



Bancos de Dados Geográficos

Tipos e Operações Espaciais

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27 de Junho de 2018

Campos x Entidades

Matricial x Vetorial

Entidades Discretas (Geo-Objetos)

Coleção de Feições

unidades_federativas				
ufid	nome	populacao	e_vida	fronteira
31	Minas Gerais	20.997.560	77	
35	São Paulo	44.396.484	77,8	
...

Representação Geométrica



Hidrelétricas/Termoelétricas

Representação Geométrica
através de Pontos

Logradouros

Representação Geométrica
através de Linhas

Municípios

Representação Geométrica
através de Polígonos

Tipos Geométricos

Open Geospatial Consortium Inc.

Date: 2011-05-28

Reference number of this document: OGC 06-103r4

Version: 1.2.1

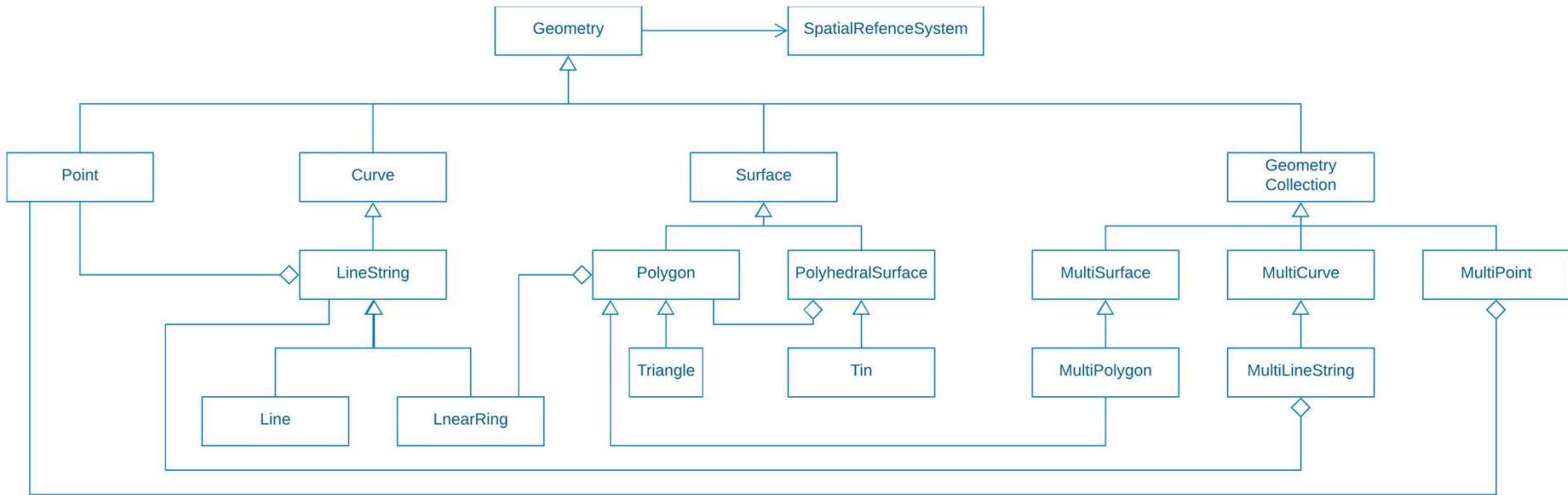
Status: Corrigendum

Category: OpenGIS ® Implementation Standard

Editor: John R. Herring

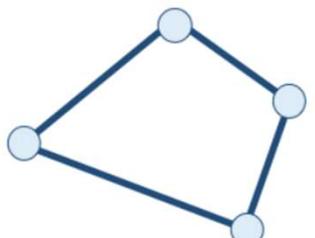
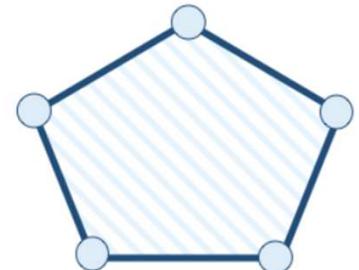
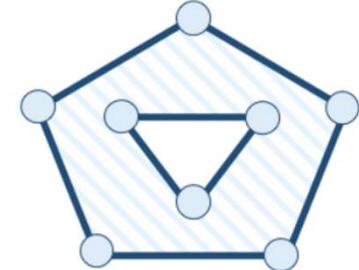
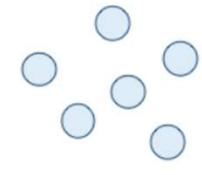
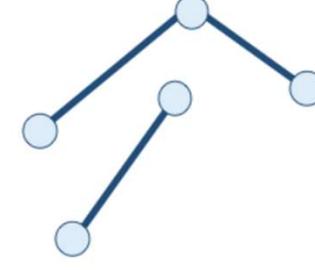
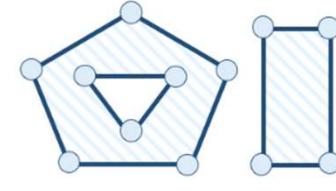
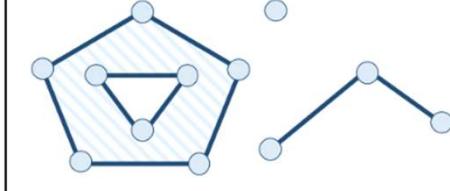
**OpenGIS® Implementation Standard for Geographic
information - Simple feature access - Part 1: Common
architecture**

OGC Simple Feature

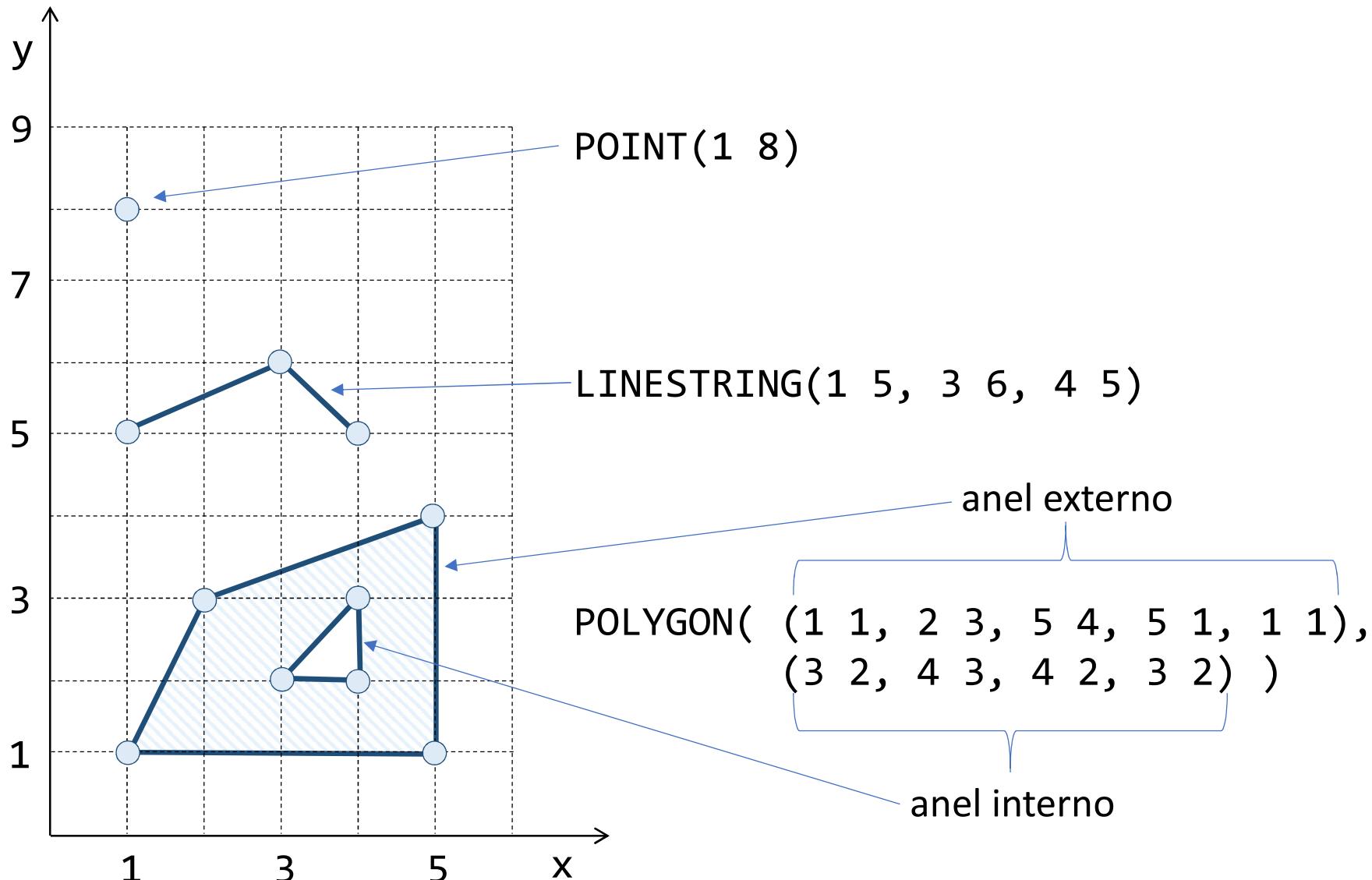


Fonte: Adaptado de Herring (2011).

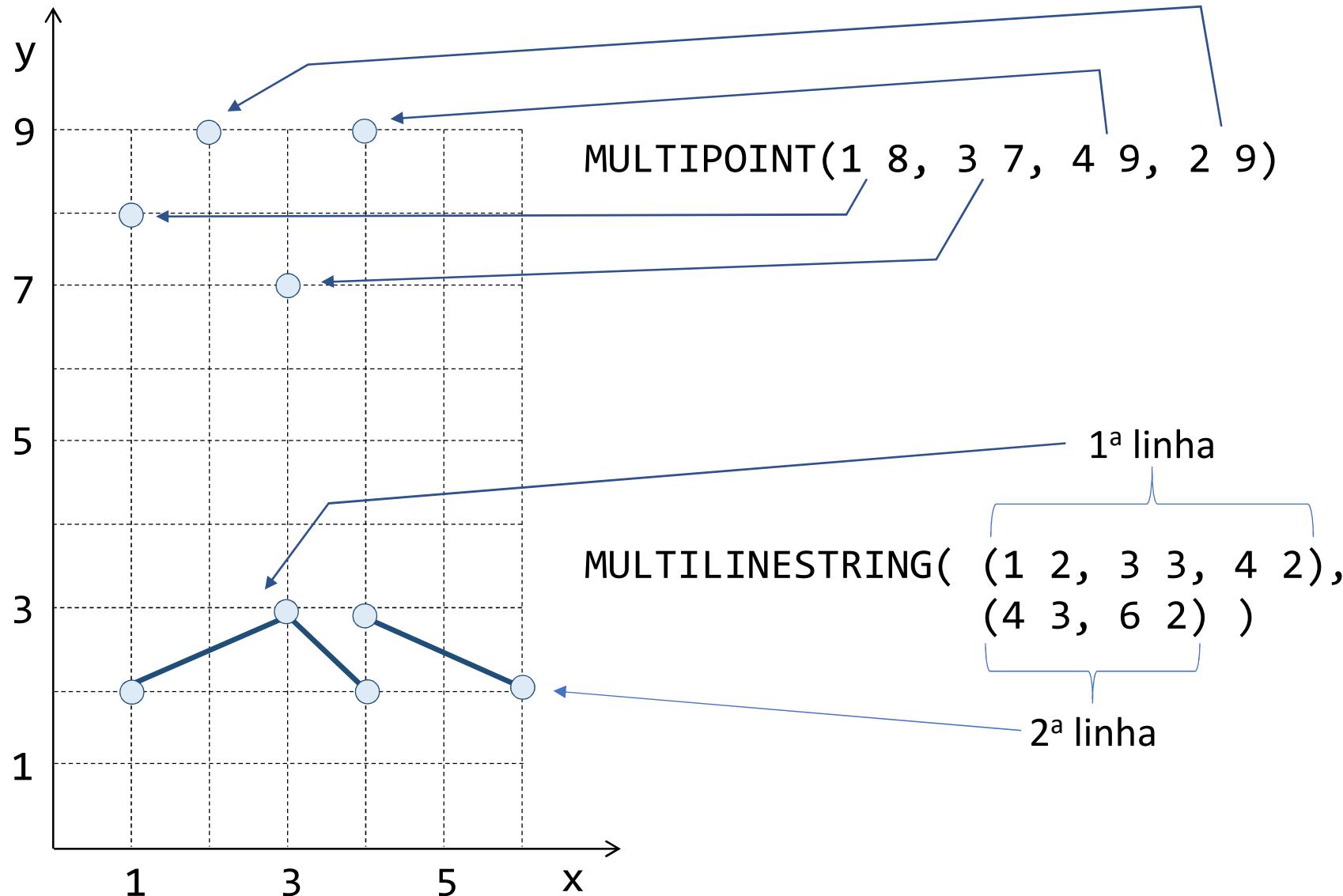
OGC Simple Feature

(a) Point	(b) LineString	(c) LinearRing
		
(d) Polygon	(e) Polygon (com buracos/ilhas)	(f) MultiPoint
		
(g) MultiLineString	(h) MultiPolygon	(i) GeometryCollection
		

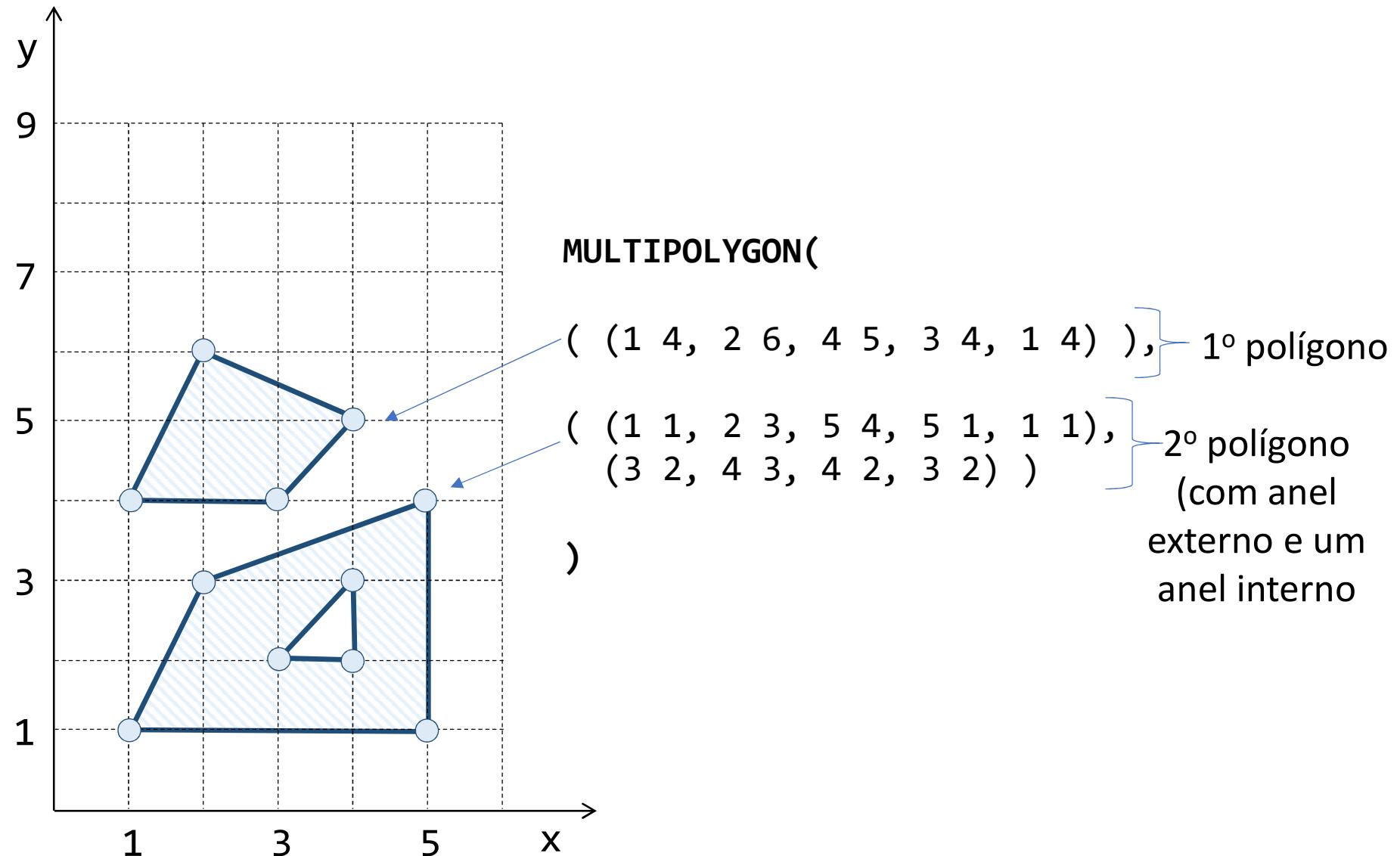
OGC-SFS: Well-Known Text (WKT)



