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)

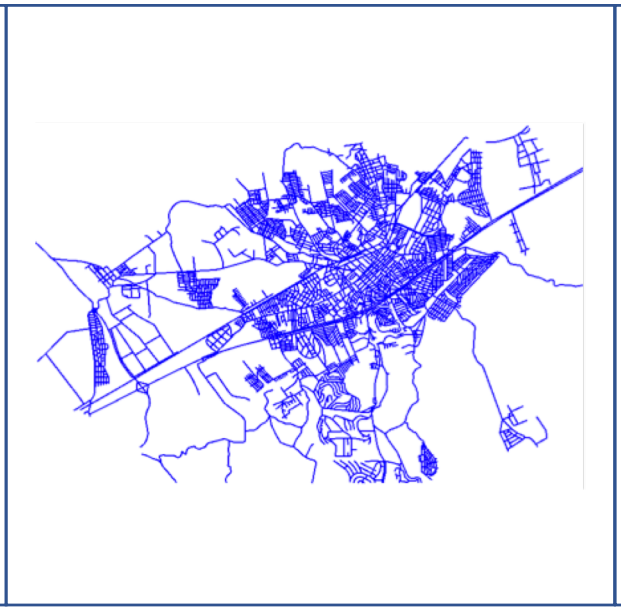
Coleção de Feições

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

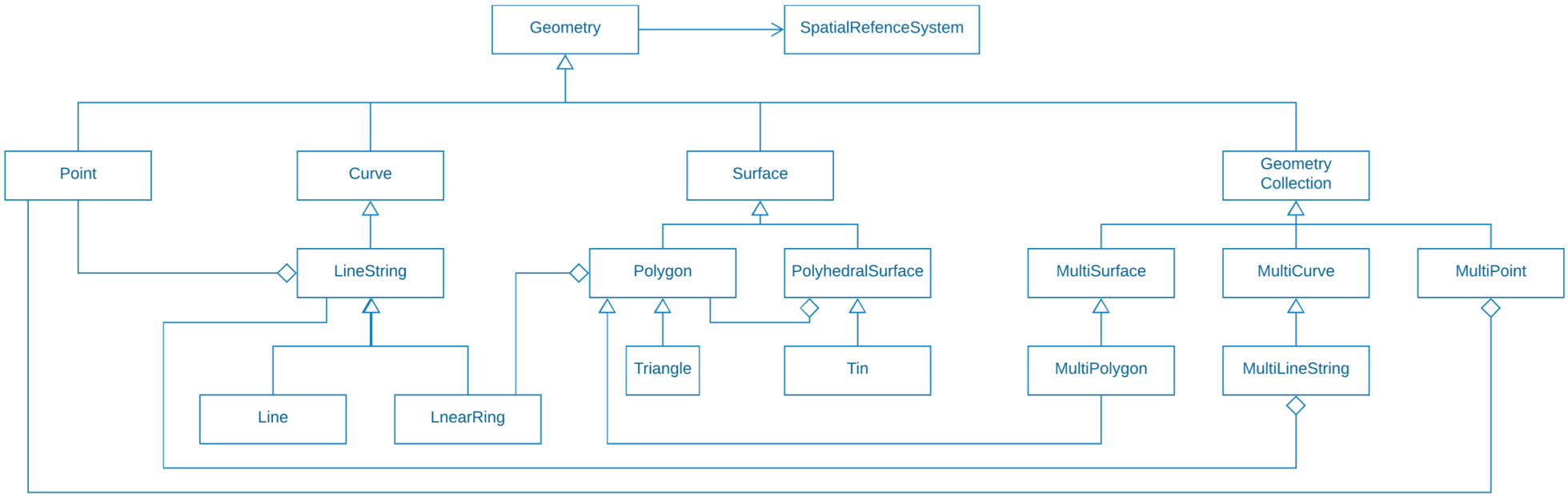
Status: Corrigendum

Category: OpenGIS ® Implementation Standard

Editor: John R. Herring

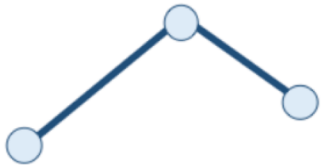
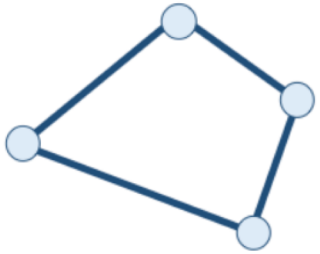
OpenGIS® Implementation Standard for Geographic information - Simple feature access - Part 1: Common architecture

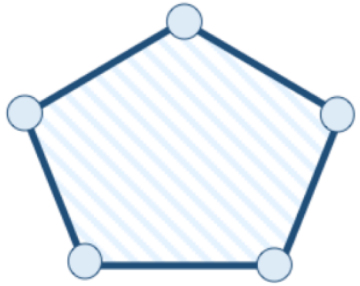
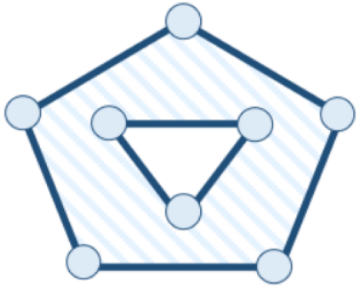
OGC Simple Feature

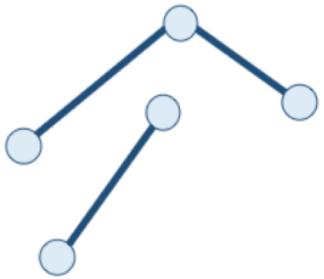
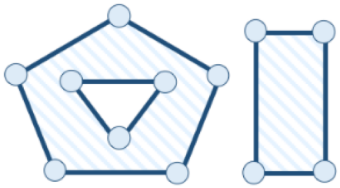
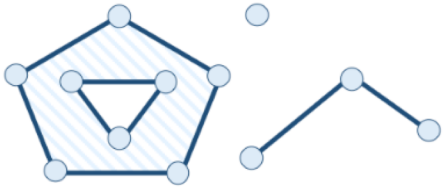


Fonte: Adaptado de Herring (2011).

