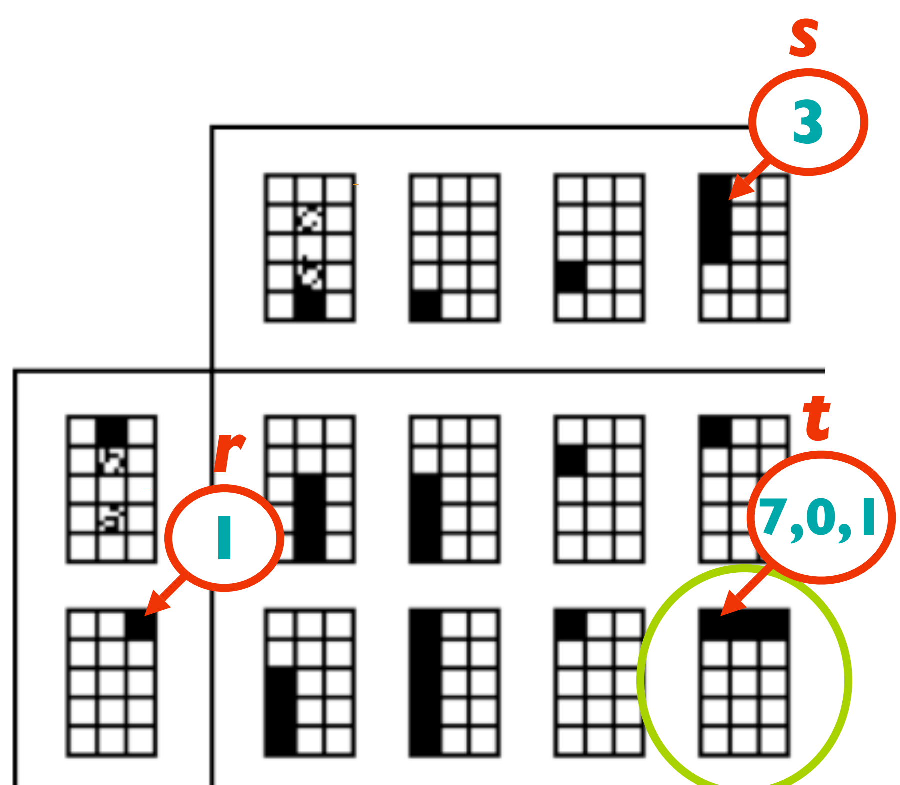
t orientation wrt. ***ab***

__r__ and __s__ are odd:

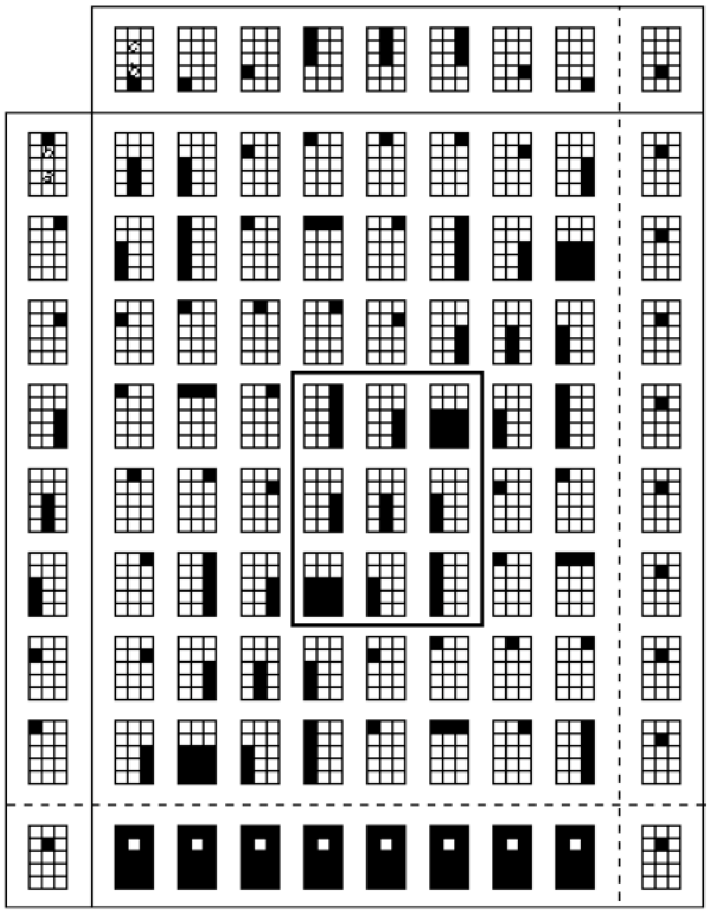
t ={(r+s-1)…(r+s+1)} mod 8

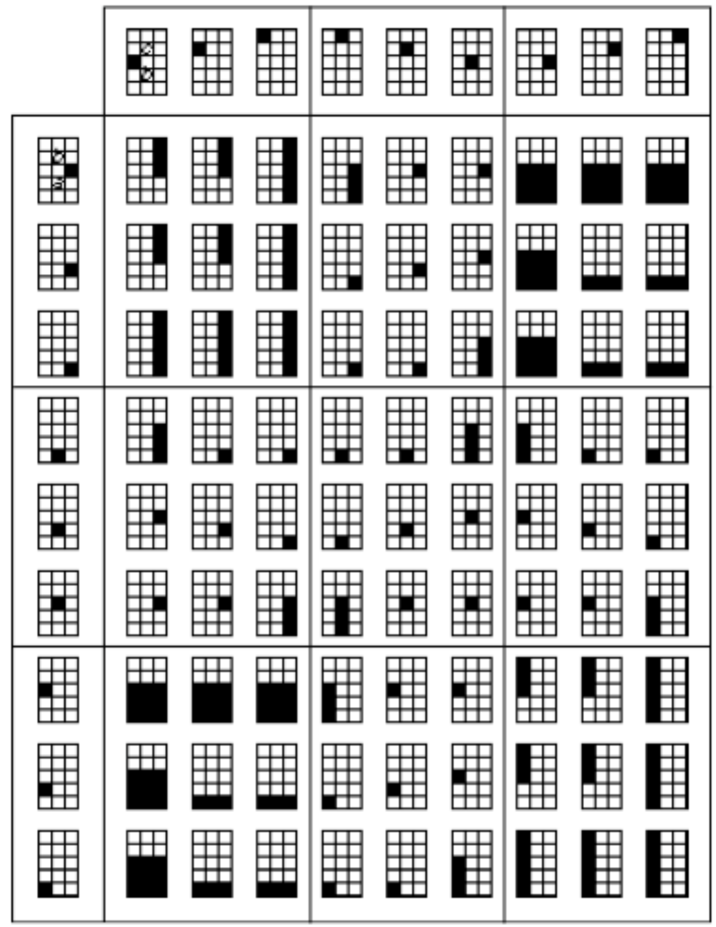
t ={(1+ 3 -1)…(1+ 3+ 1)} mod 8

t = {3 … 5} mod 8



Fine grain composition table





Applications

- Determine an unknown location in space based on own location and known location

- Wayfinding & route descriptions

Referencing work

257 citations in Google Scholar

A few examples:

- Computational methods for ***representing geographical concepts*** *(Egenhofer, Glasgow, et al)*
- Schematic maps for ***robot navigation*** *(Freksa, et al)*
- Pictorial language for retrieval of spatial relations from ***image databases*** *(Papadias, et al)*

Questions?