OGC-SFS: Well-Known Text (WKT)

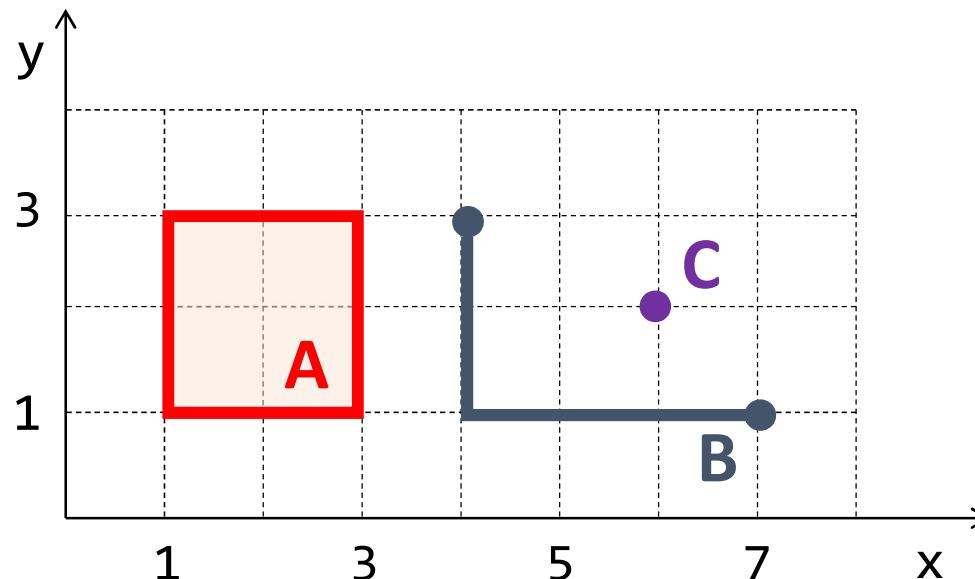


OGC-SFS: Well-Known Text (WKT)



PostGIS Geometry

- Implementação da OGC-SFS (ISO SQL-MM):
 - Geometria no Plano Cartesiano
 - Operações são realizadas em 2D mesmo quando a geometria possui valores de coordenada z.
 - Operações como área e perímetro são realizadas na unidade do sistema de referência espacial associada à geometria.



Habilitando a Extensão PostGIS

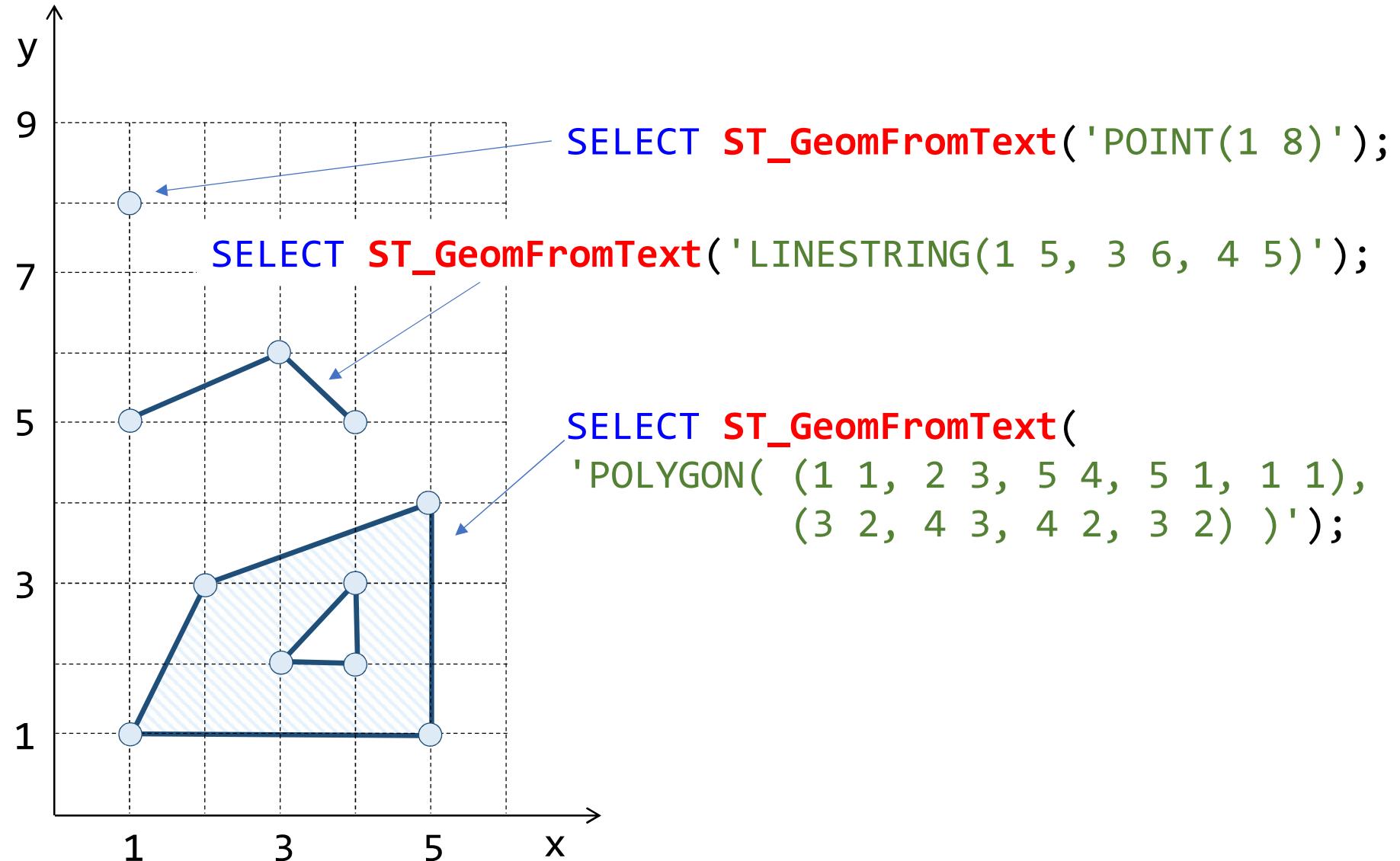
- Para criar um novo banco de dados:

```
CREATE DATABASE cap349 TEMPLATE template1;
```

- Para carregar a extensão PostGIS no banco criado:

```
CREATE EXTENSION postgis;
```

PostGIS Geometry: WKT



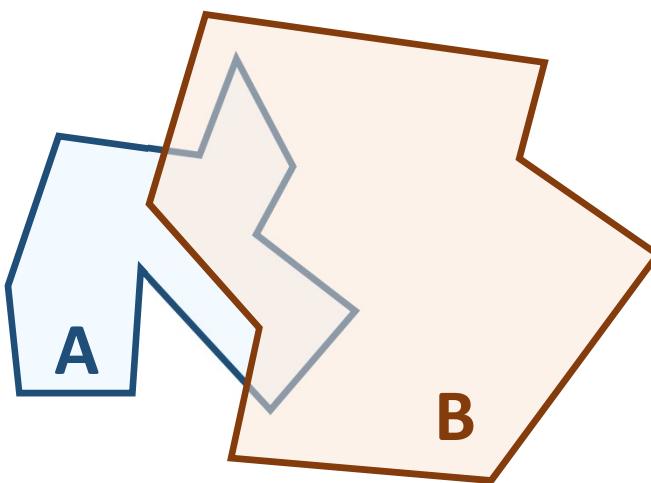
PostGIS **Geometry**

- A extensão PostGIS segue a especificação:
 - ISO SQL/MM – Parte 3 – Spatial.
- Desta forma, o tipo **Geometry** do PostGIS suporta também os tipos circulares e compostos:
 - CIRCULARSTRING
 - COMPOUNDCURVE
 - CURVEPOLYGON
- No entanto, as operações sempre pressupõem que os segmentos tenham interpolação linear.

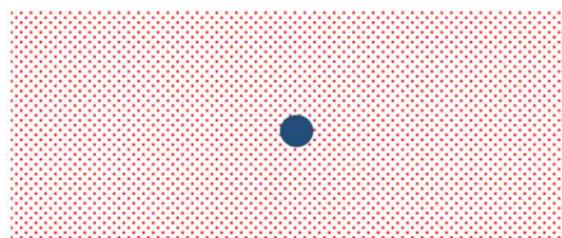
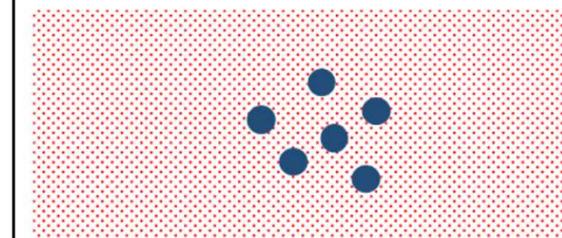
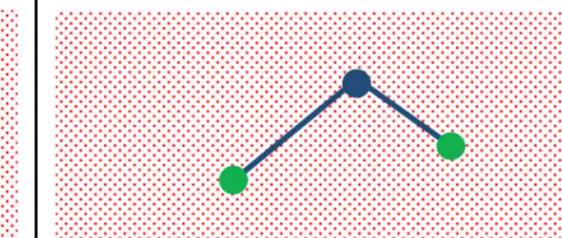
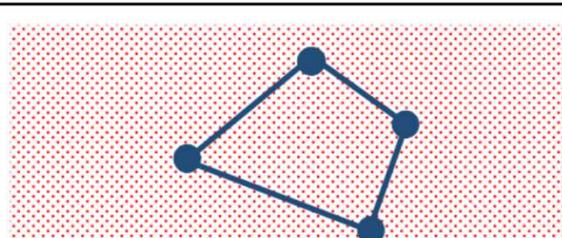
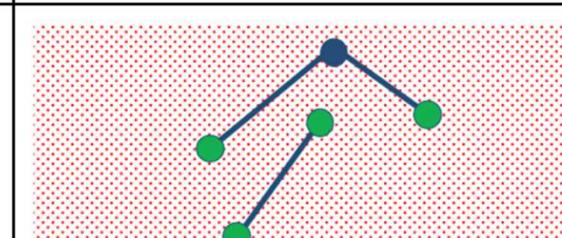
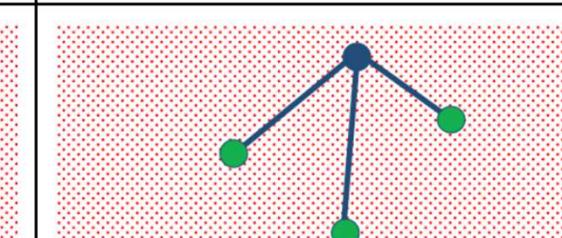
Relacionamentos Espaciais

Matriz de 9-intersecções Estendida Dimensionalmente

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	$\dim(I(A) \cap I(B))$	$\dim(I(A) \cap F(B))$	$\dim(I(A) \cap E(B))$
<i>Fronteira(A)</i>	$\dim(F(A) \cap I(B))$	$\dim(F(A) \cap F(B))$	$\dim(F(A) \cap E(B))$
<i>Exterior(A)</i>	$\dim(E(A) \cap I(B))$	$\dim(E(A) \cap F(B))$	$\dim(E(A) \cap E(B))$



Interior, Fronteira e Exterior dos Diversos Tipos Geométricos

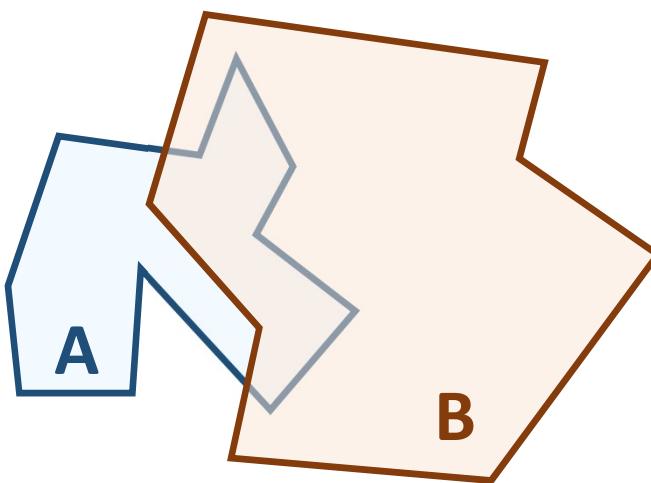
(a) I e E Ponto	(b) I e E Coleção Pontos	(c) I, F e E Curva Aberta
		
(d) I e E Curva Fechada	(e) I, F e E Coleção Curvas Abertas	(f) I e E Coleção Curvas Abertas
		
(g) I, F e E Polígono	(h) I, F e E Coleção Polígonos	(i) I, F e E Coleção Geom.
		

Objetos Resultantes da Intersecção

- A dimensionalidade máxima dos objetos resultantes da intersecção dos componentes avaliados, $\dim(x)$, pode ser:
 - **0**: Caso os componentes não tenham intersecção. Adotaremos o valor -1 para este caso.
 - **1**: Se a intersecção dos componentes resulta em uma curva.
 - **2**: Se a intersecção dos componentes resulta em alguma superfície. Adotaremos também o termo *Área* ou *Região* como sinônimos.

Relacionamento(A, B)

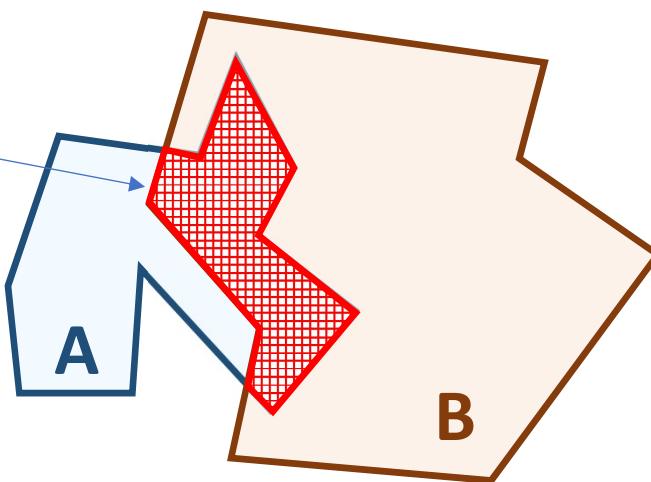
	$Interior(B)$	$Fronteira(B)$	$Exterior(B)$
$Interior(A)$	2	1	2
$Fronteira(A)$	1	0	1
$Exterior(A)$	2	1	2



Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

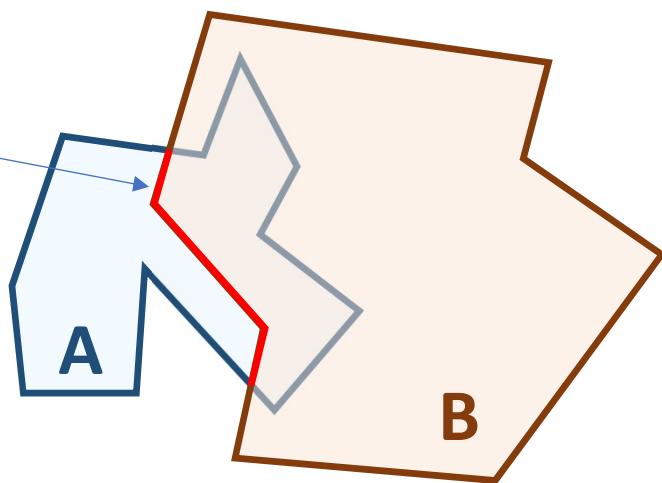
$$\dim(I(A) \cap I(B)) = 2$$



Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

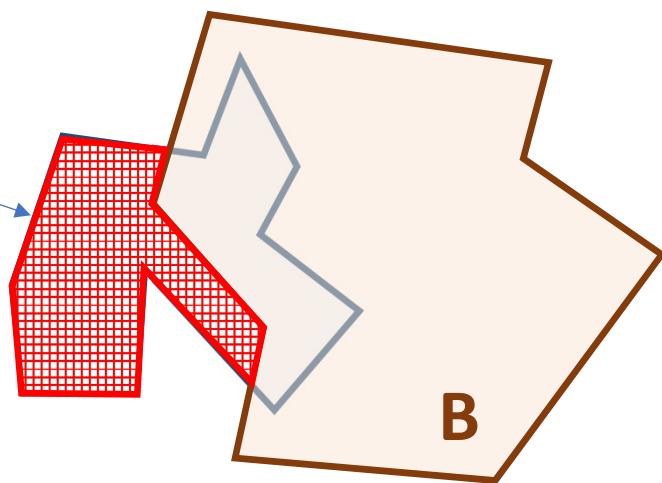
$$\dim(I(A) \cap F(B)) = 1$$



Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

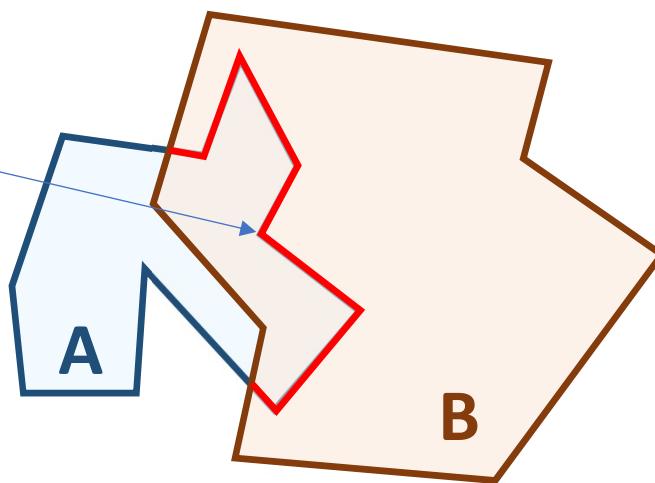
$$\dim(I(A) \cap E(B)) = 2$$



Relacionamento(A, B)

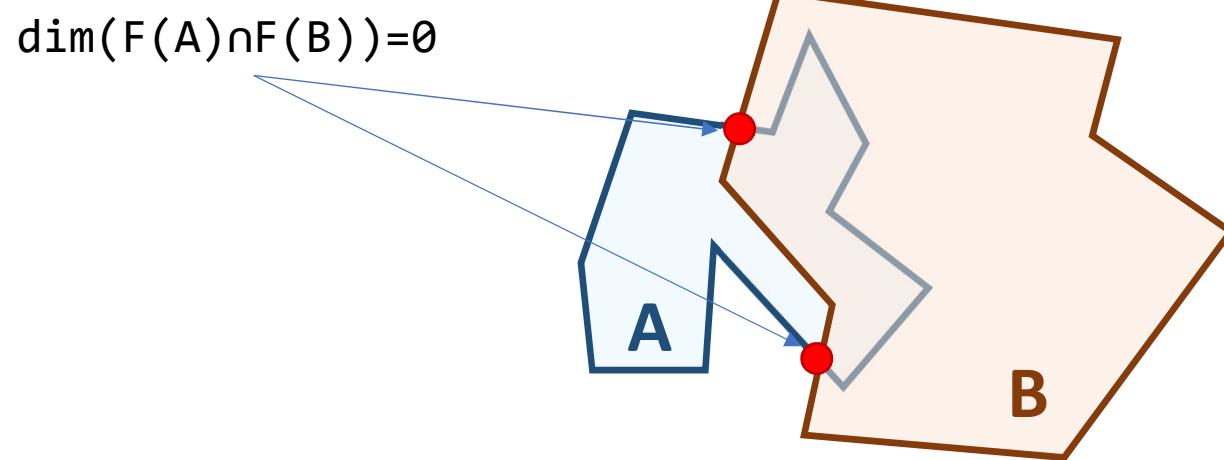
	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

$$\dim(F(A) \cap I(B)) = 1$$



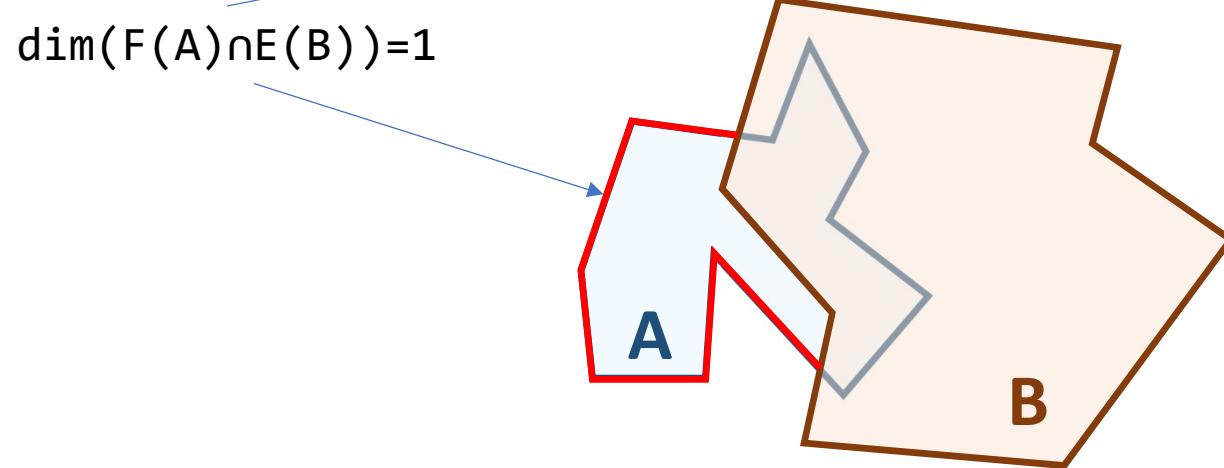
Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2



Relacionamento(A, B)

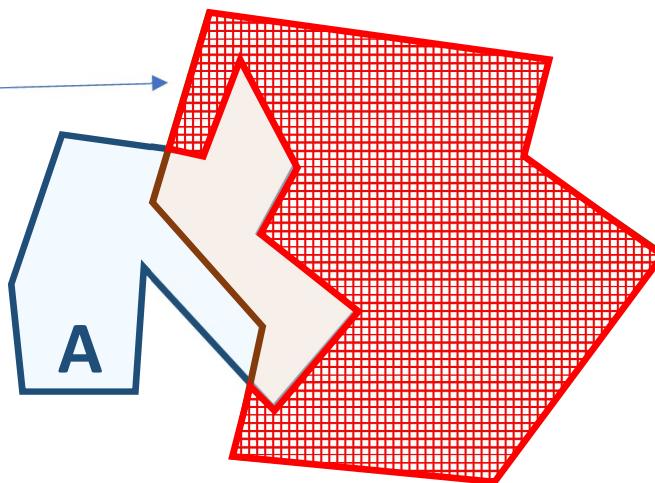
	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2



Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

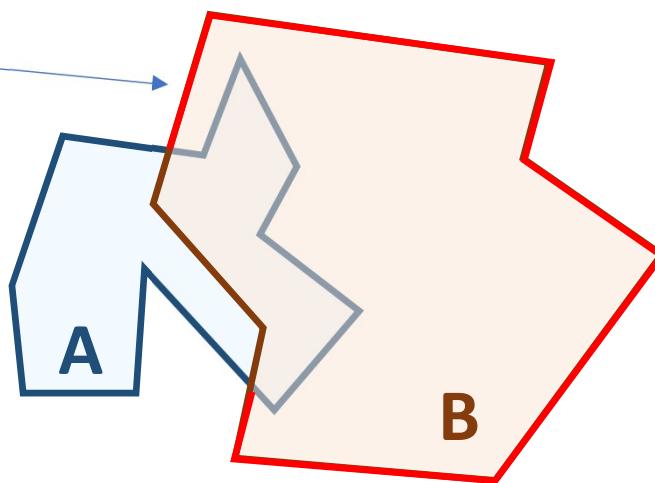
$$\dim(E(A) \cap I(B)) = 2$$



Relacionamento(A, B)

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

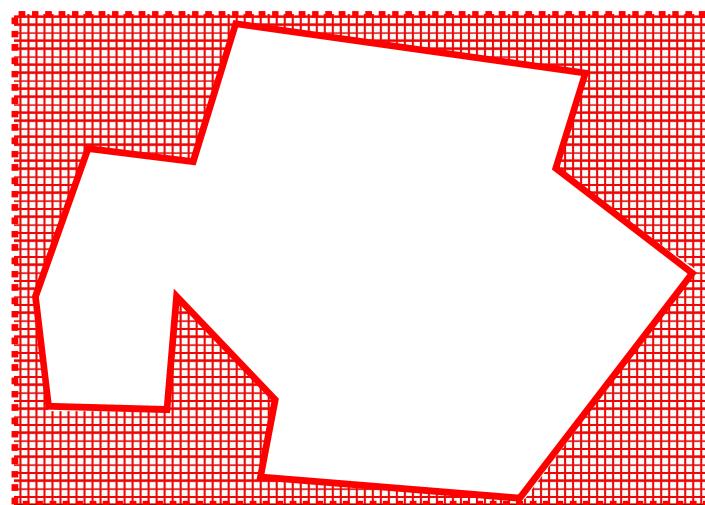
$$\dim(E(A) \cap F(B)) = 1$$



Relacionamento(A, B)

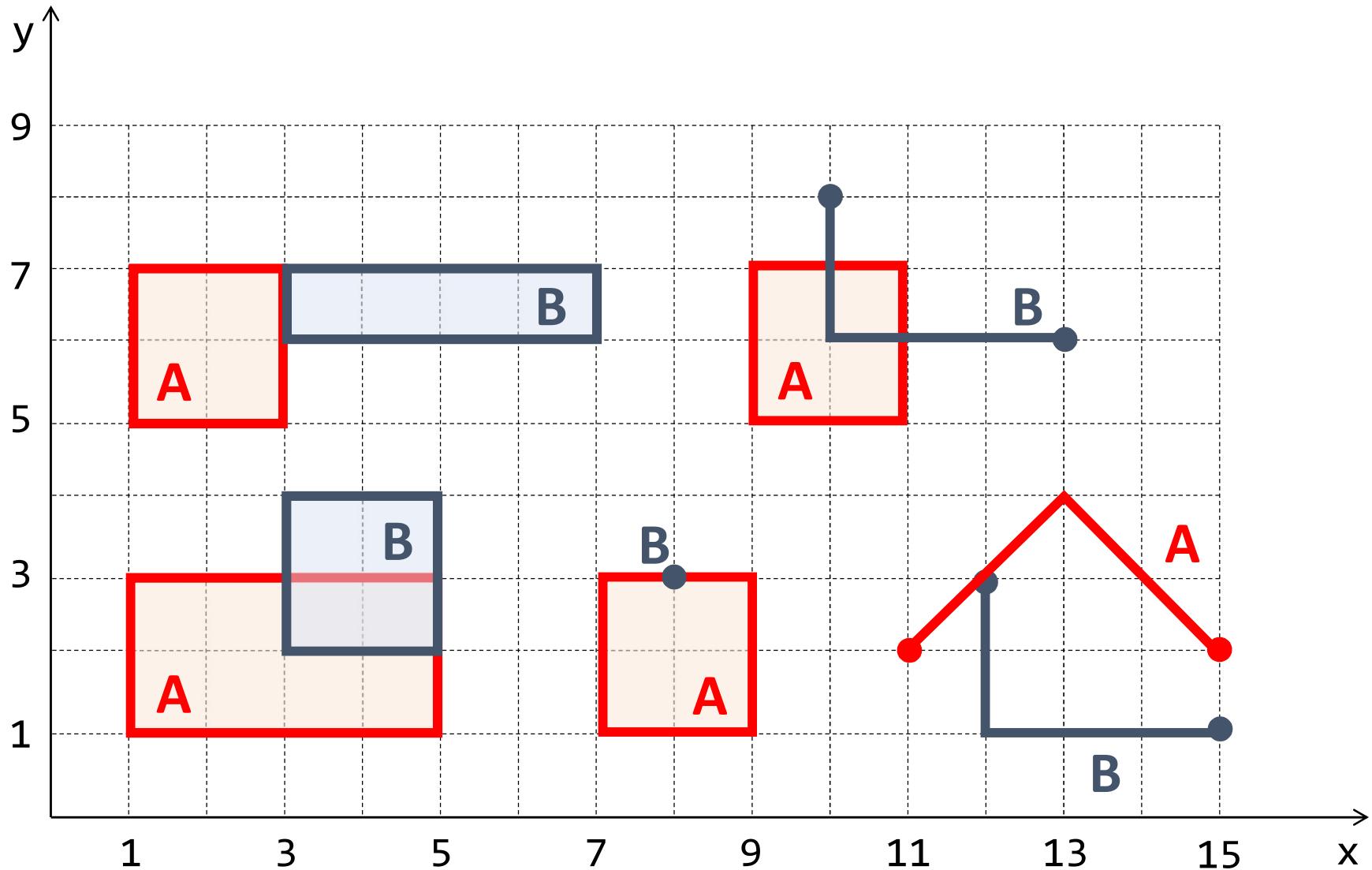
	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	2	1	2
<i>Fronteira(A)</i>	1	0	1
<i>Exterior(A)</i>	2	1	2

$$\dim(E(A) \cap E(B)) = 2$$



Operador ST_Relate

Qual o relacionamento espacial entre
as geometrias A e B?



Qual o relacionamento espacial entre as geometrias A e B?

```
SELECT ST_Relate( 'POLYGON( ( 1 1, 1 3, 5 3, 5 1, 1 1 ) )',  
                  'POLYGON( ( 3 2, 3 4, 5 4, 5 2, 3 2 ) )' );
```

```
SELECT ST_Relate( 'POLYGON( ( 1 1, 1 3, 5 3, 5 1, 1 1 ) )',  
                  'POLYGON( ( 3 2, 3 4, 5 4, 5 2, 3 2 ) )' );
```

```
SELECT ST_Relate( 'POLYGON( ( 7 1, 7 3, 9 3, 9 1, 7 1 ) )',  
                  'POINT( 8 3 )' );
```

```
SELECT ST_Relate( 'POLYGON( ( 9 5, 9 7, 11 7, 11 5, 9 5 ) )',  
                  'LINESTRING( 13 6, 10 6, 10 8 )' );
```

```
SELECT ST_Relate( 'LINESTRING( 11 2, 13 4, 15 2 )',  
                  'LINESTRING( 12 3, 12 1, 15 1 )' );
```

As geometrias A e B seguem um determinado relacionamento espacial?

`ST_Relate(A, B, 'T*T***F**') ?`

$T \rightarrow \dim(x) \in \{0, 1, 2\}$, ou seja, $x \neq \emptyset$

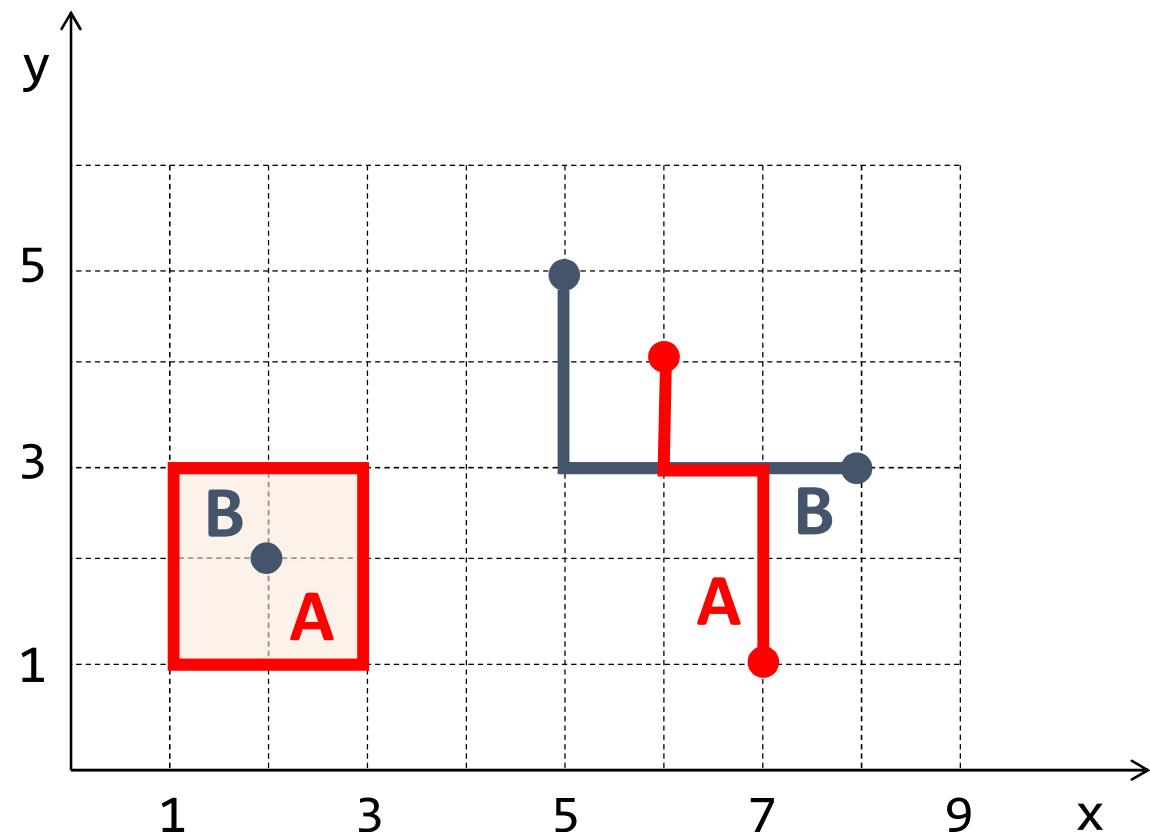
$F \rightarrow \dim(x) = \emptyset$, ou seja, $x = \emptyset \rightarrow \dim(x) = -1$

$*$ → $\dim(x) \in \{-1, 0, 1, 2\}$

$0 \rightarrow \dim(x) = 0$

$1 \rightarrow \dim(x) = 1$

$2 \rightarrow \dim(x) = 2$



As geometrias A e B possuem o relacionamento espacial informado?