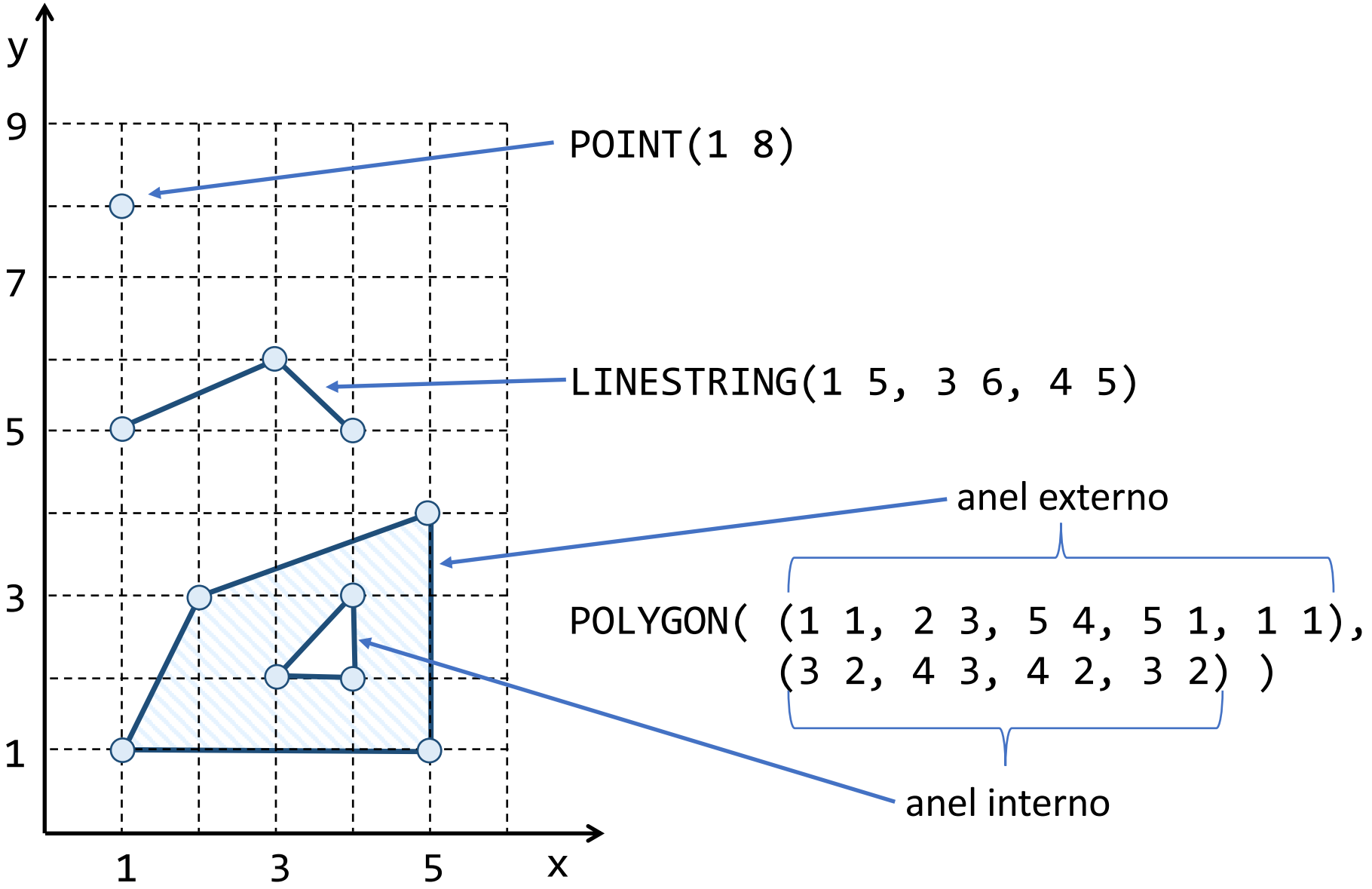
OGC Simple Feature

(a) `Point`	(b) `LineString`	(c) `LinearRing`
		

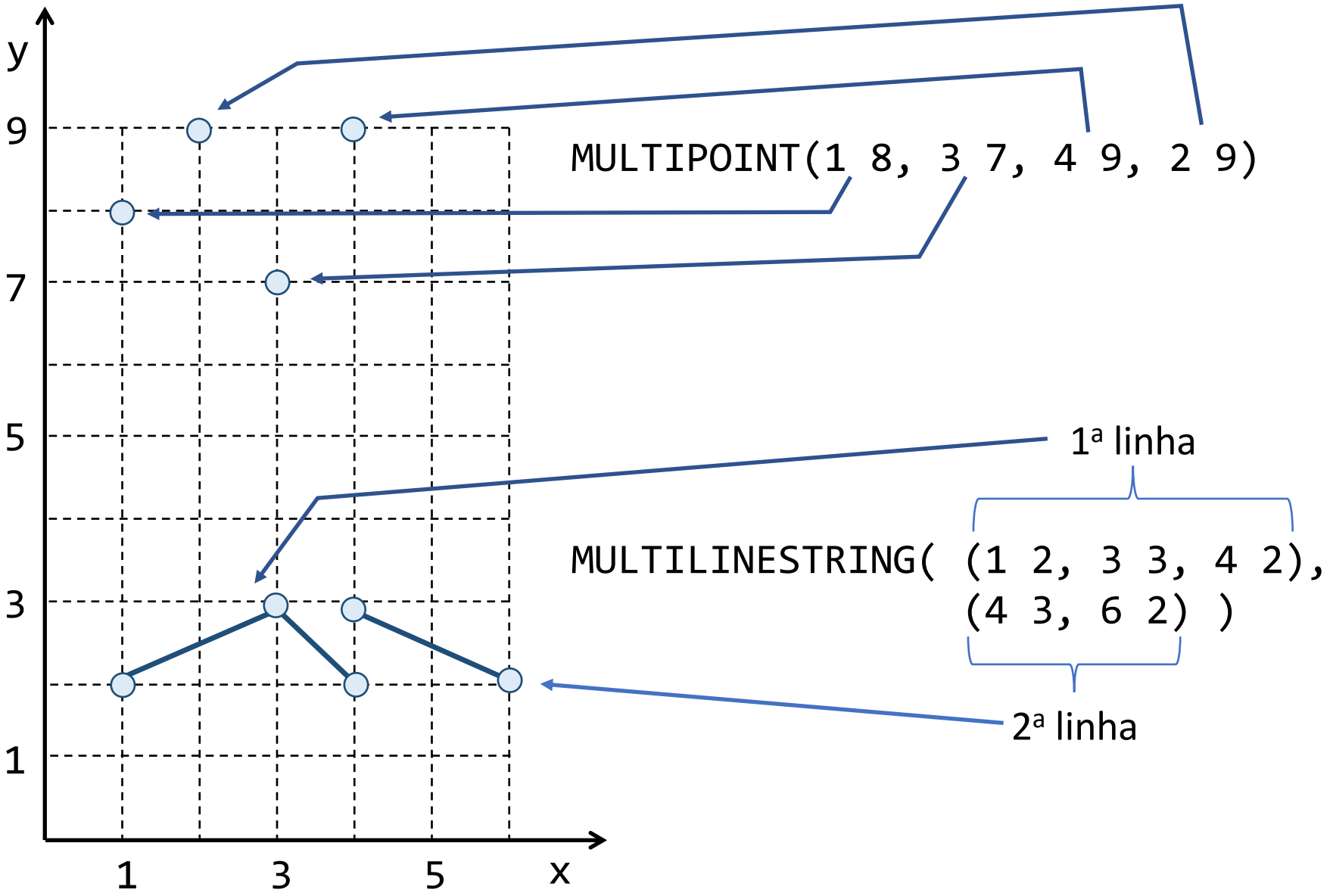
(d) `Polygon`	(e) `Polygon` (com buracos/ilhas)	(f) `MultiPoint`
		

(g) `MultiLineString`	(h) `MultiPolygon`	(i) `GeometryCollection`
		

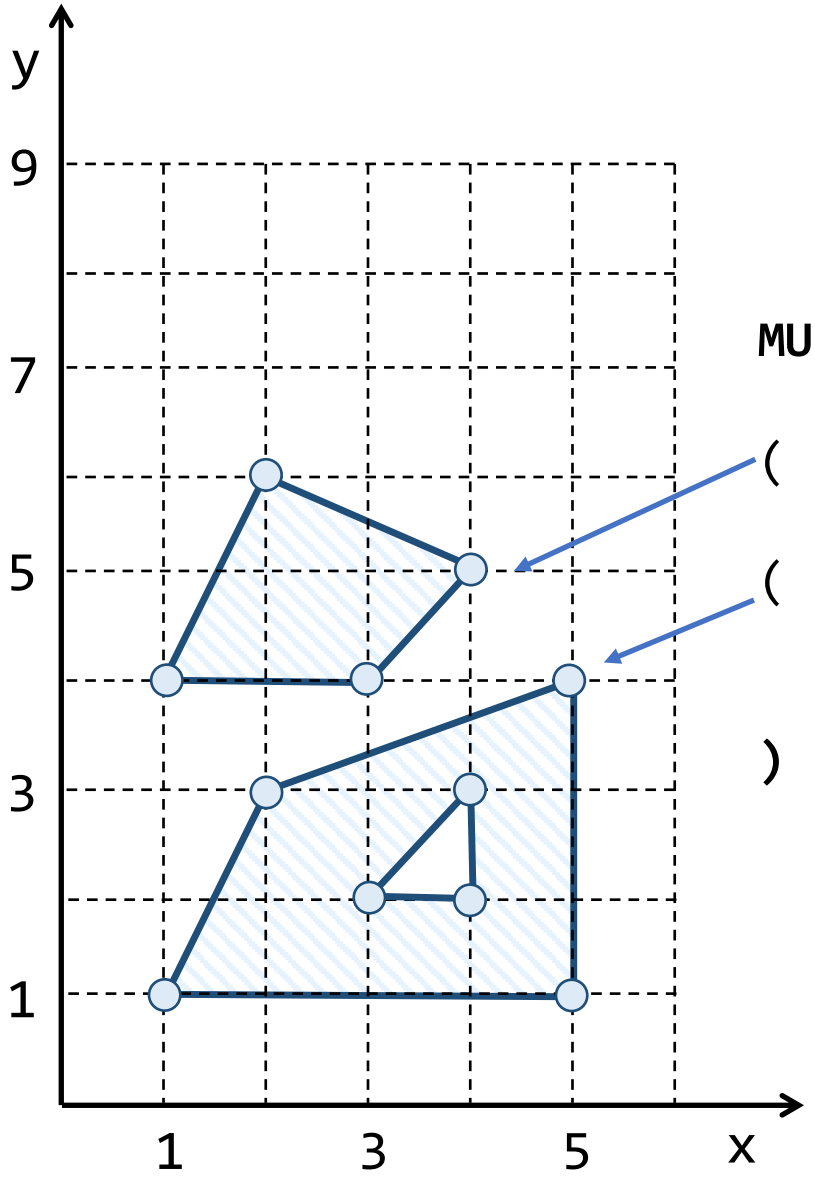
OGC-SFS: Well-Known Text (WKT)



OGC-SFS: Well-Known Text (WKT)



OGC-SFS: Well-Known Text (WKT)



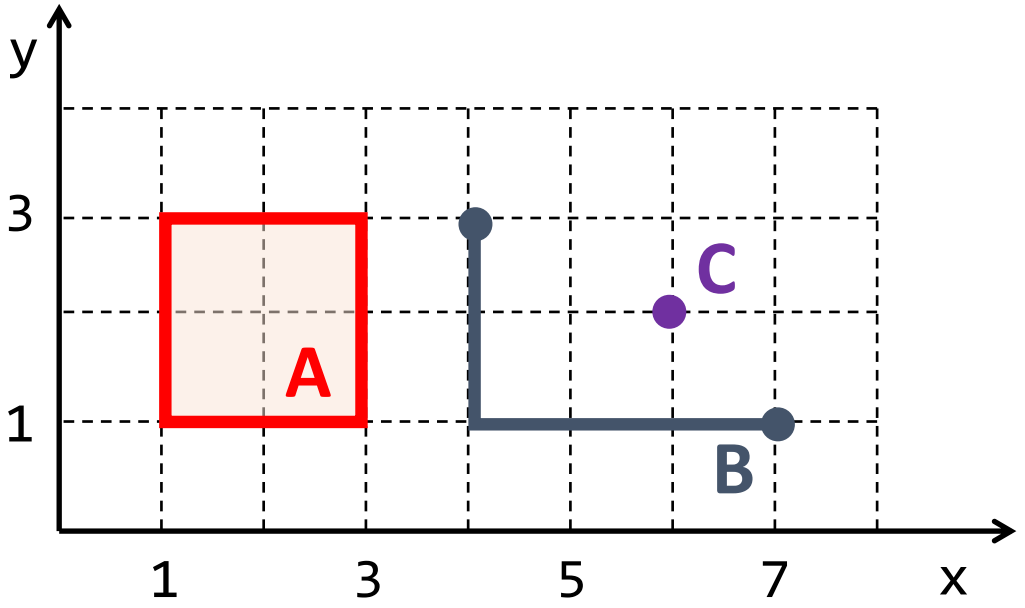

```
MULTIPOLYGON(

( (1 4, 2 6, 4 5, 3 4, 1 4) ),

( (1 1, 2 3, 5 4, 5 1, 1 1),
  (3 2, 4 3, 4 2, 3 2) )

)
```

