Pictorial Query by Example
PQBE

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Symbolic Image

• Symbolic image: is an array representing a set of objects and a set of direction relations among them

• Used in
  – Context-based retrieval in image databases
  – Spatial reasoning
  – Path planning
  – Image similarity retrieval
Direction Relations

• Primitive Direction relations:
  - \{NorthWest, RestrictedNorth, NorthEast, RestrictedWest, SamePosition, RestrictedEast, SouthWest, RestrictedSouth, SouthEast\}

<table>
<thead>
<tr>
<th>NorthWest</th>
<th>RestrictedNorth</th>
<th>NorthEast</th>
</tr>
</thead>
<tbody>
<tr>
<td>RestrictedWest</td>
<td>Y</td>
<td>RestrictedEast</td>
</tr>
<tr>
<td>SouthWest</td>
<td>RestrictedSouth</td>
<td>SouthEast</td>
</tr>
</tbody>
</table>

• Y: reference object
• Direction relation of primary object
• All primitives are transitive, SamePosition is symmetric
Introducing PQBE

• Pictorial Query-by-example
  – Generalizes from example given by user
  – Uses skeleton images (which are symbolic images) as queries
  – Ability to express negation, union, intersection, join, etc
Description by Sets

- $O(I)$: objects of image $I$
- $C(I)$: primitive direction relations (constraints) between all pairs of objects in image $I$

Example:
- $O(u)=\{O, P, Q\}$
- $C(u)=\{\text{RestrictedEast}(Q,O), \text{SouthWest}(O,P), \text{RestrictedNorth}(P,Q)\}$

Note SamePosition and converse relations not included for simplicity
Queries with one skeleton image

Database
Queries with one skeleton image
Queries with one skeleton image

Database

Image Constant

Skeleton Image

Query
Queries with one skeleton image

Queries with one skeleton image

Database

Image Constant

_: variables (for objects/ images) are preceded by ‘_’
Queries with one skeleton image

P: printing character, when before an object variable/constant causes its value to be retrieved and displayed

_: variables (for objects/images) are preceded by ‘_’

Database

Image Constant

Skeleton Image

Query
Query

• A symbolic image I is a subimage of J iff $O(I) \subseteq O(J) \land C(I) \subseteq C(J)$

• Result of a query: set of all symbolic (sub)images that satisfy the spatial conditions imposed by sets $O$ and $C$ of skeleton images

• Assumptions: closed world, domain closure, unique name
Example: Query 1

Retrieve the subimages of s that contain an object X where X is NorthEast of B in s.

\[ O(I) = \{ X \mid X \in O(s) \land \text{NorthEast}(X, B) \in C(s) \} \]

\[ C(I) = \{ \} \]
Example: Query 1

Retrieve the subimages of s that contain an object X where X is NorthEast of B in s.

\[ \text{O}(I) = \{ X \mid X \in \text{O}(s) \land \text{NorthEast}(X, B) \in \text{C}(s) \} \]

\[ \text{C}(I) = \{ \} \]
Example: Query 2

\[ O(I) = \{ X \mid \exists Y, \text{NorthEast}(X, Y) \in C(s) \} \]

\[ C(I) = \{ \} \]
Example: Query 2

\[ O(I) = \{ X \mid \exists Y, \text{NorthEast}(X, Y) \in C(s) \} \]
\[ C(I) = \{ \} \]
Example: Query 3 & 4
Example: Query 3 & 4
Example: Query 3 & 4
Example: Query 3 & 4
Example: Queries 5-7
Example: Queries 5-7
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Example: Queries 5-7
Example: Queries 5-7

\[\text{s} \quad \text{P}_X \quad \sim \text{Y} \quad \text{M} \quad \text{D} \quad \text{I} \]

\[\text{t} \quad \text{P}_X \quad \text{B} \quad \text{M} \quad \text{E} \quad \text{H} \quad \text{D} \quad \text{I} \quad \text{O} \]

\[\text{u} \quad \text{P}_X \quad \text{B} \]
Example: Queries 5-7
Querying object configurations