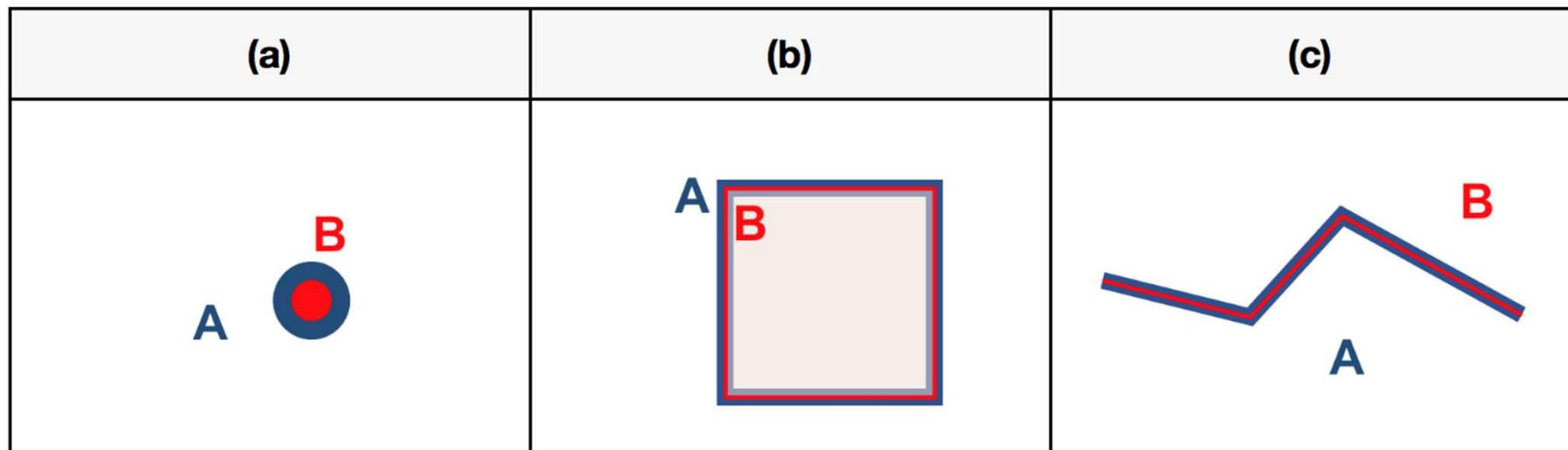
```
SELECT ST_Relate( 'POLYGON( ( 1 1, 1 3, 3 3, 3 1, 1 1 ) )',  
                  'POINT( 2 2 )',  
                  'T*T***F**' );
```

```
SELECT ST_Relate( 'LINESTRING( 6 4, 6 3, 7 3, 7 1 )',  
                  'LINESTRING( 5 5, 5 3, 8 3 )',  
                  'T*T***F**' );
```

Relacionamentos Espaciais Nomeados

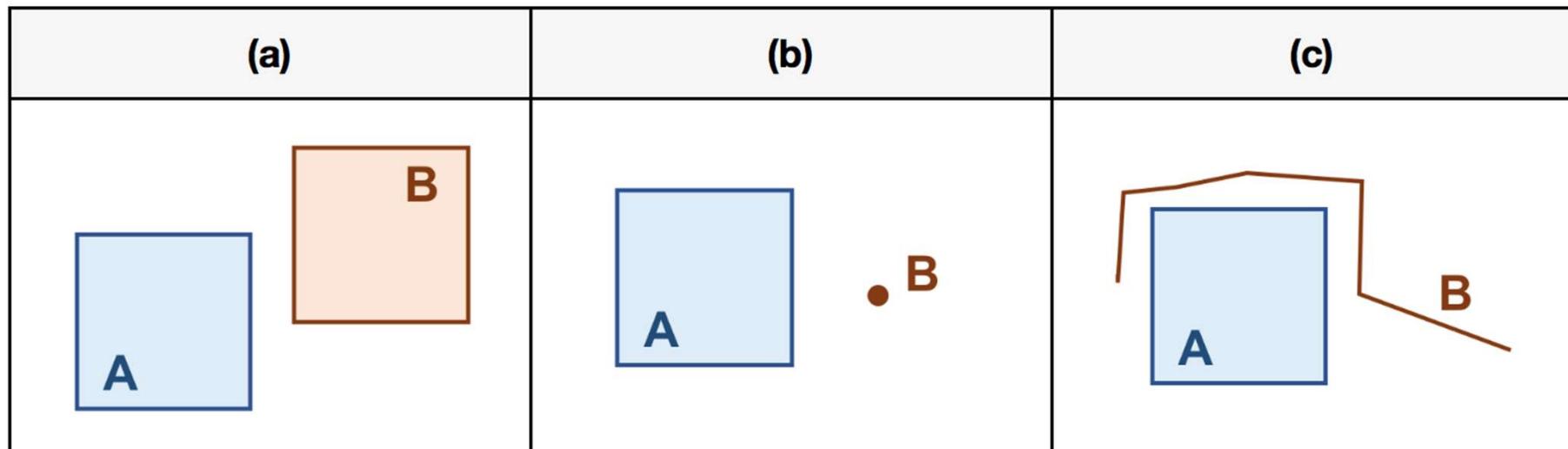
$\text{Equals}(A, B) \rightarrow \text{bool}$

	$Interior(B)$	$Fronteira(B)$	$Exterior(B)$
$Interior(A)$	T	F	F
$Fronteira(A)$	F	T	F
$Exterior(A)$	F	F	T



$\text{Disjoint}(A, B) \rightarrow \text{bool}$

	$Interior(B)$	$Fronteira(B)$	$Exterior(B)$
$Interior(A)$	F	F	*
$Fronteira(A)$	F	F	*
$Exterior(A)$	*	*	*

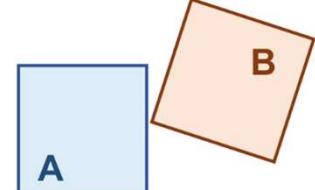
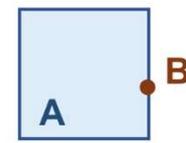
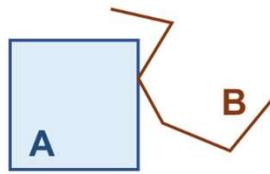
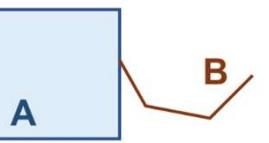


Touches(A, B) → bool

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	<i>F</i>	<i>T</i>	*
<i>Fonteira(A)</i>	*	*	*
<i>Exterior(A)</i>	*	*	*

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	<i>F</i>	*	*
<i>Fonteira(A)</i>	<i>T</i>	*	*
<i>Exterior(A)</i>	*	*	*

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	<i>F</i>	*	*
<i>Fonteira(A)</i>	*	<i>T</i>	*
<i>Exterior(A)</i>	*	*	*

(a)	(b)	(c)	(d)
			

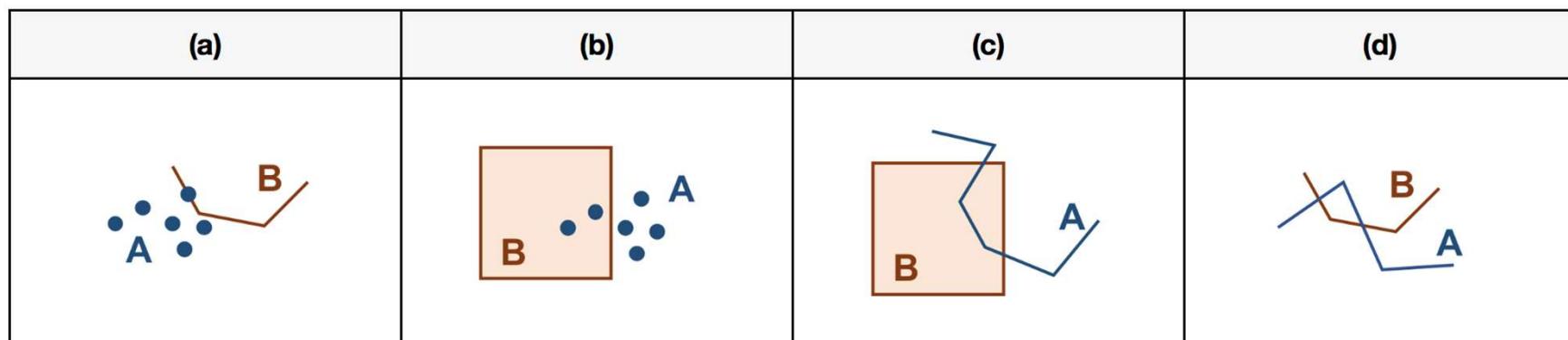
Crosses(A, B) → bool

Nos casos P/L, P/A, ou L/A:

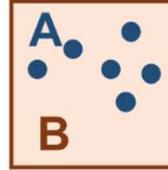
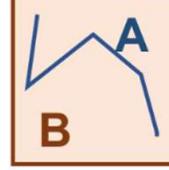
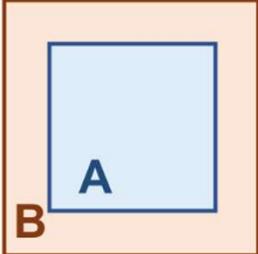
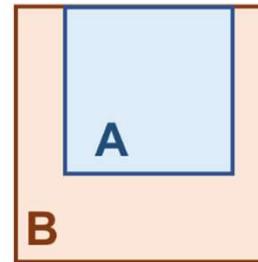
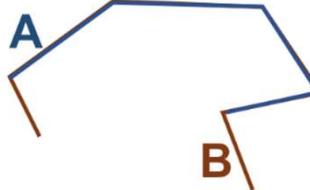
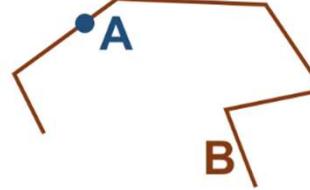
	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	<i>T</i>	*	<i>T</i>
<i>Fronteira(A)</i>	*	*	*
<i>Exterior(A)</i>	*	*	*

No caso L/L:

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	0	*	*
<i>Fronteira(A)</i>	*	*	*
<i>Exterior(A)</i>	*	*	*



$\text{Within}(A, B) \rightarrow \text{bool}$

	$Interior(B)$	$Fronteira(B)$	$Exterior(B)$
$Interior(A)$	T	*	F
$Fronteira(A)$	*	*	F
$Exterior(A)$	*	*	*
		(a)	(b)
			
		(c)	
		(d)	(e)
			
		(f)	

$\text{Contains}(A, B) \rightarrow \text{bool}$

$$\text{Contains}(A, B) \iff \text{Within}(B, A)$$

	$\text{Interior}(B)$	$\text{Fronteira}(B)$	$\text{Exterior}(B)$
$\text{Interior}(A)$	T	*	*
$\text{Fronteira}(A)$	*	*	*
$\text{Exterior}(A)$	F	F	*

Obs.: Na matriz acima podemos observar que o interior das duas geometrias devem ter intersecção e que a fronteira e interior da segunda (**B**) não pode ter intersecção com o exterior da primeira (**A**).

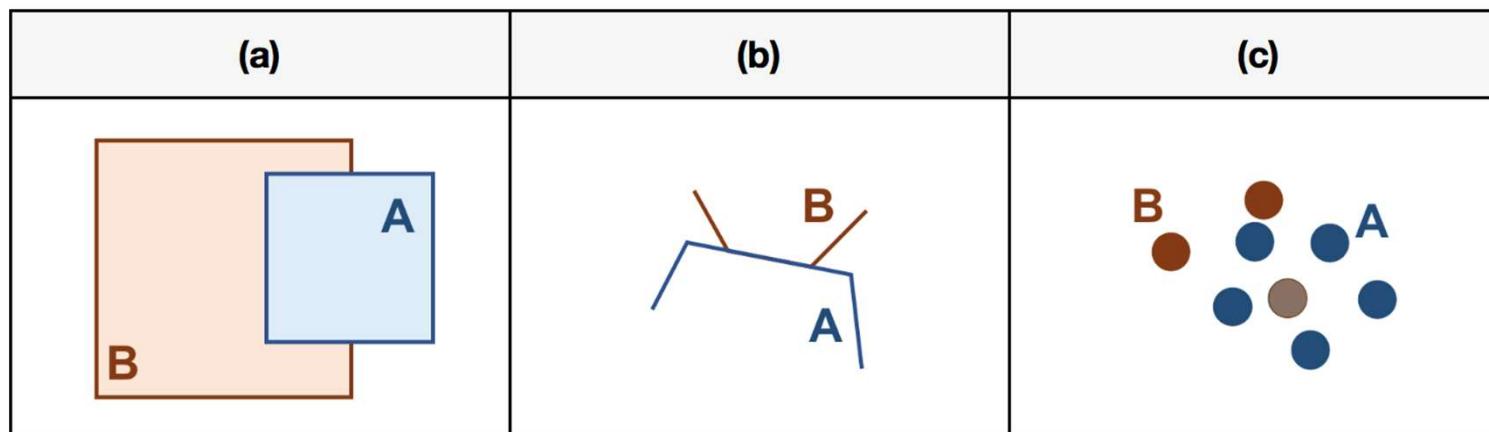
Overlaps(A, B) → bool

No caso P/P ou A/A:

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	T	*	T
<i>Fronteira(A)</i>	*	*	*
<i>Exterior(A)</i>	T	*	*

No caso L/L:

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	1	*	T
<i>Fronteira(A)</i>	*	*	*
<i>Exterior(A)</i>	T	*	*



Intersects(A, B) → bool

$$\text{Intersects}(A, B) \iff \neg \text{Disjoint}(A, B)$$

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	<i>T</i>	*	*
<i>Fonteira(A)</i>	*	*	*
<i>Exterior(A)</i>	*	*	*

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	*	*	*
<i>Fonteira(A)</i>	*	<i>T</i>	*
<i>Exterior(A)</i>	*	*	*