1º polígono

2º polígono (com anel externo e um anel interno

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

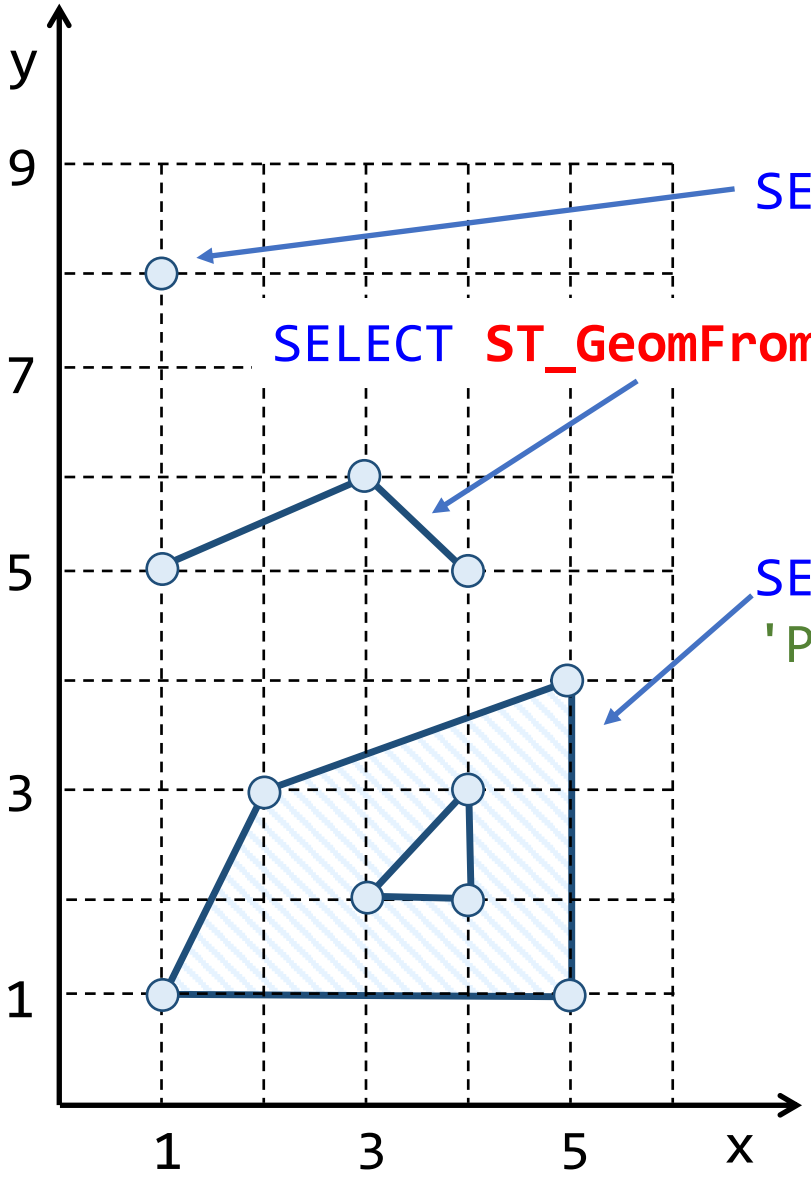
- Para criar um novo banco de dados:

```
CREATE DATABASE bdgeo TEMPLATE template1;
```

- Para carregar a extensão PostGIS no banco criado:

```
CREATE EXTENSION postgis;
```

PostGIS **Geometry**: WKT




```
SELECT ST_GeomFromText('POINT(1 8)');
```

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

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

PostGIS **Geometry**

- A extensão PostGIS segue a especificação:
  - ISO SQL/MM – Parte 3 – Spatial.

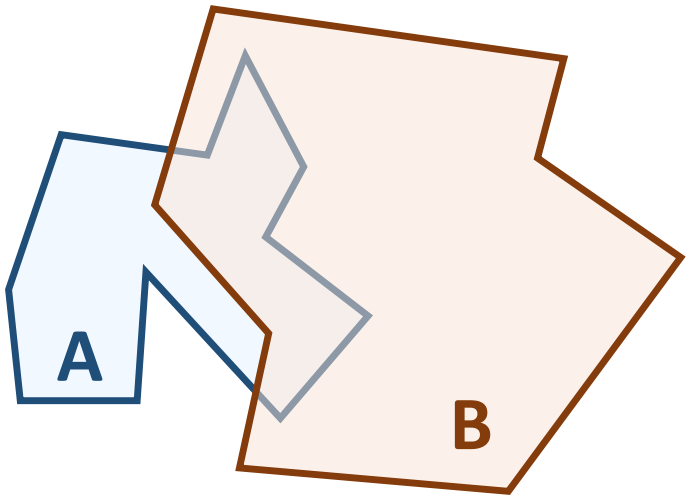
- Desta forma, o tipo `Geometry` do PostGIS suporta também os tipos circulares e compostos:
  - CIRCULARSTRING
  - COMPOUNDCURVE
  - CURVEPOLYGON

- No entanto, as operações sempre pressupõem que os segmentos tenham interpolação linear.

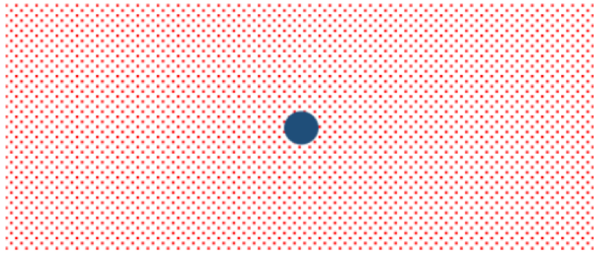
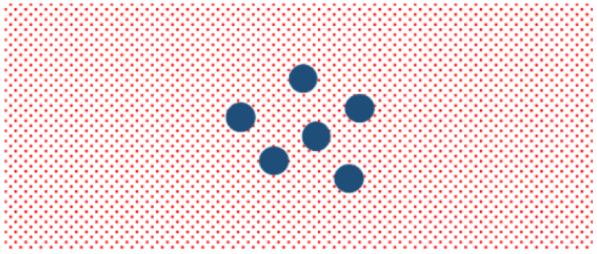
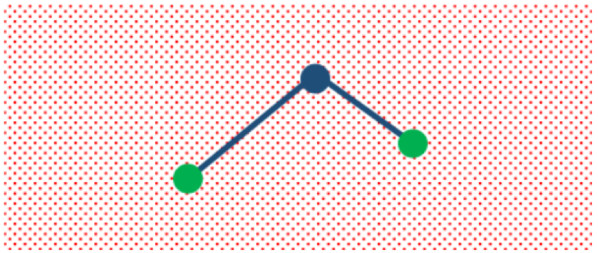
Relacionamentos Espaciais

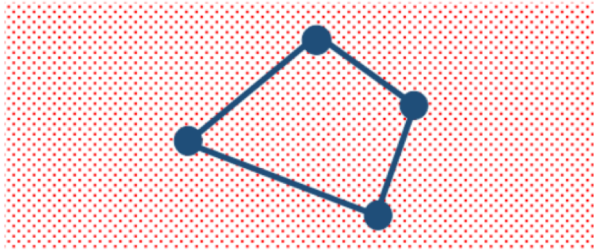
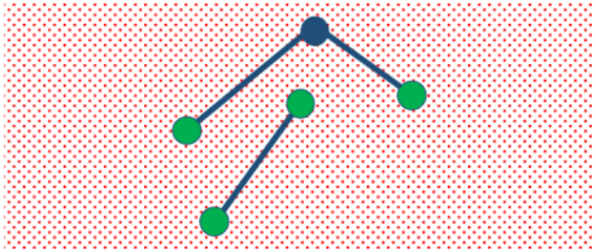
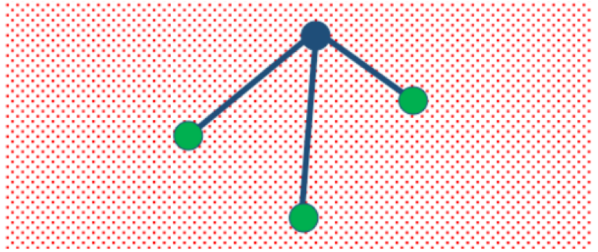
Matriz de 9-intersecções Estendida Dimensionalmente

	Interior(B)	*Fronteira(B)*	*Exterior(B)*
Interior(A)	$dim(I(A) \cap I(B))$	$dim(I(A) \cap F(B))$	$dim(I(A) \cap E(B))$
Fonteira(A)	$dim(F(A) \cap I(B))$	$dim(F(A) \cap F(B))$	$dim(F(A) \cap E(B))$
Exterior(A)	$dim(E(A) \cap I(B))$	$dim(E(A) \cap F(B))$	$dim(E(A) \cap E(B))$



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
		

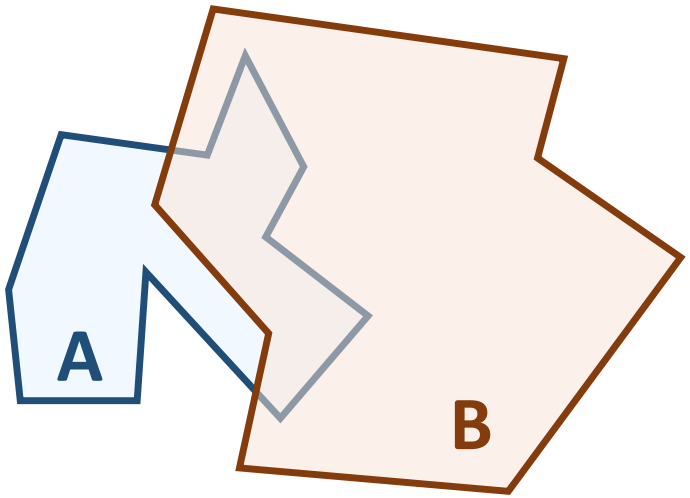
(g) I, F e E Polígono	(h) I, F e E Coleção Polígonos	(i) I, F e E Coleção Geom.
		