\[
O(I) = \{X, Y, W, Z | \exists J (SW(X, W) \in C(J) \land RW(X, Z) \in C(J) \\
\land NW(X, Y) \in C(J) \land NW(W, Z) \in C(J) \land RN(W, Y) \in C(J) \\
\land NE(Z, Y) \in C(J))\} \]

\[
C(I) = \{SW(X, W), RW(X, Z), NW(X, Y), NW(W, Z), \\
RN(W, Y), NE(Z, Y)\} \]
Querying object configurations

\[ O(I) = \{X, Y, W, Z \mid \exists J (SW(X, W) \in C(J) \land RW(X, Z) \in C(J) \land NW(X, Y) \in C(J) \land NW(W, Z) \in C(J) \land RN(W, Y) \in C(J) \land NE(Z, Y) \in C(J) ) \} \]

\[ C(I) = \{SW(X, W), RW(X, Z), NW(X, Y), NW(W, Z), RN(W, Y), NE(Z, Y) \} \]
Querying relations between objects
Querying relations between objects
Querying relations between objects
Querying relations between objects
Querying relations between objects
Querying relations between objects
Union, Intersection, Join
Union, Intersection, Join

\[ \text{Diagram with cells labeled } A, B, C, D, \ldots, J, P_X, B, C, \text{ etc.} \]
Union, Intersection, Join
Union, Intersection, Join

\[
\begin{array}{cccccccc}
F & E & H & I \\
G & M & D \\
K & B & C & L \\
A & & & J \\
\end{array}
\]

\[
\begin{array}{cccc}
F & O \\
B & N \\
P & O & Q \\
\end{array}
\]

\[
\begin{array}{cccc}
P_X & B & & \\
& & C & \\
& X & B & C \\
P_X & & & C \\
\end{array}
\]

\[
\begin{array}{cccccccc}
K & F & G & B & M & E & H & D & J \\
& & & & M & E \\
\end{array}
\]
Union, Intersection, Join

\[
\begin{array}{cccc}
F & E & H & I \\
G & M & D \\
K & B & C \\
A & s \\
\end{array}
\quad
\begin{array}{c}
F \\
O \\
P \\
O \\
\end{array}
\quad
\begin{array}{c}
P \\
O \\
Q \\
\end{array}
\quad
\begin{array}{c}
t \\
u \\
\end{array}
\]

\[
\begin{array}{cc}
P_X & B \\
P_X & C \\
_X & B \\
P_X & C \\
\_Y & B \\
P_X & \_Y \\
\end{array}
\]

K F G B M E H D I

M E
Union, Intersection, Join

Union:

Intersection:

Join:
Queries with multiple images
Queries with multiple images
Queries with multiple images
Queries with multiple images
Queries with image retrieval
Queries with image retrieval

Output Images
{s}
Queries with image retrieval
Queries with image retrieval

Output Images \{s\}
Queries with image retrieval
Queries with image retrieval

Output Images \{s\}

Output Images \{s\}

Output Images \{s\}
Update Operations

- P: printing character $\rightarrow$ Select
- R: removing character $\rightarrow$ Delete
- I: inserting character $\rightarrow$ Insert
Application: Geographical Queries

Maps of cities in Central Europe

Symbolic Image

A sample query
Spatial Representation

- preserve location in space
- without incorporating information such as shape, size, texture, or color of objects
- e.g. subway maps contain no information about the shapes of the stations
Different Areas, Different Goals

• Explanatory and predictive power
  – Computational models of Vision and Imagery

• Expressive power and inferential adequacy
  – Artificial Intelligence representation schemes

• Efficient manipulation of large amounts of geographic and geometric data
  – Spatial Databases
Construction of 2D-G string

Cutting function: detects and records differences in object projections on the x and y axis

a. Differences in object projections  b. Corresponding 2D-G string

u: AB | B | BC | BCD | D | es | E
v: ABDE | ABCDE | BCD | CD
Construction of Symbolic Arrays

a. Sub-regions of the original objects  b. Corresponding symbolic array
References