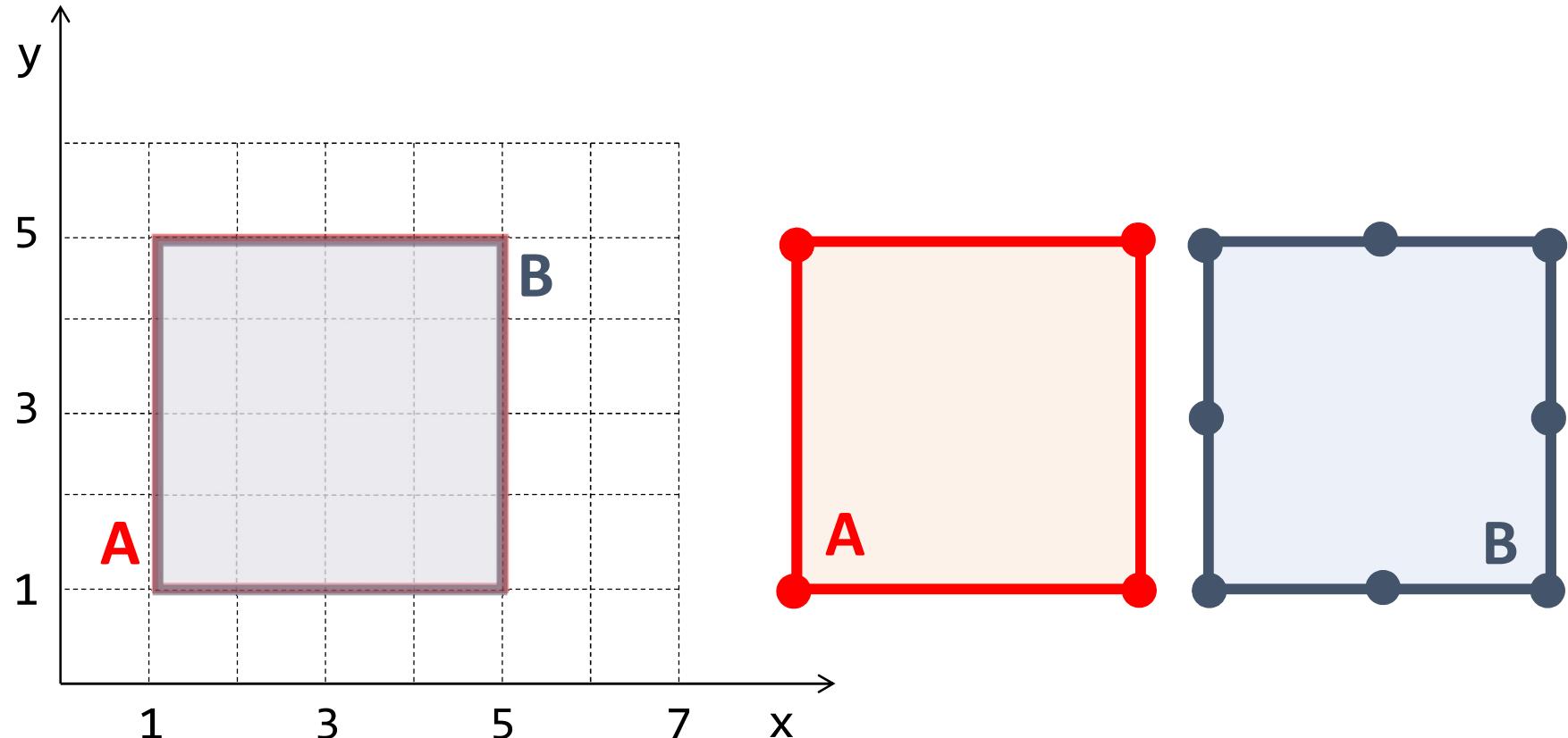
	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	*	<i>T</i>	*
<i>Fonteira(A)</i>	*	*	*
<i>Exterior(A)</i>	*	*	*

	<i>Interior(B)</i>	<i>Fronteira(B)</i>	<i>Exterior(B)</i>
<i>Interior(A)</i>	*	*	*
<i>Fonteira(A)</i>	<i>T</i>	*	*
<i>Exterior(A)</i>	*	*	*

Relacionamentos Espaciais no PostGIS

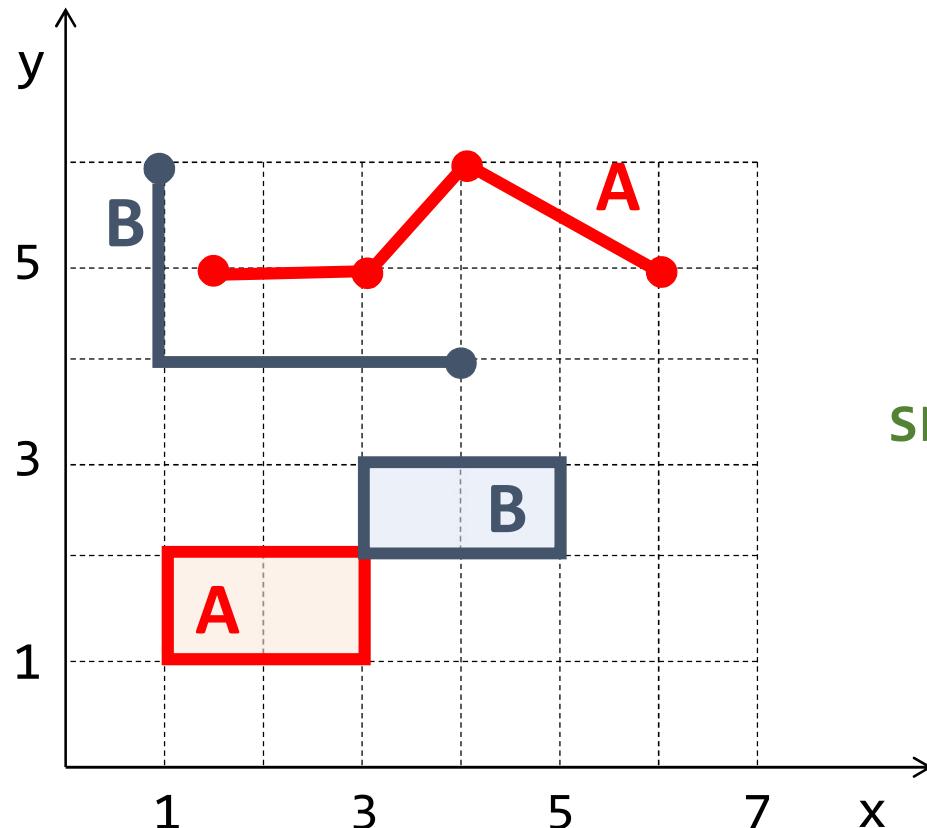
As geometrias A e B são iguais?

```
SELECT ST_Equals(  
    'POLYGON( ( 1 1, 1 5, 5 5, 5 1, 1 1 ) )',  
    'POLYGON( (5 3, 5 5, 3 5, 1 5, 1 3, 1 1, 3 1, 5 1, 5 3 ) )' );
```



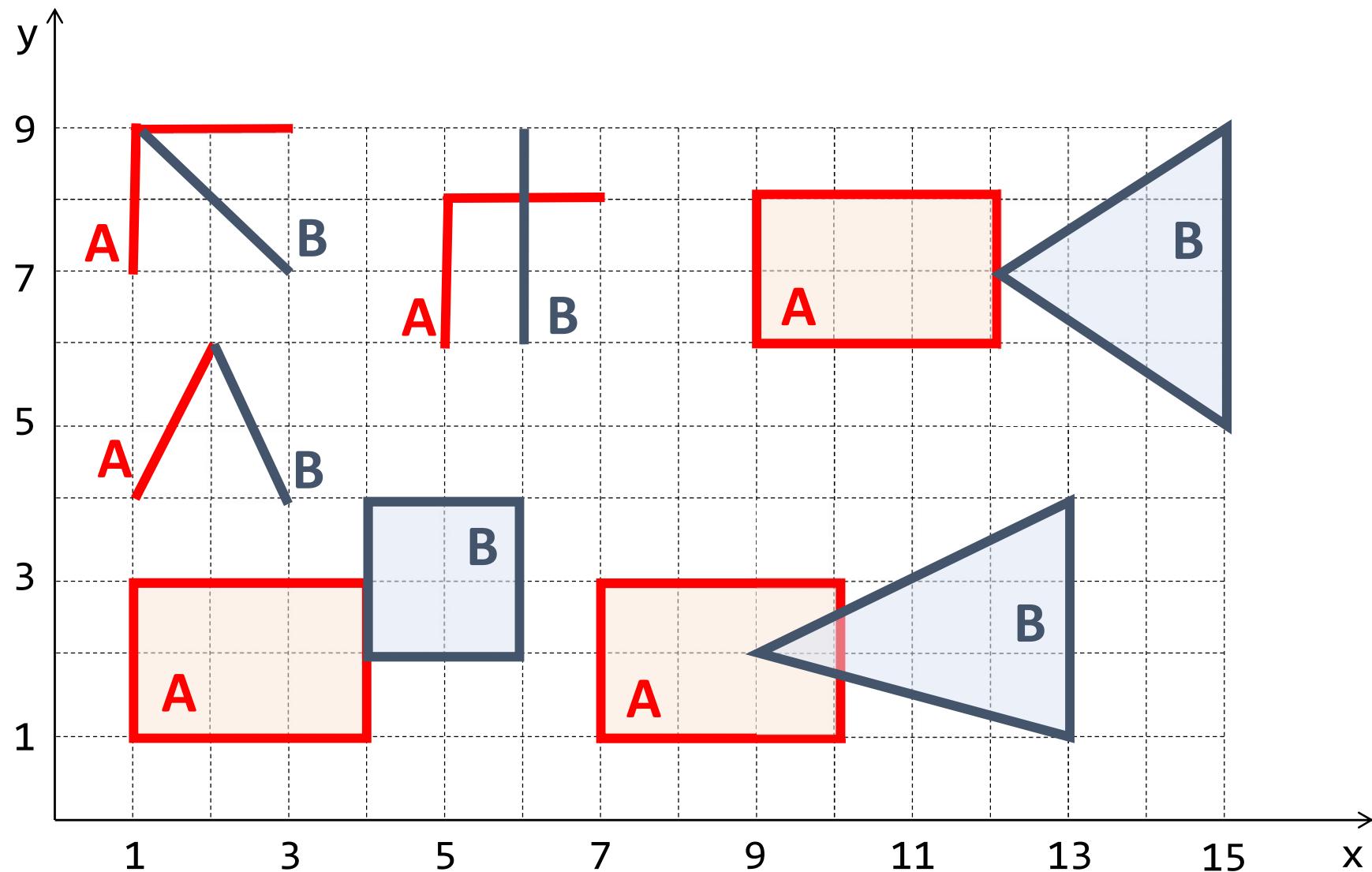
As geometrias A e B são disjuntas?

```
SELECT ST_Disjoint(  
    'LINESTRING( 1.5 5, 3 5, 4 6, 6 5 )',  
    'LINESTRING( 1 6, 1 4, 4 4 )' );
```

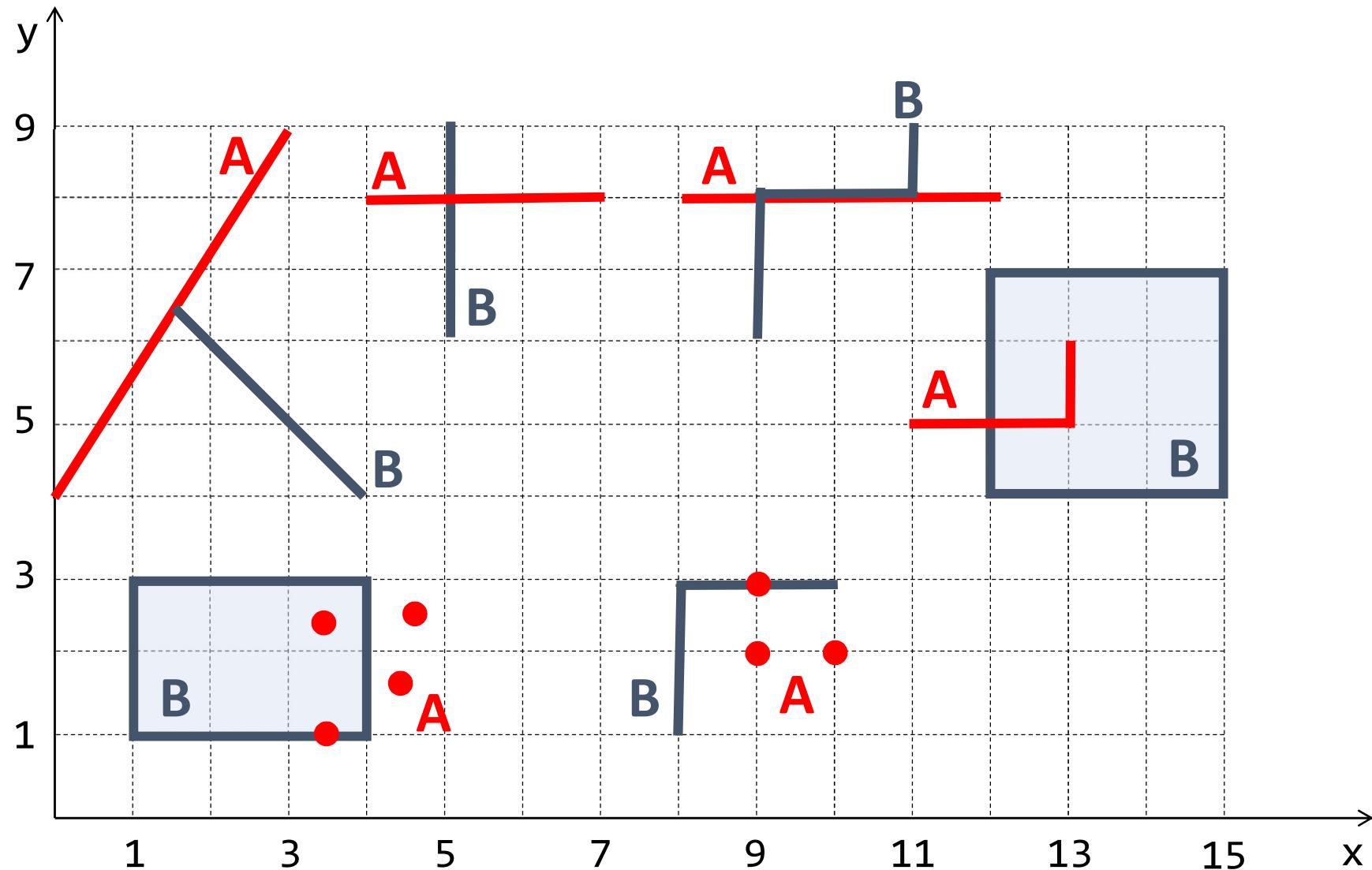


```
SELECT ST_Disjoint(  
    'POLYGON( ( 1 1, 1 2, 3 2,  
                3 1, 1 1 ) )',  
    'POLYGON( ( 3 3, 5 3, 5 2,  
                3 2, 3 3 ) )' );
```

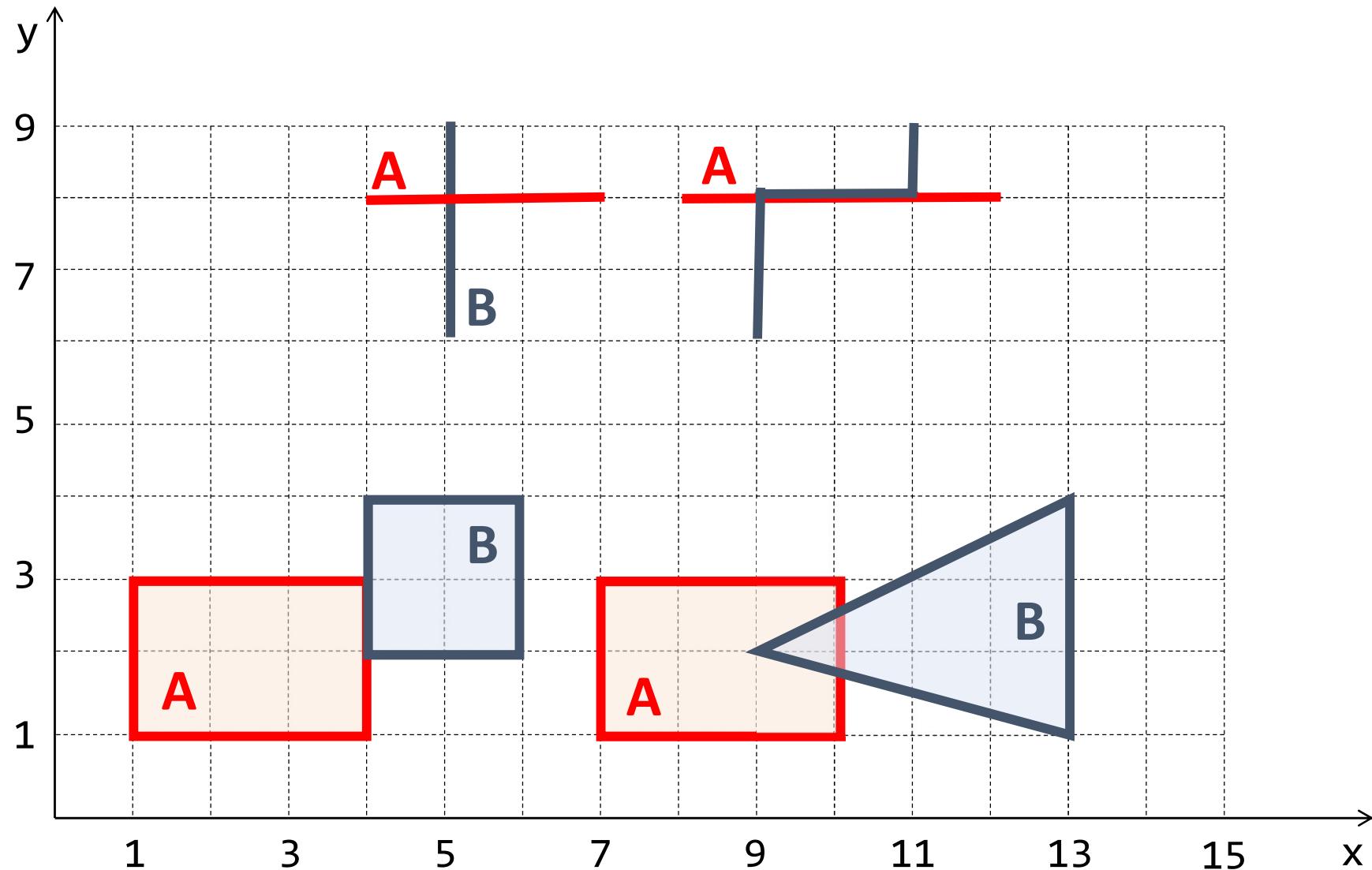
A geometria A toca B?