Objetos Resultantes da Intersecção

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

Relacionamento(A, B)

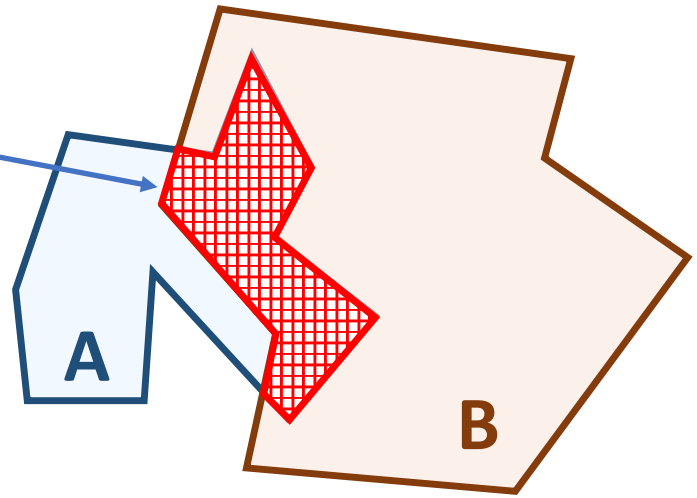
	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2



Relacionamento(A, B)

	Interior(B)	*Fronteira(B)*	*Exterior(B)*
Interior(A)	2	1	2
Fonteira(A)	1	0	1
Exterior(A)	2	1	2

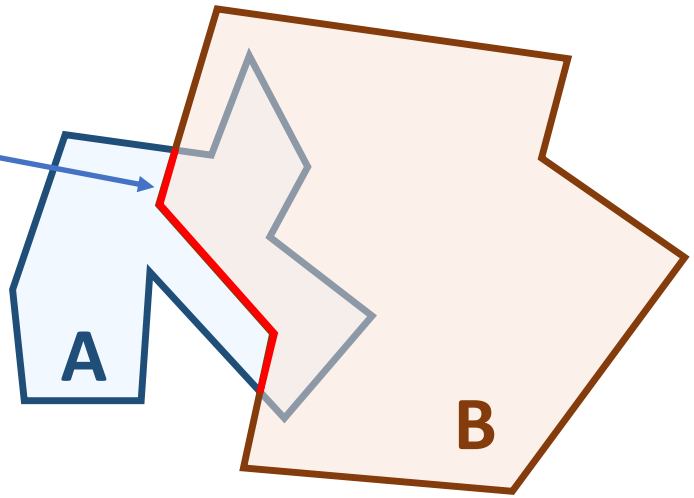
$\dim(I(A) \cap I(B)) = 2$



Relacionamento(A, B)

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2

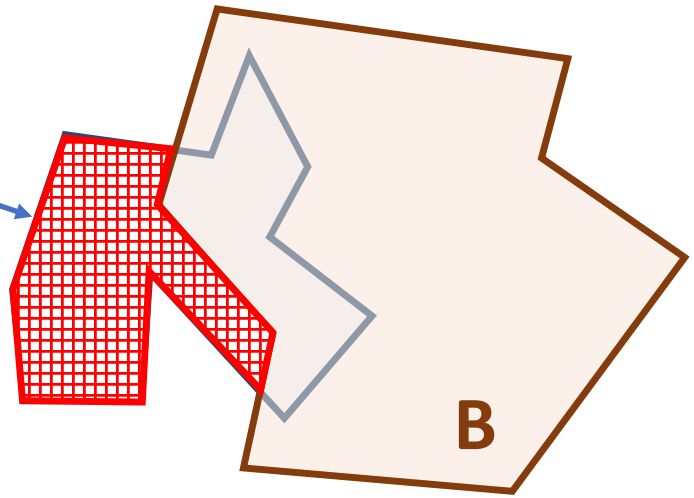
`dim(I(A)∩F(B))=1`



Relacionamento(A, B)

	Interior(B)	*Fronteira(B)*	*Exterior(B)*
Interior(A)	2	1	2
Fonteira(A)	1	0	1
Exterior(A)	2	1	2

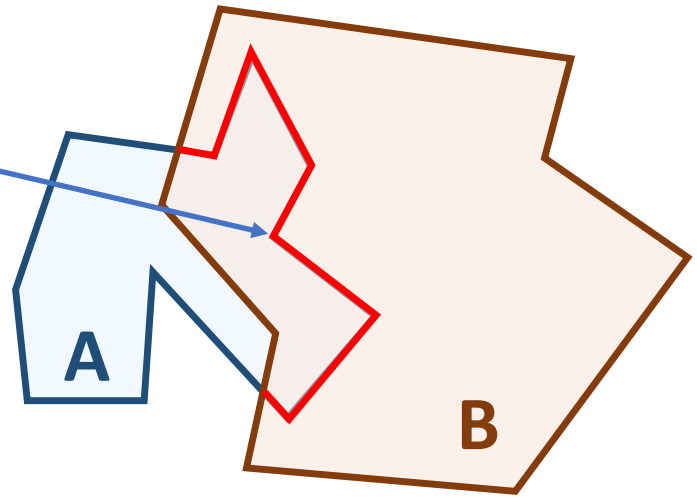
$\dim(I(A) \cap E(B)) = 2$



Relacionamento(A, B)

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2

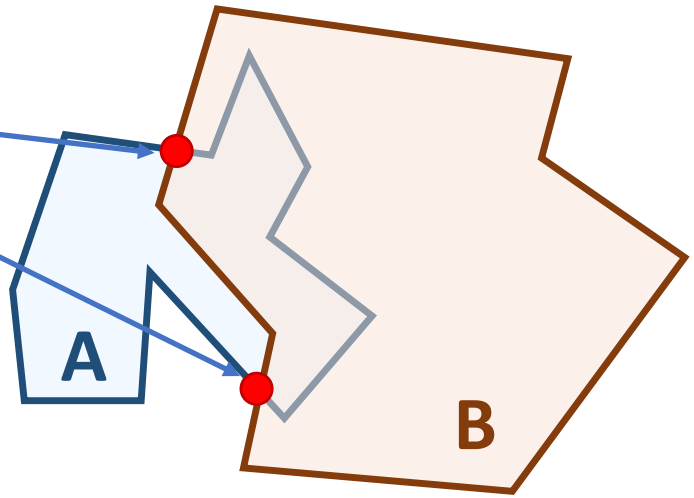
`dim(F(A)∩I(B))=1`



Relacionamento(A, B)

	Interior(B)	*Fronteira(B)*	*Exterior(B)*
Interior(A)	2	1	2
Fonteira(A)	1	0	1
Exterior(A)	2	1	2

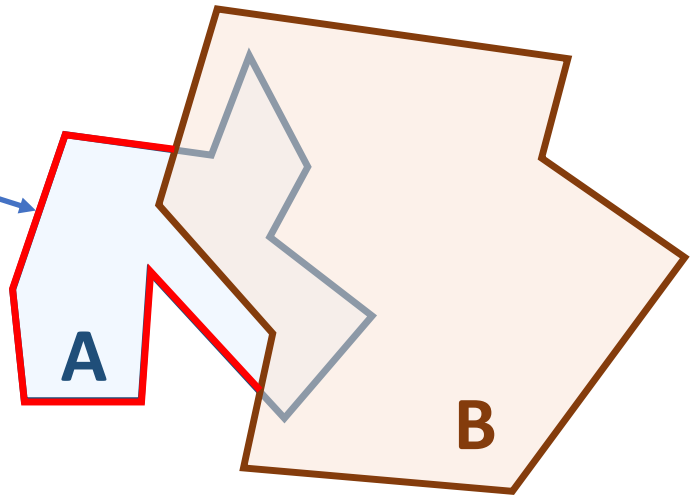
$\dim(F(A) \cap F(B)) = 0$



Relacionamento(A, B)

	Interior(B)	*Fronteira(B)*	*Exterior(B)*
Interior(A)	2	1	2
Fonteira(A)	1	0	1
Exterior(A)	2	1	2

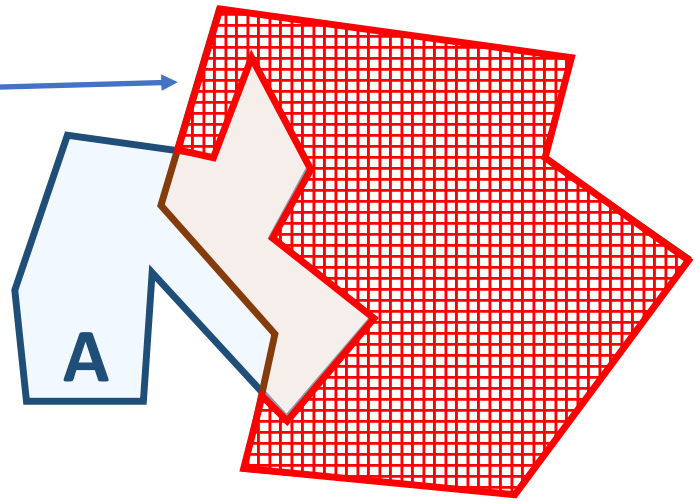
$\dim(F(A) \cap E(B)) = 1$



Relacionamento(A, B)

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2

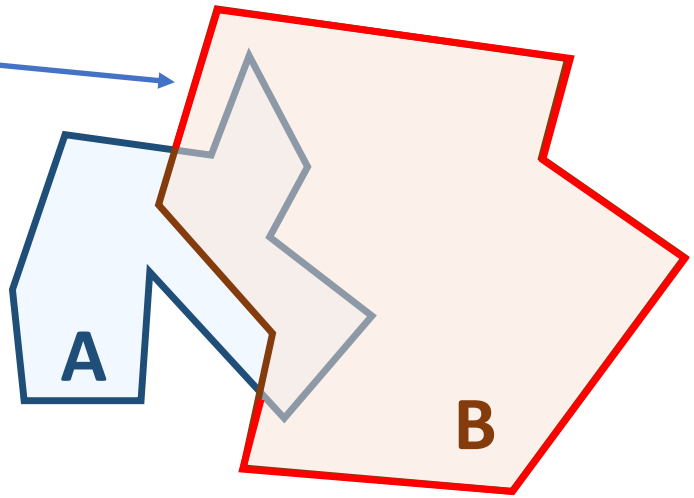
$\dim(E(A) \cap I(B)) = 2$



Relacionamento(A, B)

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2

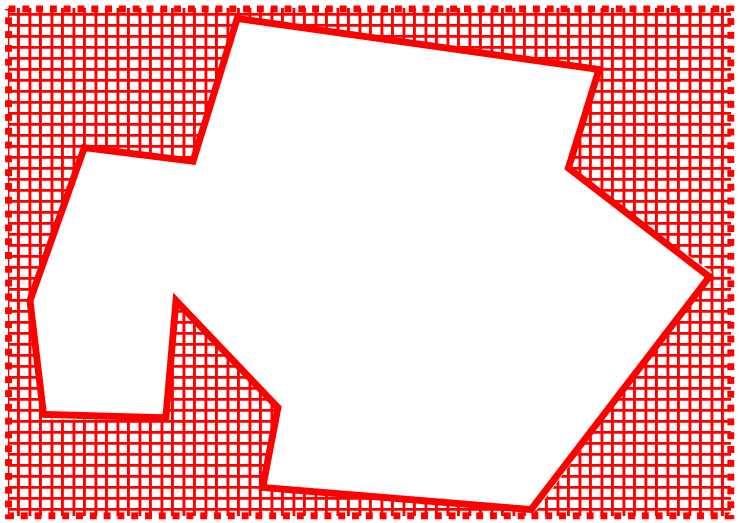
$\dim(E(A) \cap F(B)) = 1$



Relacionamento(A, B)

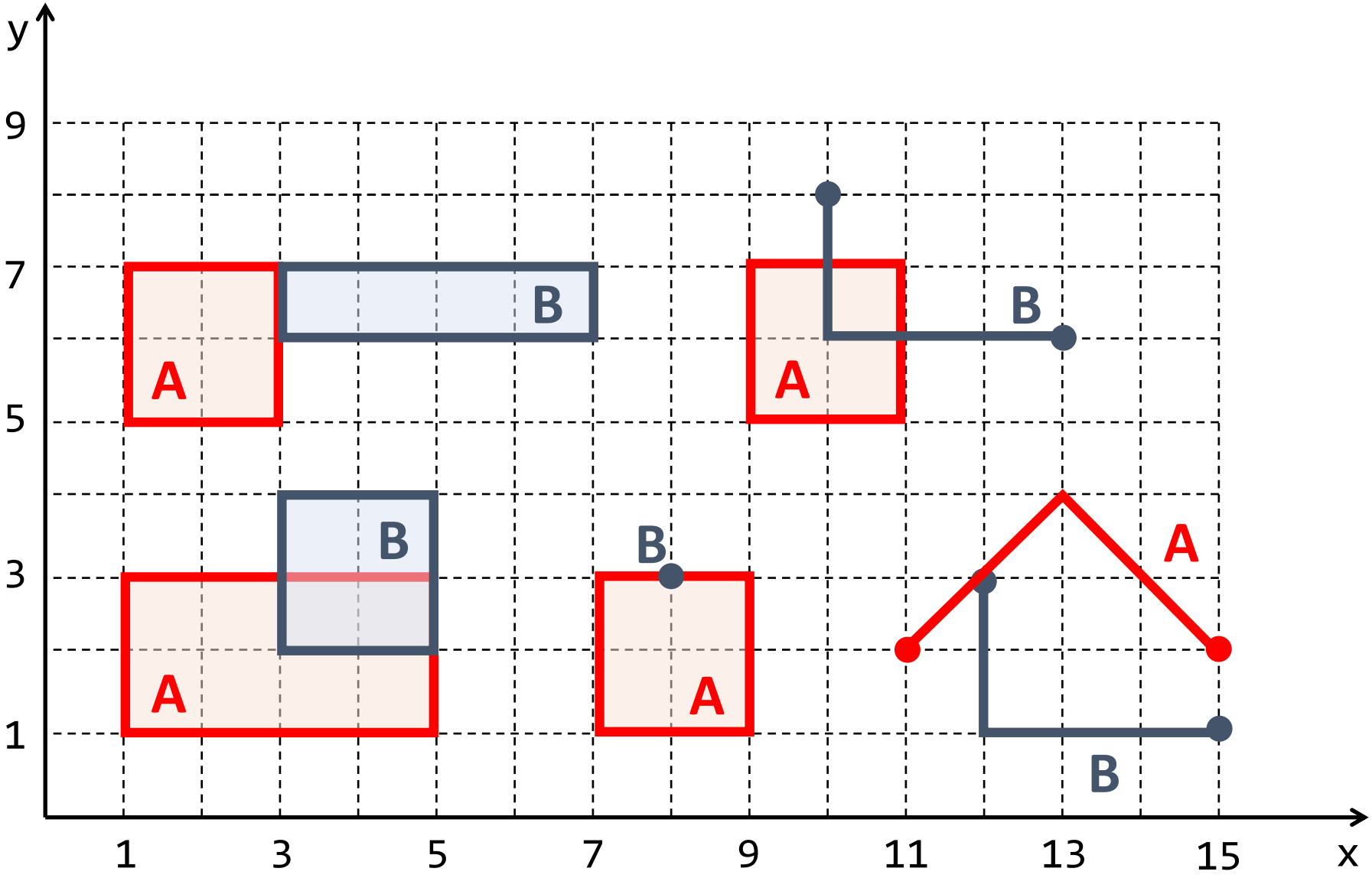
	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	2	1	2
Fonteira(*A*)	1	0	1
Exterior(*A*)	2	1	2

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



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**' ) ?`

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

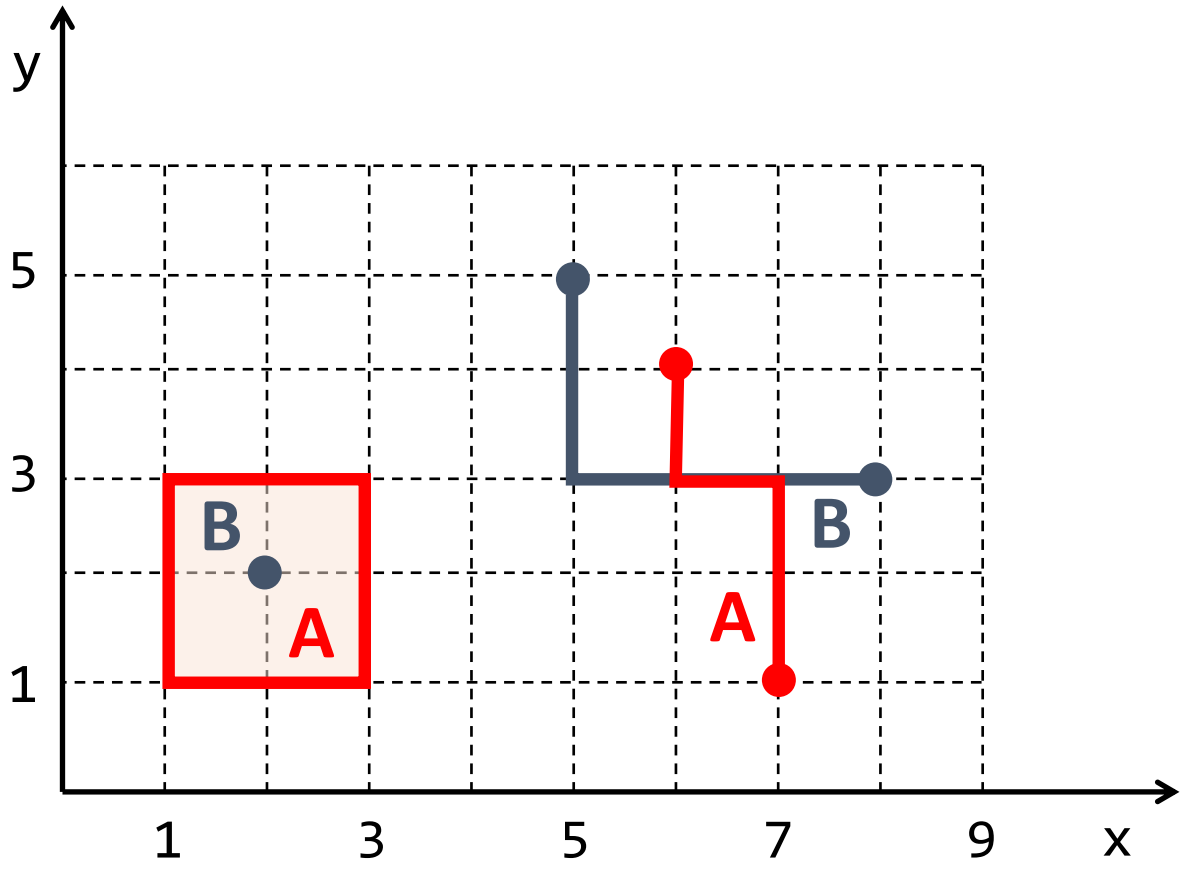
$F \rightarrow \dim(x) = \emptyset, ou\ seja, x = \emptyset \rightarrow \dim(x) = -1$

$* \rightarrow \dim(x) \in \{-1, 0, 1, 2\}$

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

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

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



As geometrias A e B possuem o relacionamento espacial informado?