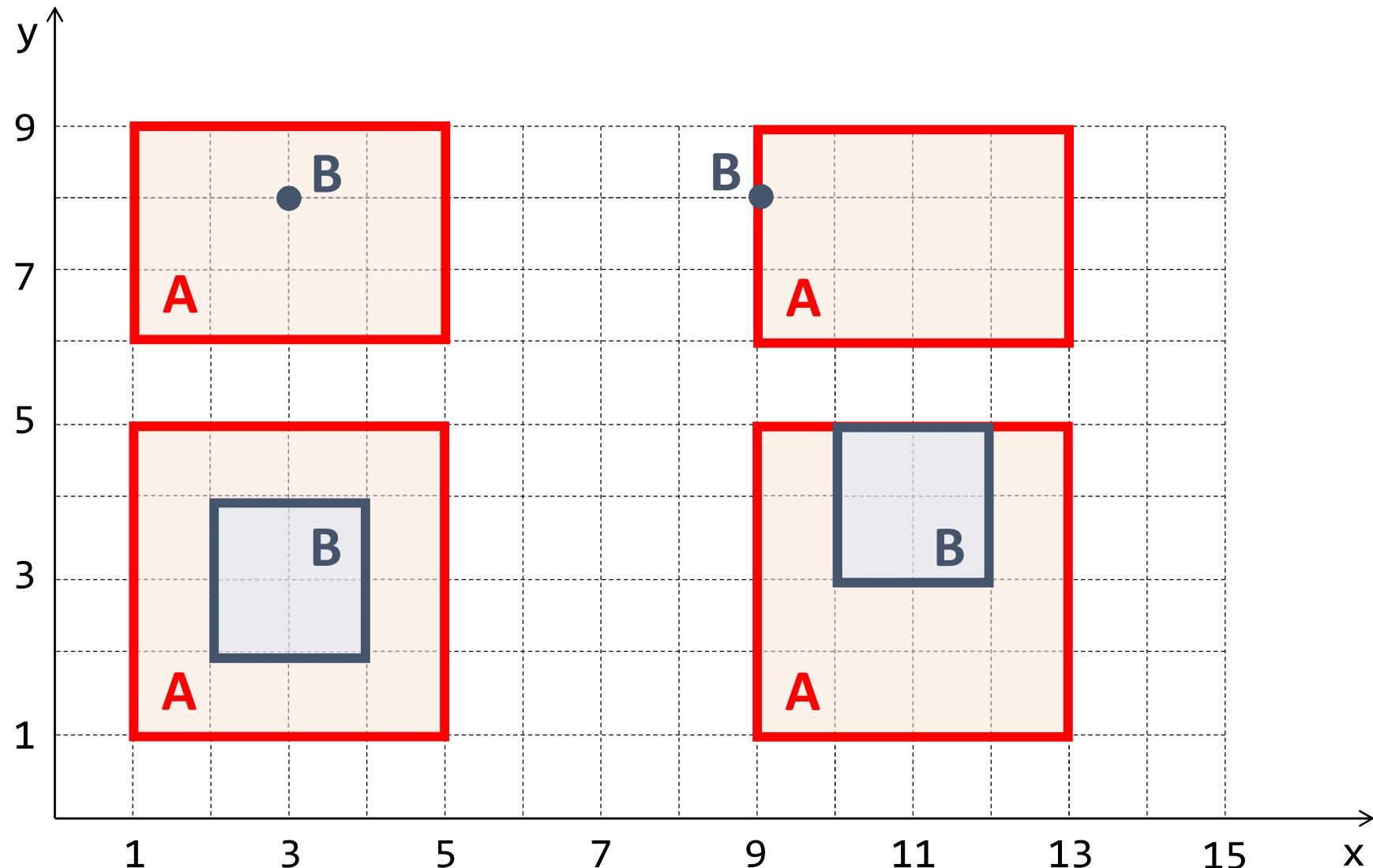
A geometria A cruza B?



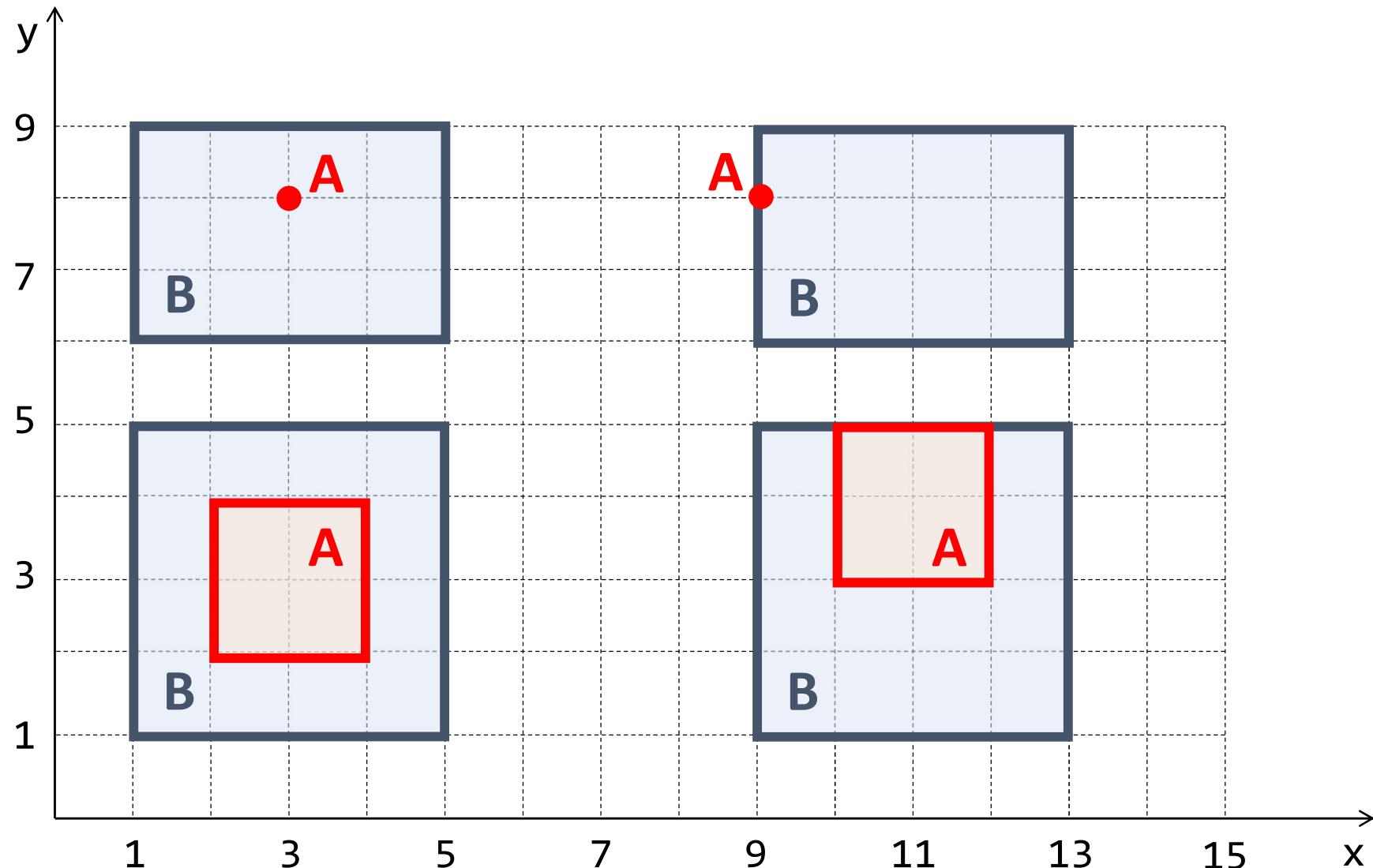
A geometria A sobrepõe B?



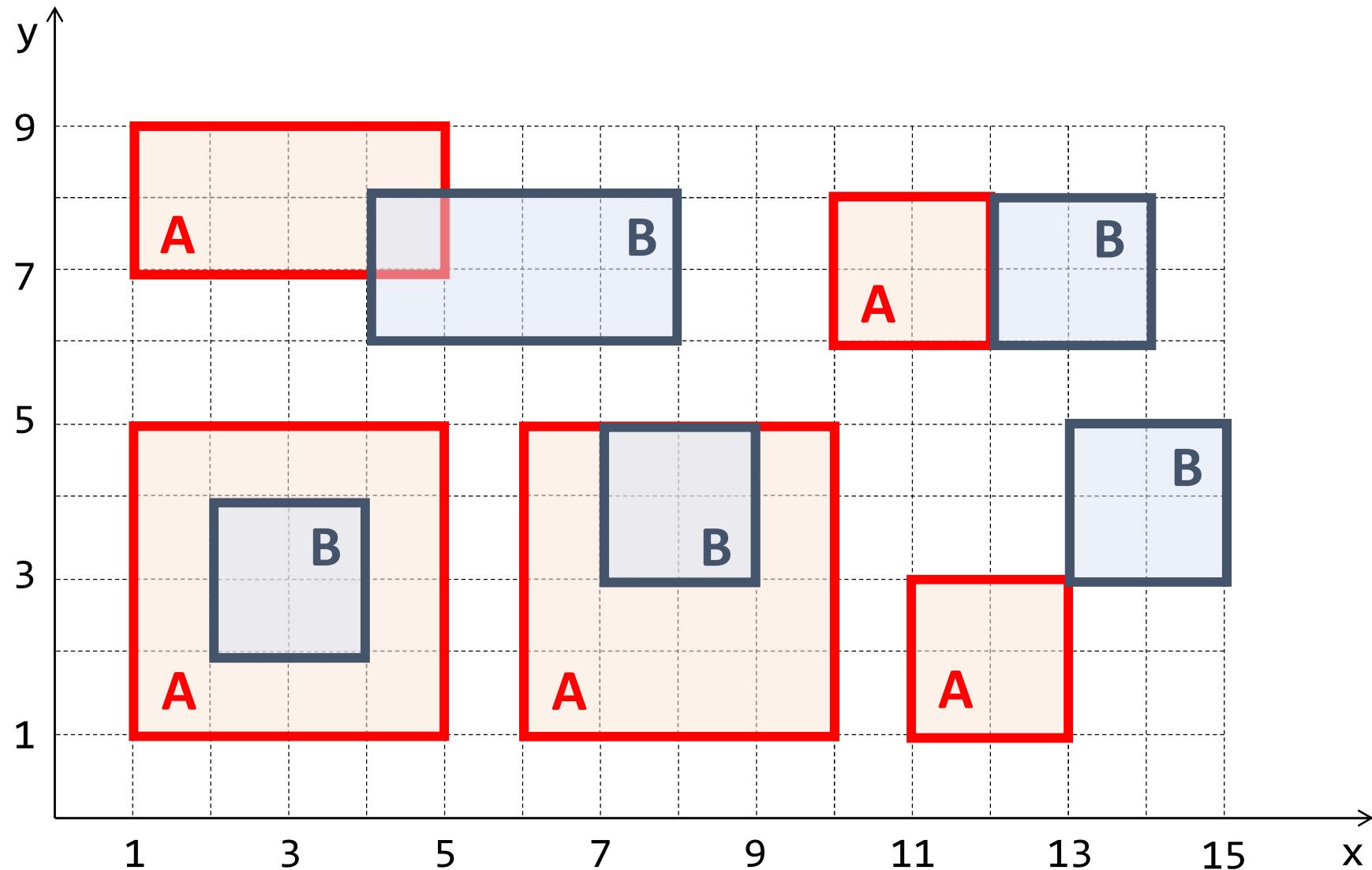
A geometria A contém B?



A geometria A está dentro de B?



A geometria A intersecta B?



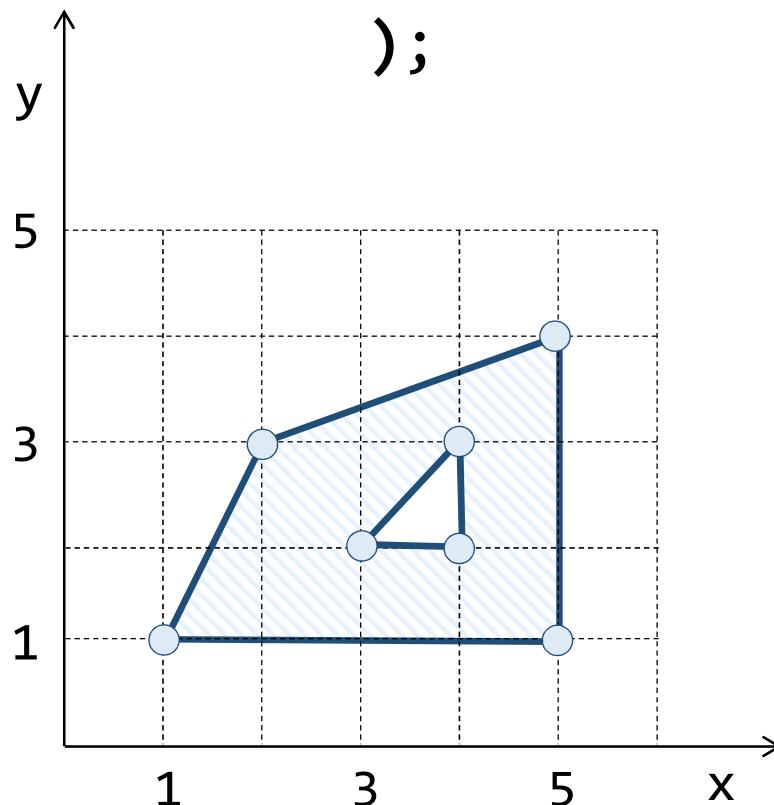
Operadores PostGIS

- O PostGIS oferece também os seguintes operadores topológicos:
 - ST_Covers
 - ST_CoveredBy
 - ST_EqualsExact

Operadores Métricos

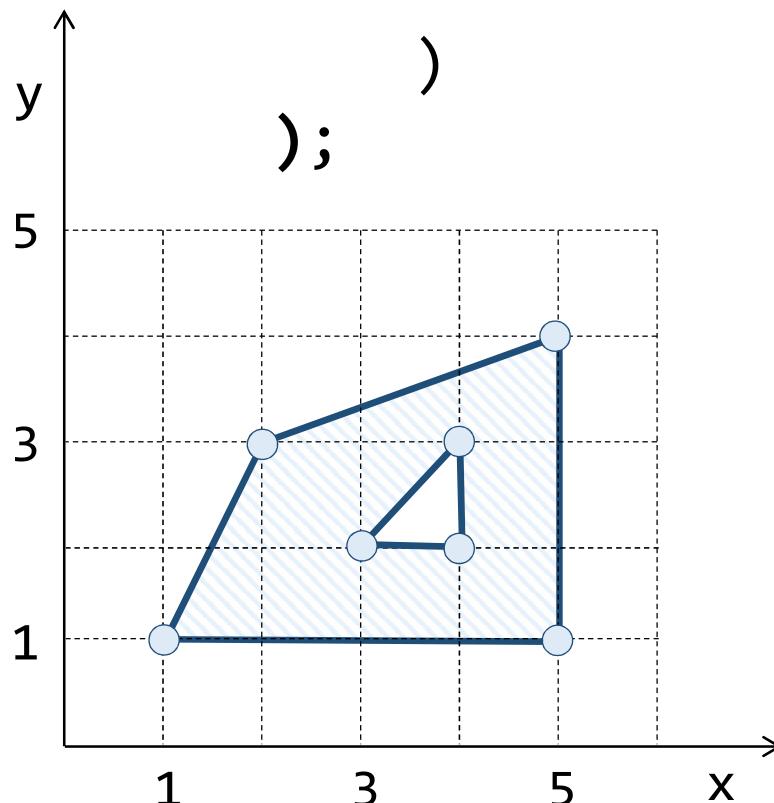
Qual a área do polígono?

```
SELECT ST_Area(  
    'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),  
                (3 2, 4 3, 4 2, 3 2) )'  
);
```



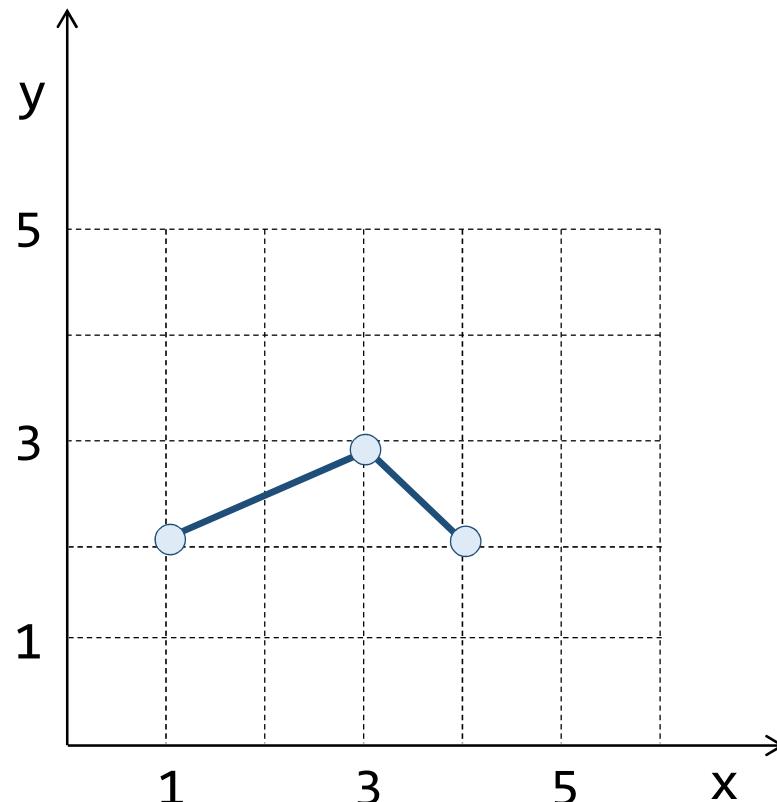
Qual o perímetro da geometria?

```
SELECT ST_Perimeter(  
    ST_GeomFromText(  
        'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),  
                  (3 2, 4 3, 4 2, 3 2) )' ))
```



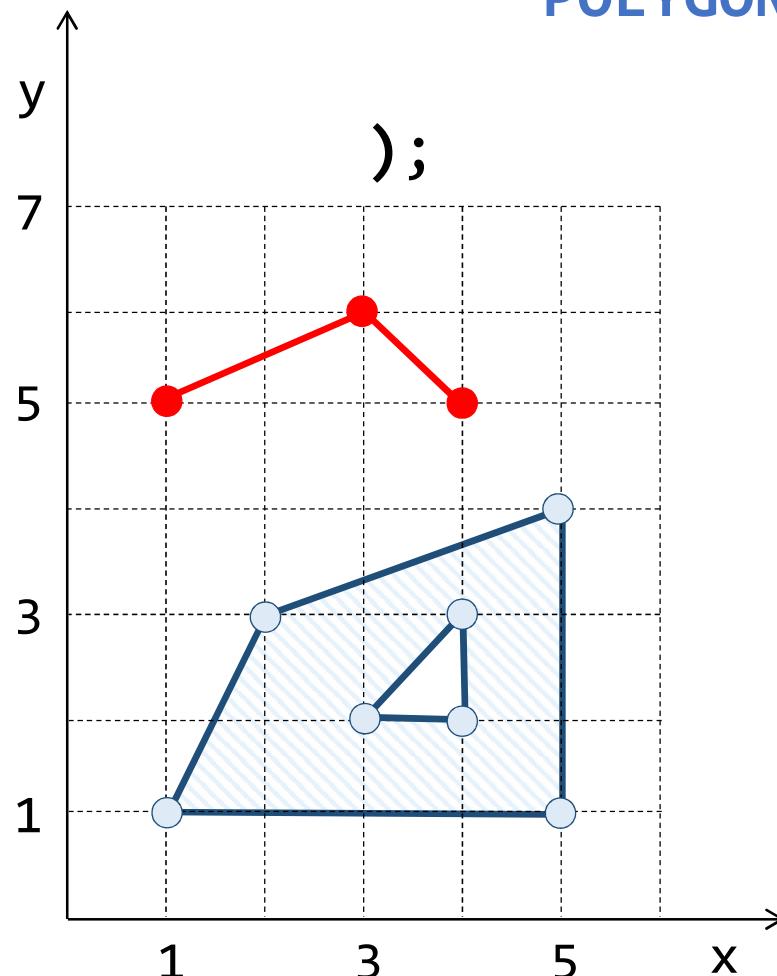
Qual o cumprimento da geometria?

```
SELECT ST_Length( 'LINESTRING( 1 2, 3 3, 4 2 )' );
```



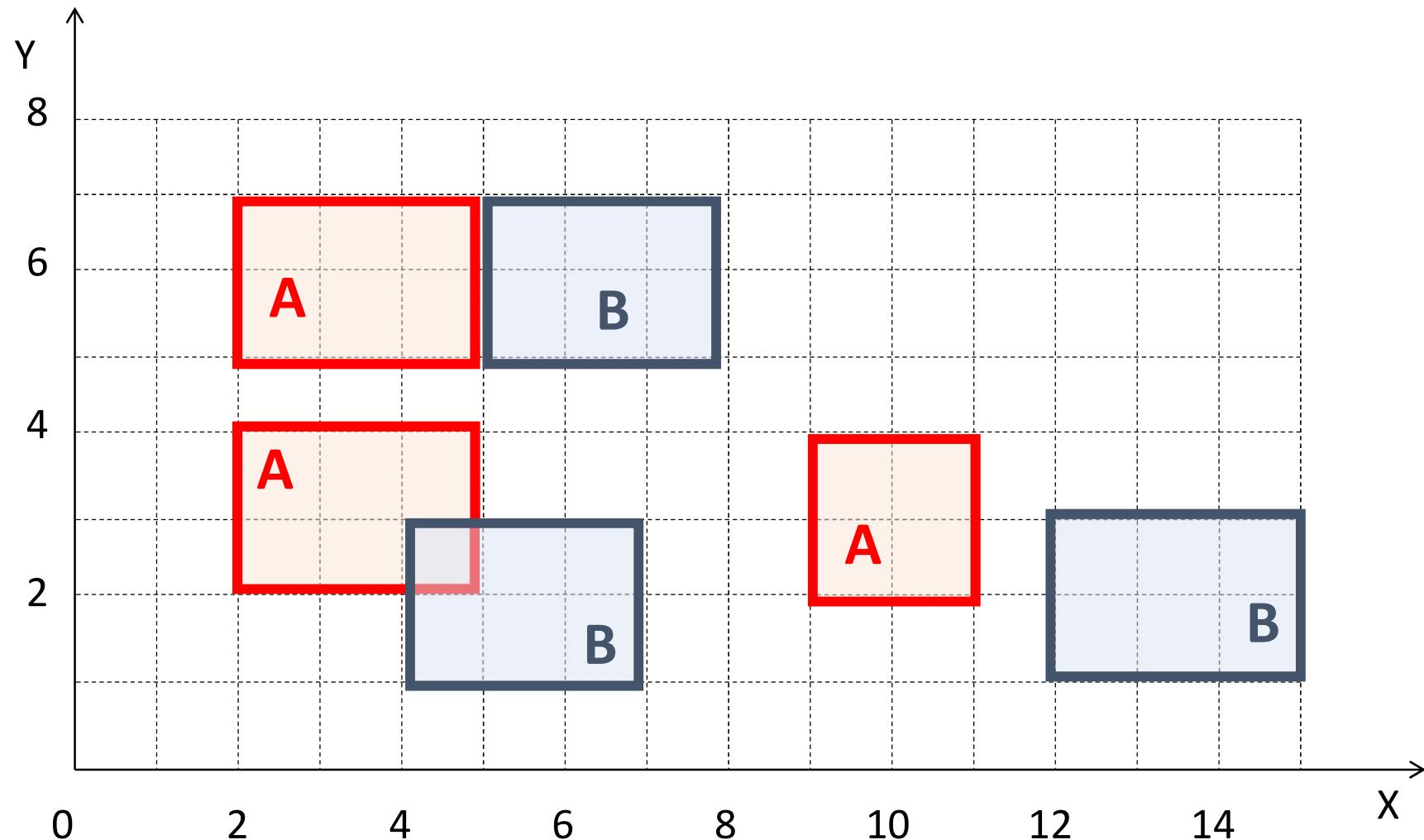
Qual a distância entre A e B?

```
SELECT ST_Distance(  
    'LINESTRING( 1 5, 3 6, 4 5 )',  
    'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),  
              (3 2, 4 3, 4 2, 3 2) )'  
);
```