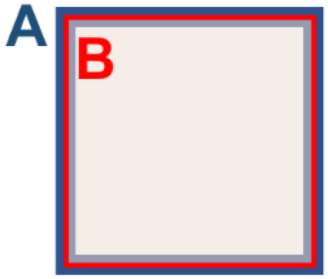
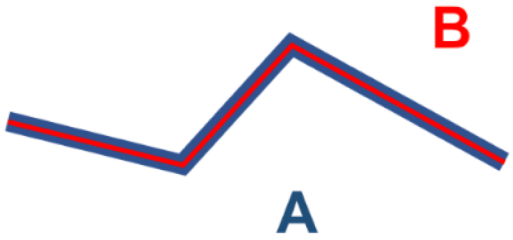
```
SELECT ST_Relate( 'POLYGON( ( 1 1, 1 3, 3 3, 3 1, 1 1 ) )',
                  'POINT( 2 2 )',
                  'T*T***F**');
```

```
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

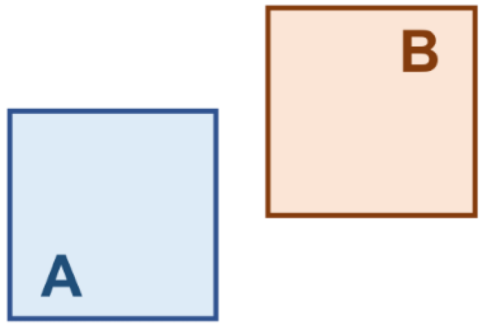
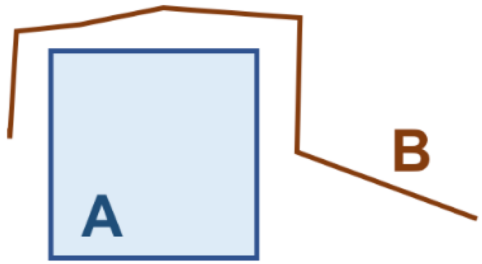
Equals(A, B) → bool

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*T*	*F*	*F*
Fonteira(*A*)	*F*	*T*	*F*
Exterior(*A*)	*F*	*F*	*T*

(a)	(b)	(c)
		

Disjoint(A, B) → bool

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

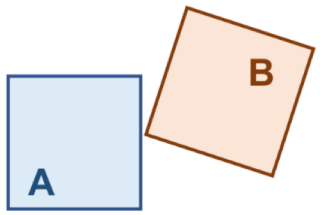
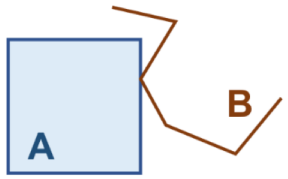
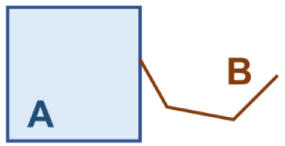
(a)	(b)	(c)
		

Touches(A, B) → bool

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*F*	*T*	*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*	*	*

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*F*	*	*
Fonteira(*A*)	*T*	*	*
Exterior(*A*)	*	*	*

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*F*	*	*
Fonteira(*A*)	*	*T*	*
Exterior(*A*)	*	*	*

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

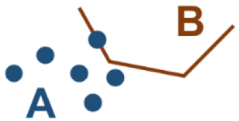
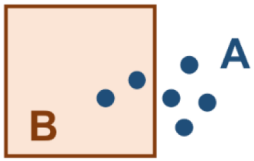
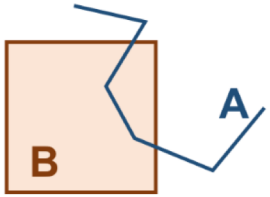
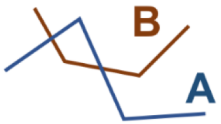
Crosses(A, B) → bool

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

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*T*	*	*T*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*	*	*

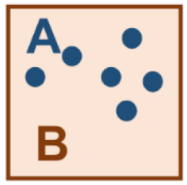
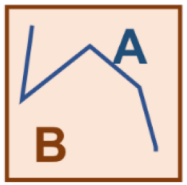
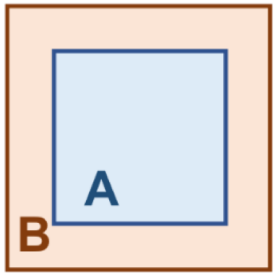
No caso L/L:

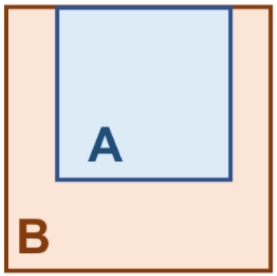
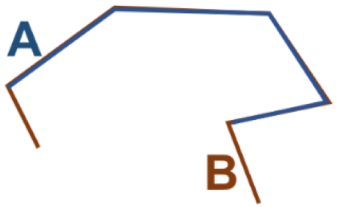
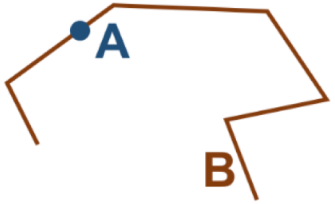
	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	0	*	*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*	*	*

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

Within(A, B) → bool

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*T*	*	*F*
Fonteira(*A*)	*	*	*F*
Exterior(*A*)	*	*	*

(a)	(b)	(c)
		

(d)	(e)	(f)
		

Contains(A, B) → bool

$$Contains(A, B) \iff Within(B, A)$$

	$Interior(B)$	$Fronteira(B)$	$Exterior(B)$
$Interior(A)$	T	$*$	$*$
$Fonteira(A)$	$*$	$*$	$*$
$Exterior(A)$	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**).

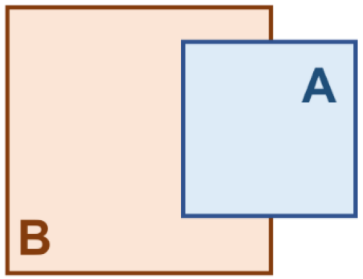
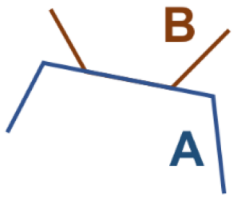
Overlaps(A, B) → bool

No caso P/P ou A/A:

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*T*	*	*T*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*T*	*	*

No caso L/L:

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	1	*	*T*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*T*	*	*

(a)	(b)	(c)
		

Intersects(A, B) → bool

$$Intersects(A, B) \iff \neg Disjoint(A, B)$$

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*T*	*	*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*	*	*

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*	*	*
Fonteira(*A*)	*	*T*	*
Exterior(*A*)	*	*	*

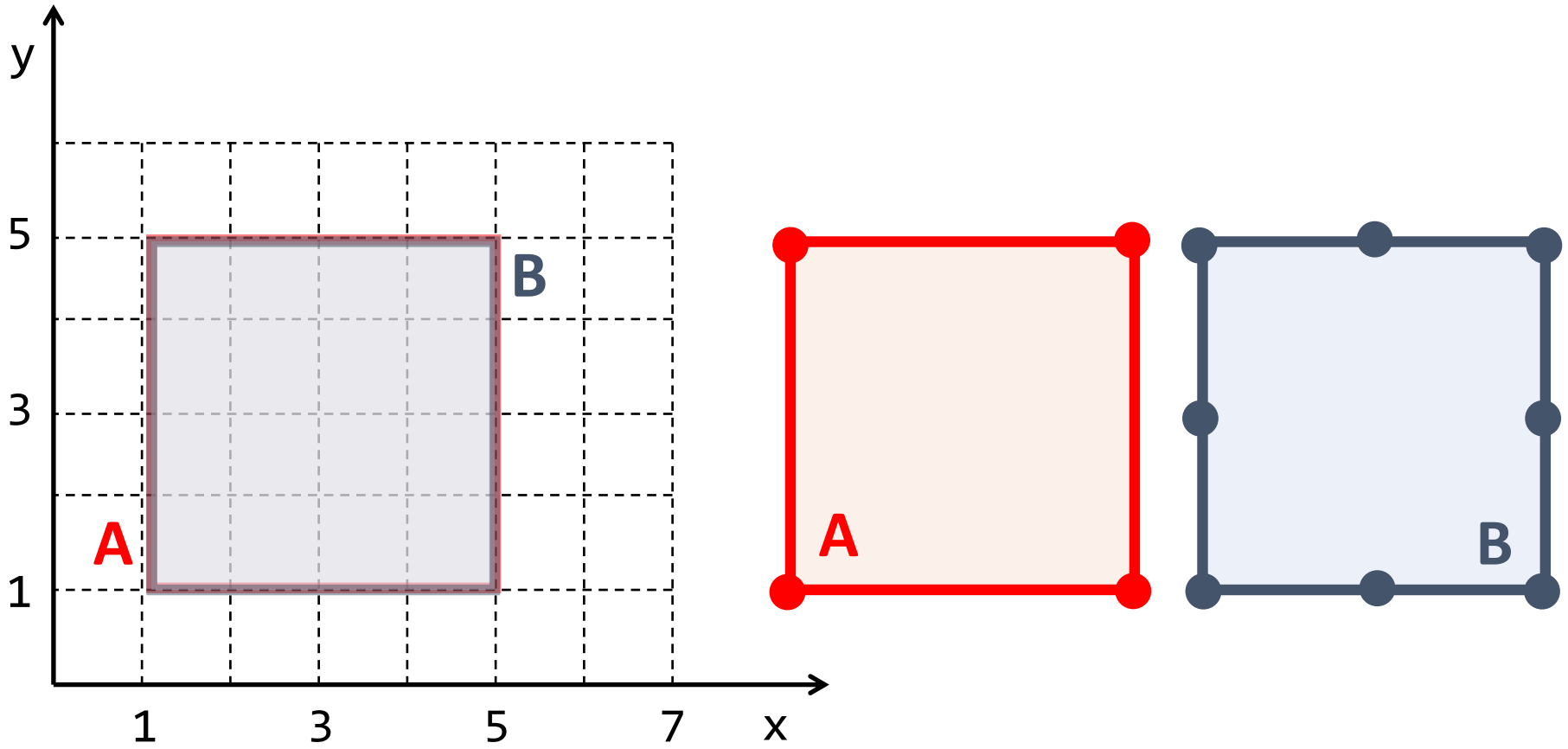
	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*	*T*	*
Fonteira(*A*)	*	*	*
Exterior(*A*)	*	*	*

	Interior(*B*)	*Fronteira*(*B*)	*Exterior*(*B*)
Interior(*A*)	*	*	*
Fonteira(*A*)	*T*	*	*
Exterior(*A*)	*	*	*

Relacionamentos Espaciais no PostGIS

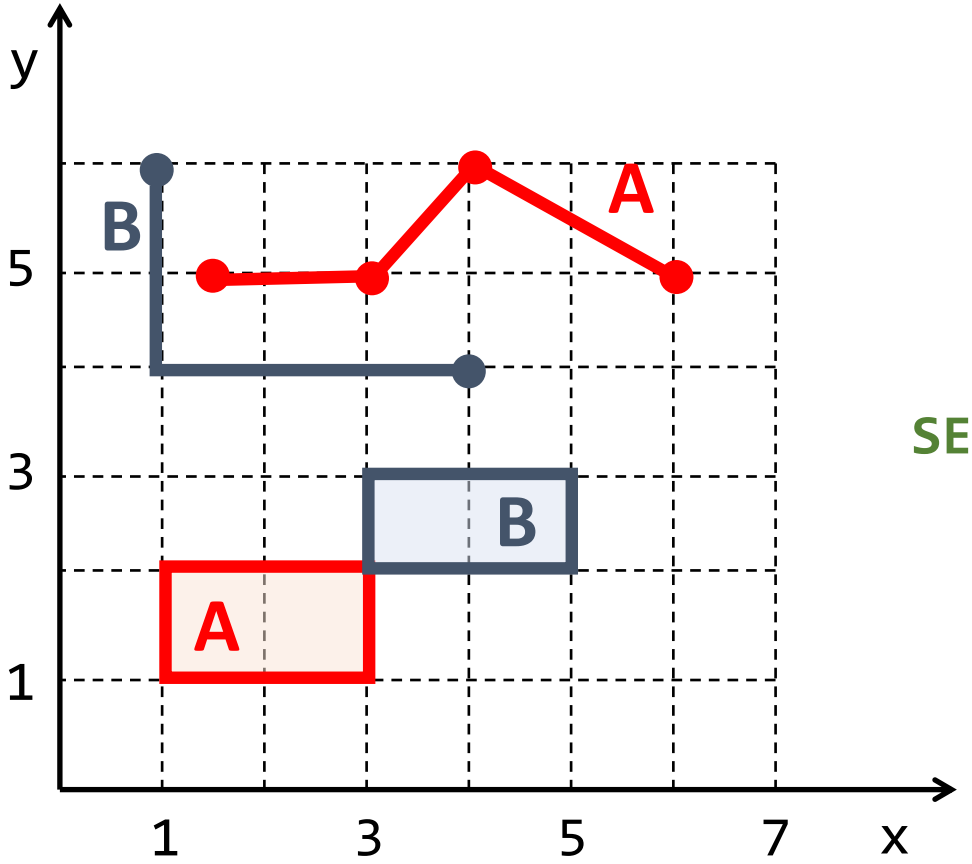
As geometrias A e B são iguais?