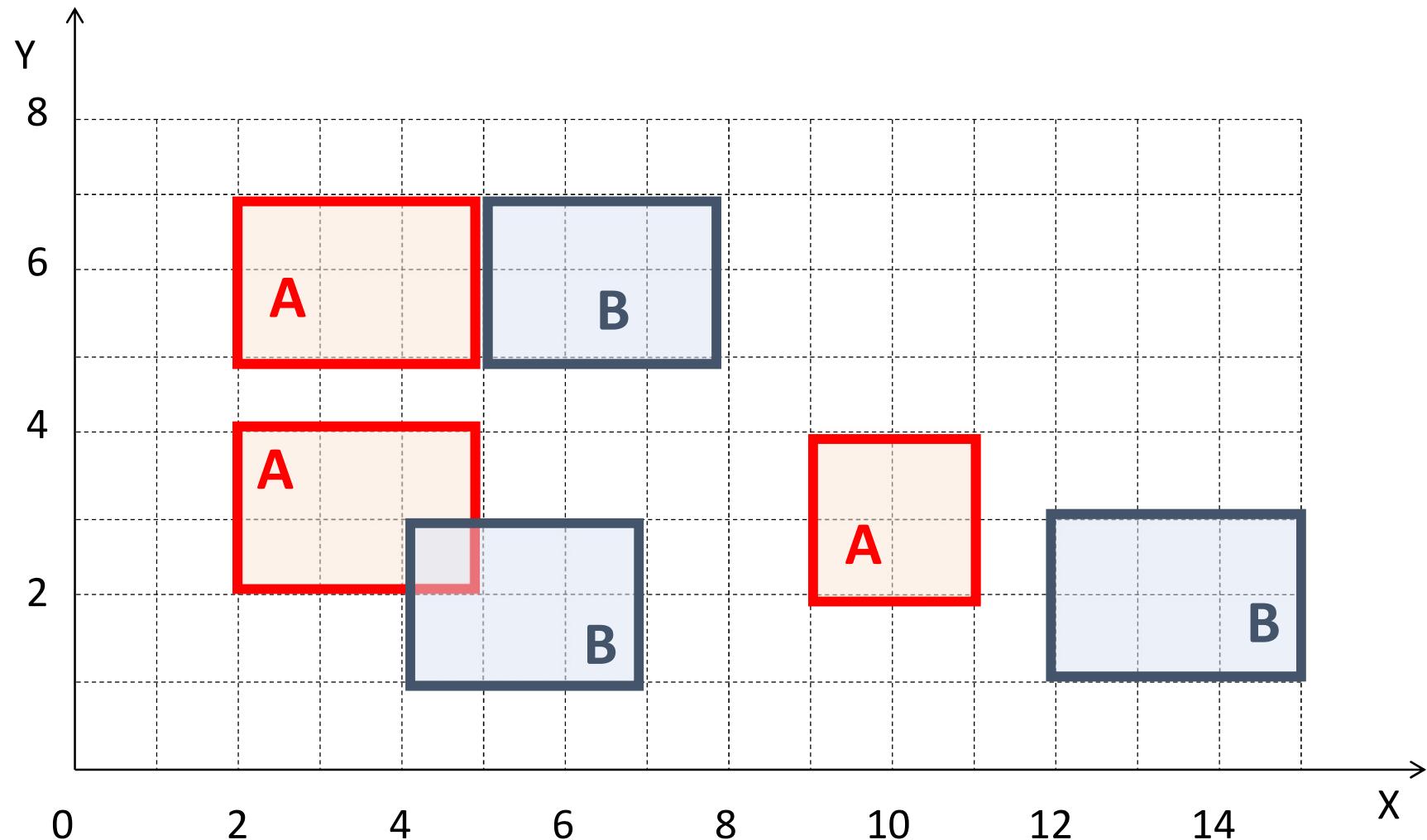


Operadores Conjunto

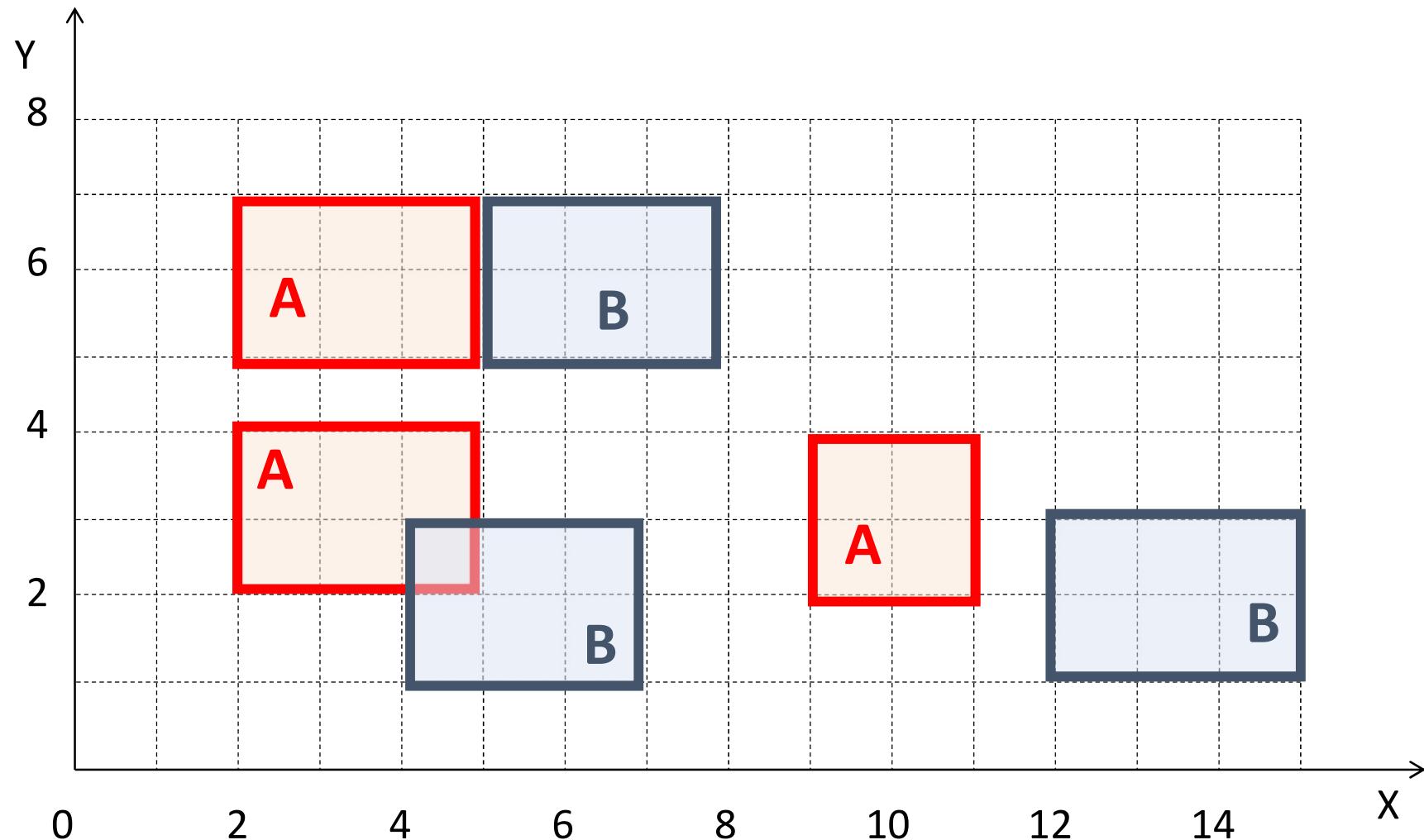
Intersecção entre as geometrias A e B



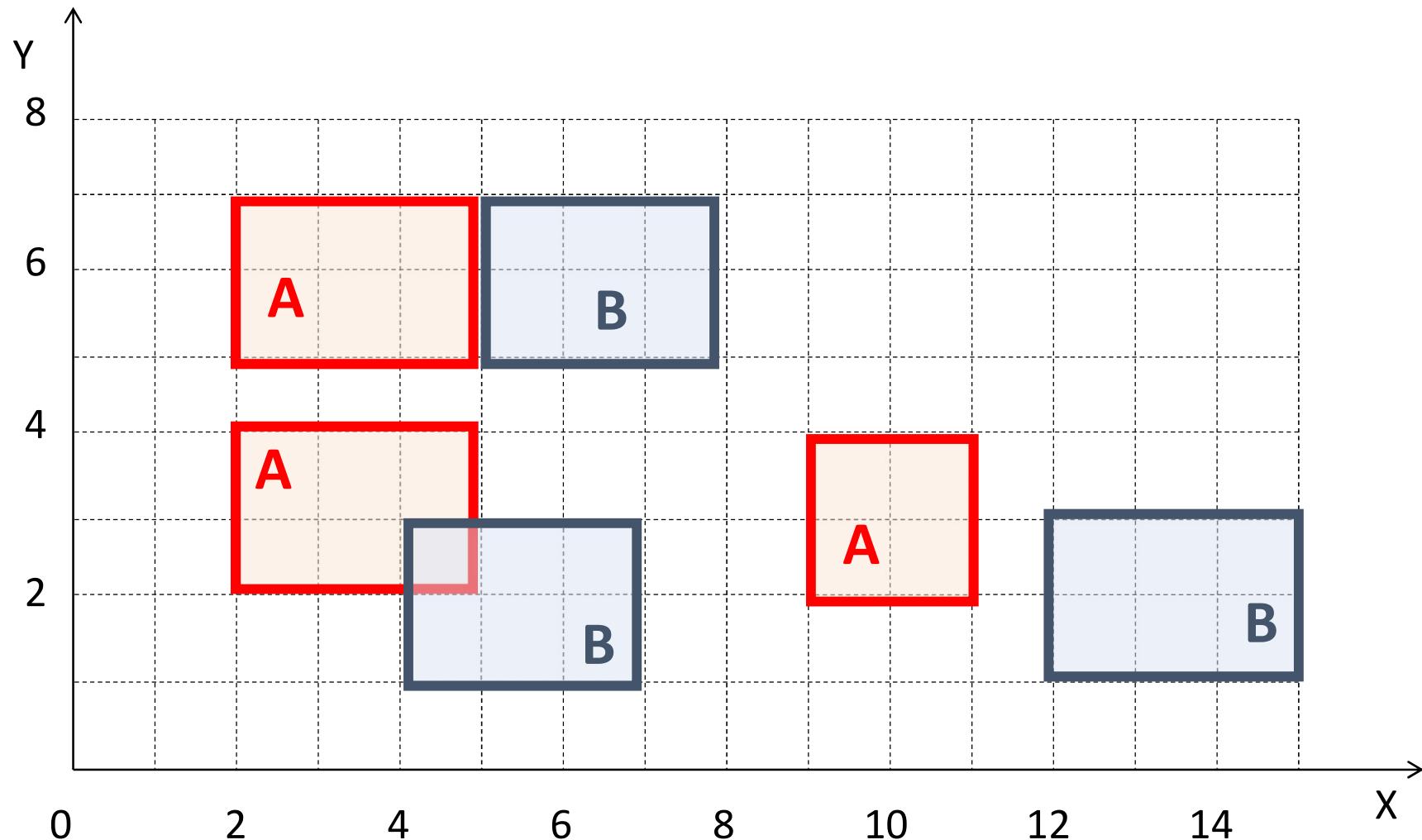
União entre as geometrias A e B



Diferença entre as geometrias A e B



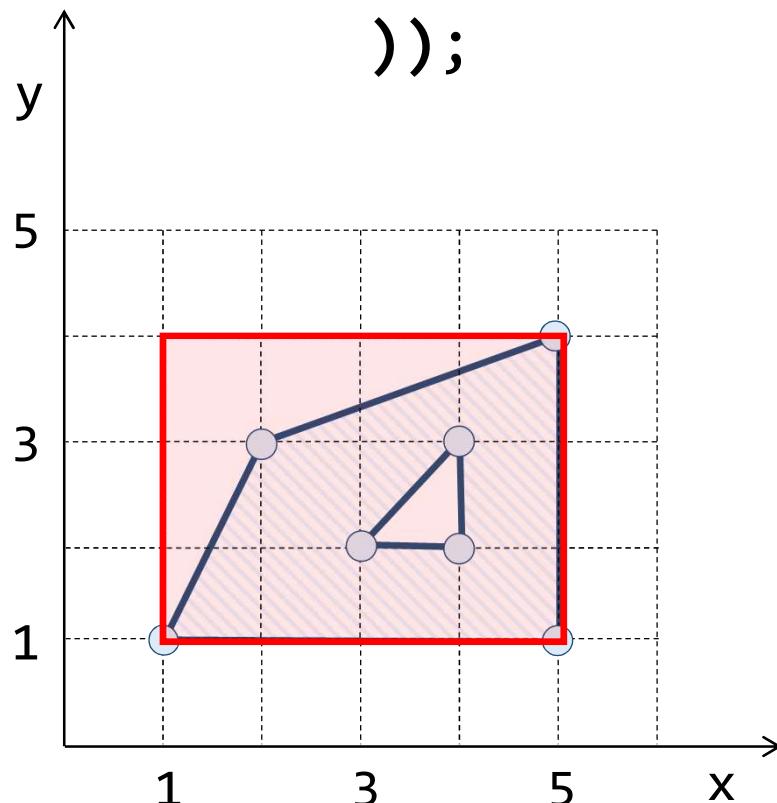
Diferença Simétrica entre as geometrias A e B



Operações Geração Geometrias

Retângulo Envolvente da Geometria

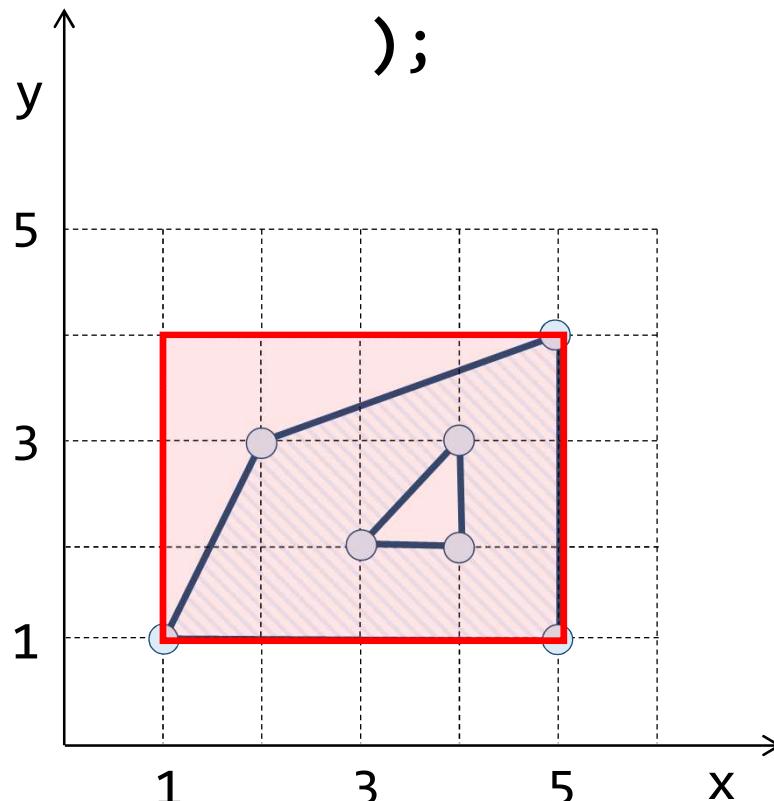
```
SELECT ST_Envelope( ST_GeomFromText(  
    'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),  
              (3 2, 4 3, 4 2, 3 2) )'  
));
```



Obs.: O objeto retornado pela operação `ST_Envelope` é uma geometria do tipo Polygon.

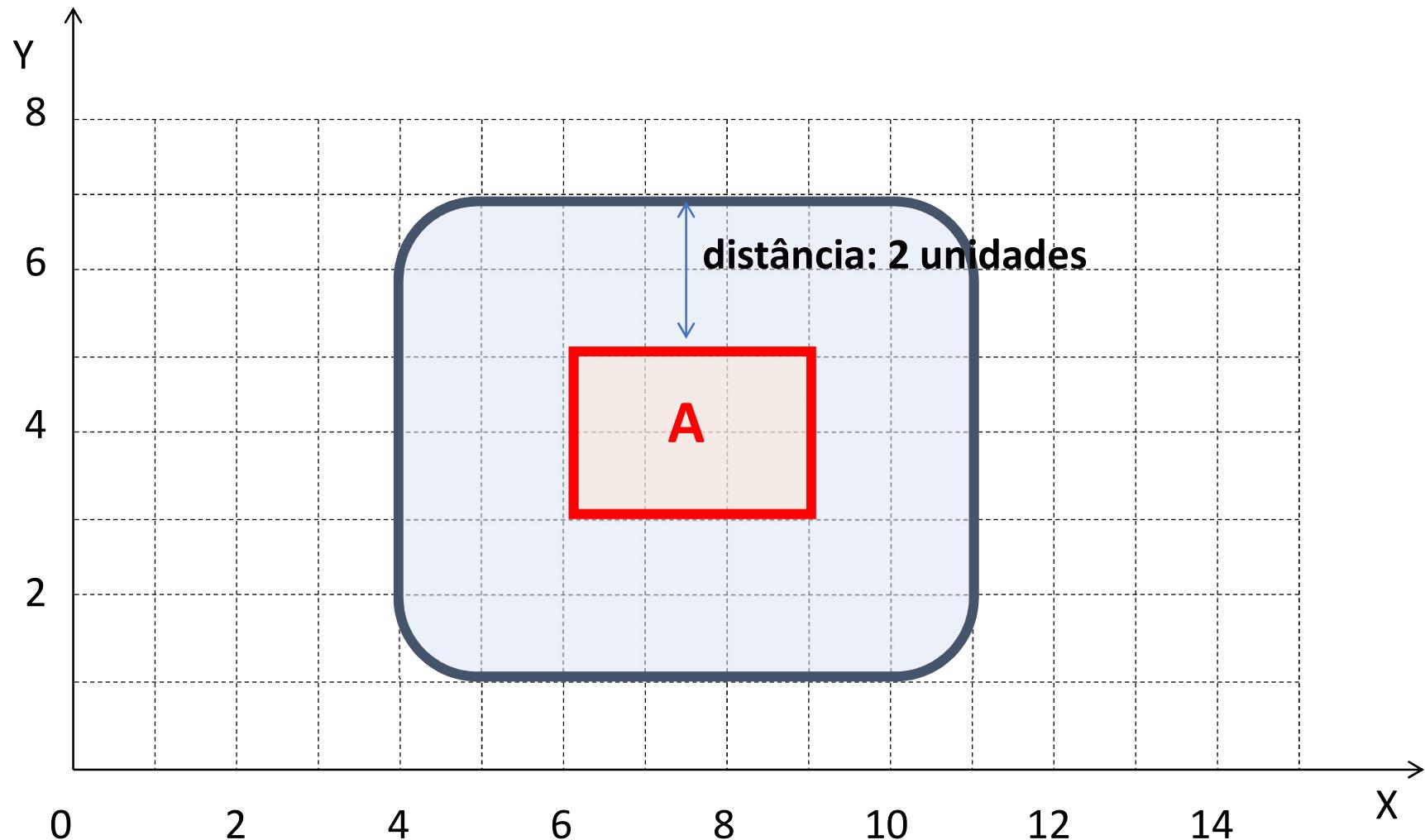
Retângulo Envolvente da Geometria

```
SELECT ST_Extent(  
    'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),  
              (3 2, 4 3, 4 2, 3 2) )'  
);
```



Obs.: Outra opção é utilizar a operação `ST_Extent` para obter um objeto que represente apenas o retângulo envolvente com as coordenadas do canto inferior esquerdo e superior direito.

ST_Buffer



Sistemas de Referência Espacial

Suporte a Projeções Cartográficas

- O PostGIS possui uma tabela de metadados com a lista de todos os sistemas de referência espacial suportados por ele:
 - Tabela: `spatial_ref_sys`
- `ST_Transform(geometria, novo-srid)`:
 - Retorna uma nova geometria com as coordenadas transformadas para um novo SRID.
 - O novo SRID deve estar presente na tabela `spatial_ref_sys`.

ST_Transform

- Coordenadas:
 - Latitude: -12; Longitude: -54
 - Datum: SAD/69; SRID: 4618
- Converter para:
 - Policonica SAD/69: 29101

```
SELECT ST_AsText(
    ST_Transform(ST_GeomFromText('POINT (-54 -12)',
        4618), 29101));
```
 - Lat/Long – SIRGAS-2000: 4674

```
SELECT ST_AsText(
    ST_Transform(ST_GeomFromText('POINT (-54 -12)',
        4618), 4674));
```

Considerações Finais

Considerações Finais

- PostGIS implementa a OGC-SFS e ISO SQL/MM – Part 3 – Spatial.
- PostGIS adotou o prefixo “ST” ao nome dos operadores geométricos devido a ISO SQL/MM – Part 3 – Spatial.
- Operações topológicas, de conjunto e buffer são intensivas em relação ao uso de CPU.
- Podemos compor as operações geométricas, isto é, o resultado de uma operação pode ser encadeada na entrada de outra.
- O PostGIS fornece também os tipos Geography e Topology.

Considerações Finais

- Outras operações suportadas pelo PostGIS são:
 - Fecho ou Envoltório Convexo
 - Triangulação
 - Diagrama de Voronoi
 - Simplificação de Geometrias
- Os operadores topológicos são essenciais para o estabelecimento dos relacionamentos de integridade espaciais.
- Nesta parte da aula demos enfoque ao tipo geométrico usado na representação vetorial dos dados geográficos.
- A próxima discussão será como utilizar essas operações para construção de consultas espaciais sobre dados reais.

Referências Bibliográficas

Padrões e Especificações

- OGC. *OpenGIS Implementation Specification for Geographic information - Simple feature access - Part 1: Common architecture*. Disponível em: <http://www.opengeospatial.org>. Acesso: Outubro de 2012.
- OGC. *OpenGIS Implementation Specification for Geographic information - Simple feature access - Part 2: SQL option*. Disponível em: <http://www.opengeospatial.org>. Acesso: Outubro de 2012.
- ISO. *SQL Multimedia and Application Packages – Part 3: Spatial*.

Artigos

- Clementini, E.; Di Felice, P.; van Oosterom, P. **A small set of formal topological relationships suitable for end-user interaction.** In: Abel D., Chin Ooi B. (eds), Advances in Spatial Databases, SSD 1993, Singapore. Lecture Notes in Computer Science, vol 692, pp. 277-295, June 1993. Springer, Berlin, Heidelberg.
- Egenhofer, M.; Sharma, J. **Topological Relations Between Regions in R^2 and Z^2 .** In: Abel D., Chin Ooi B. (eds), Advances in Spatial Databases, SSD 1993, Singapore. Lecture Notes in Computer Science, vol 692, pp. 316-336, June 1993. Springer, Berlin, Heidelberg.
- Knut Stolze. **SQL/MM Spatial: The Standard to Manage Spatial Data in Relational Database Systems.** In: Gerhard Weikum, Harald Schöning, Erhard Rahm (eds) [BTW 2003]: Database Systems for Business, Technology and Web. Acesso em: 19 de maio de 2018.

Exercícios