```
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 ) )' );
```



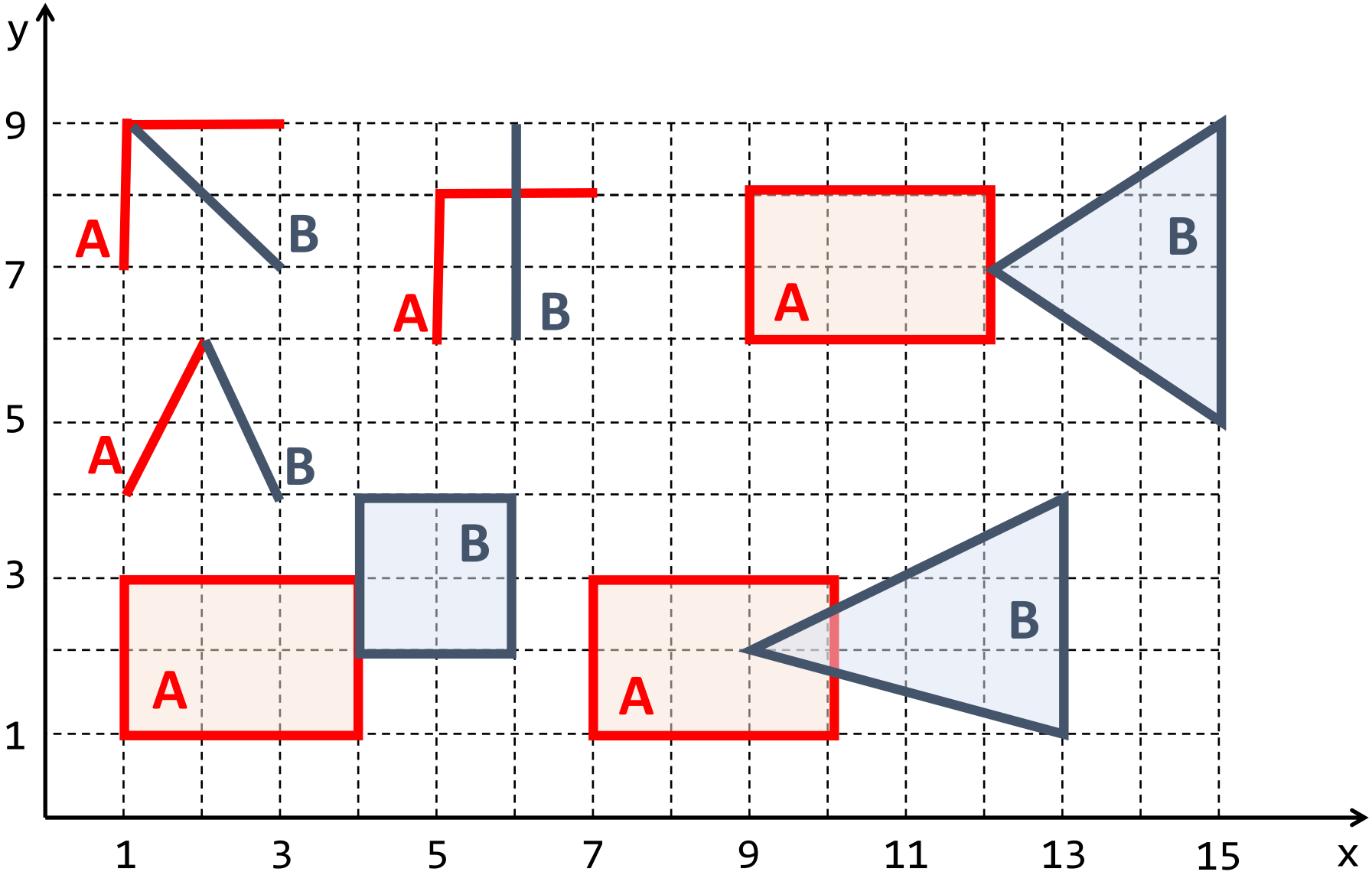
As geometrias A e B são disjuntas?

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

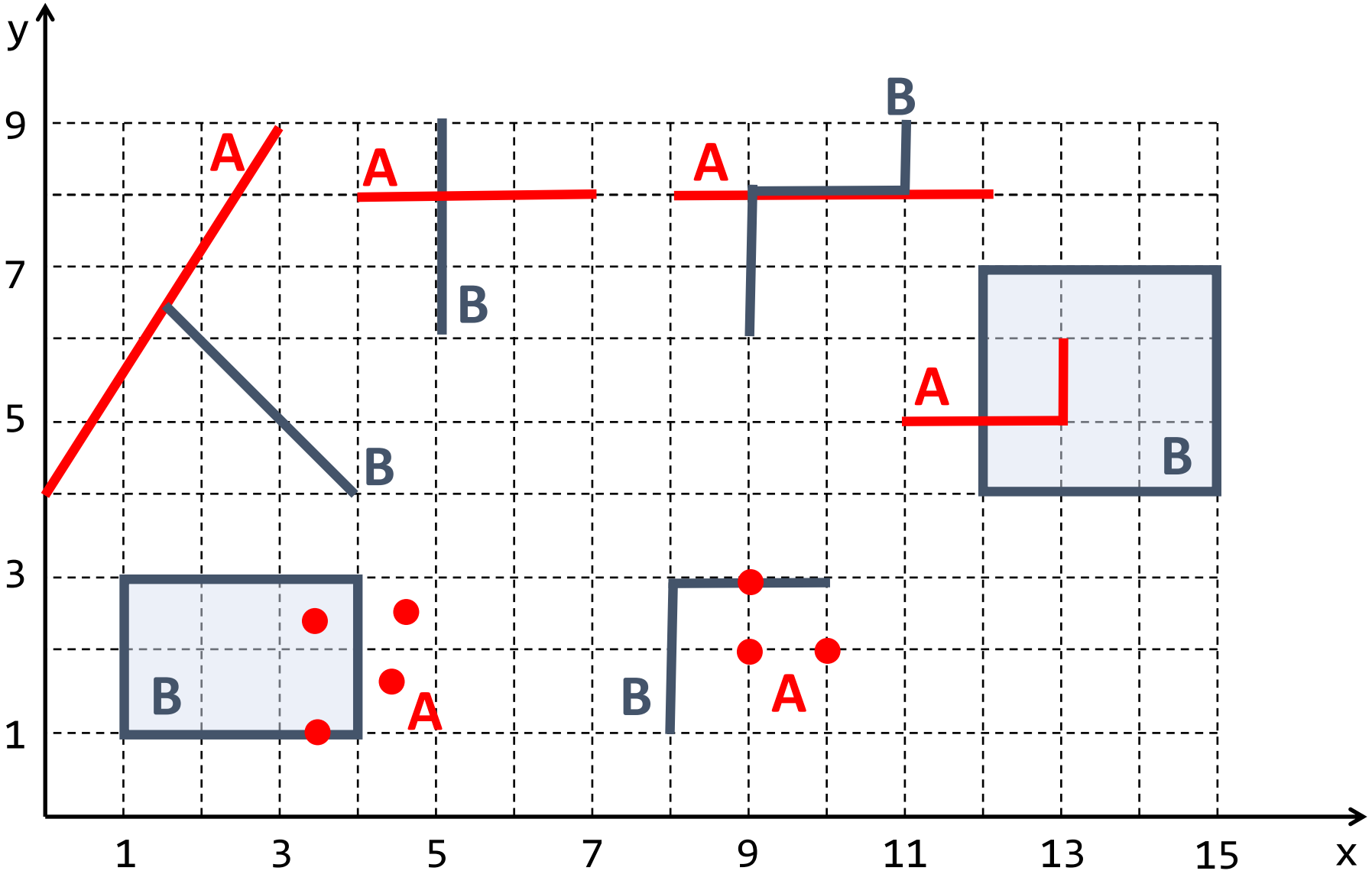



```
SELECT ST_Disjoint(
  'POLYGON( ( 1 1, 1 2, 3 2,
              3 1, 1 1 ) )',
  'POLYGON( ( 3 3, 5 3, 5 2,
              3 2, 3 3 ) )' );
```

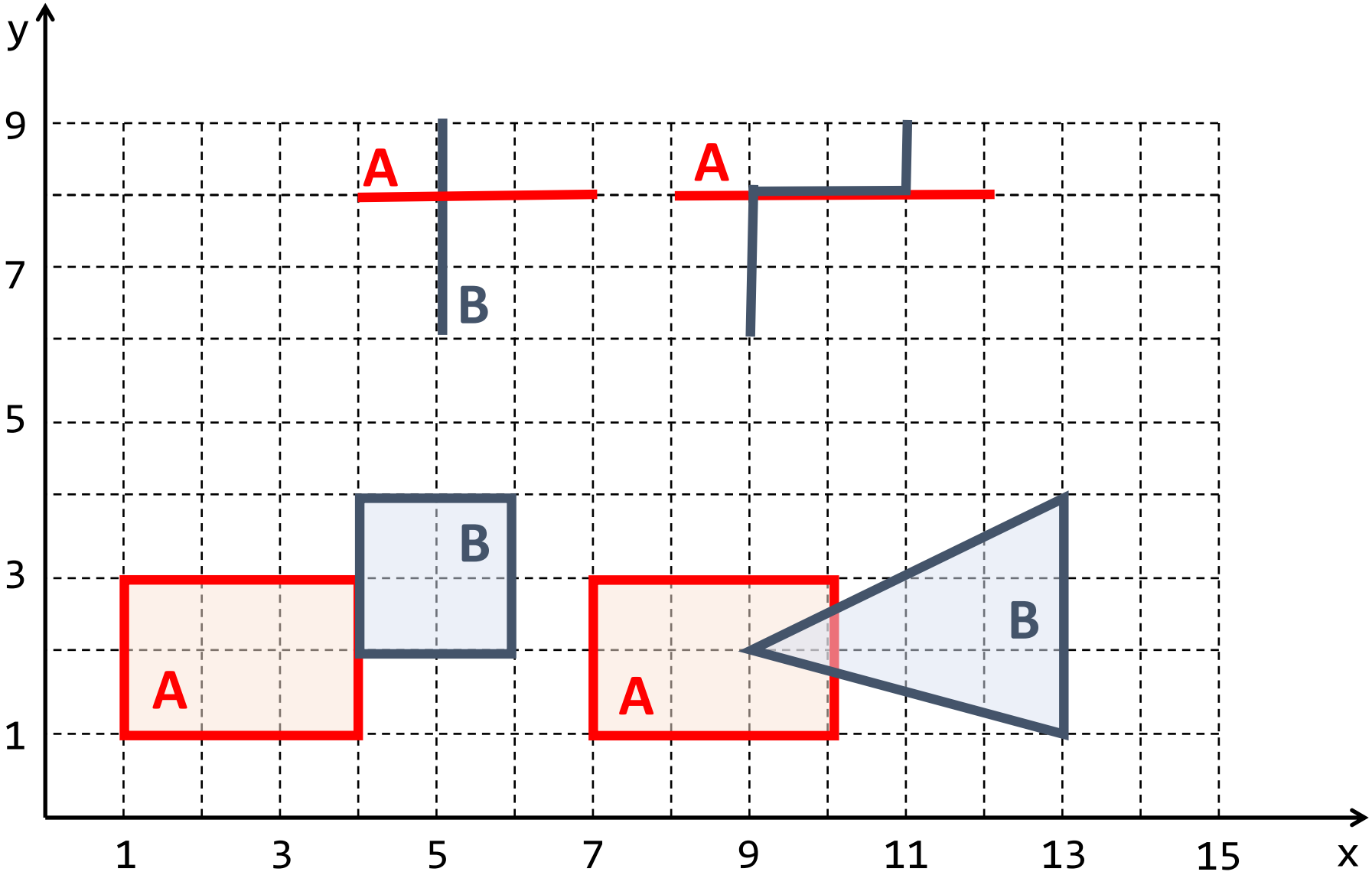
A geometria A toca B?



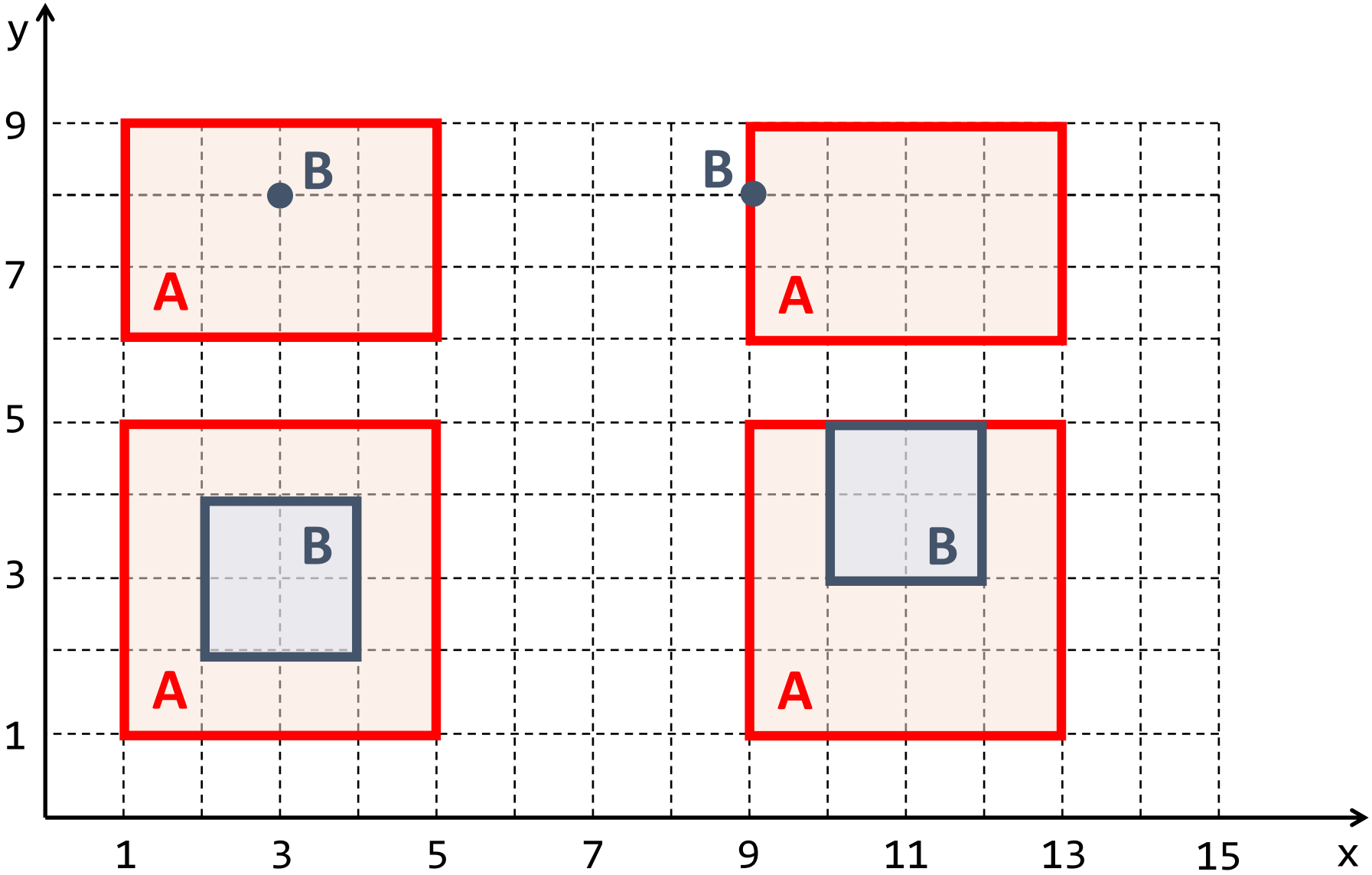
A geometria A cruza B?



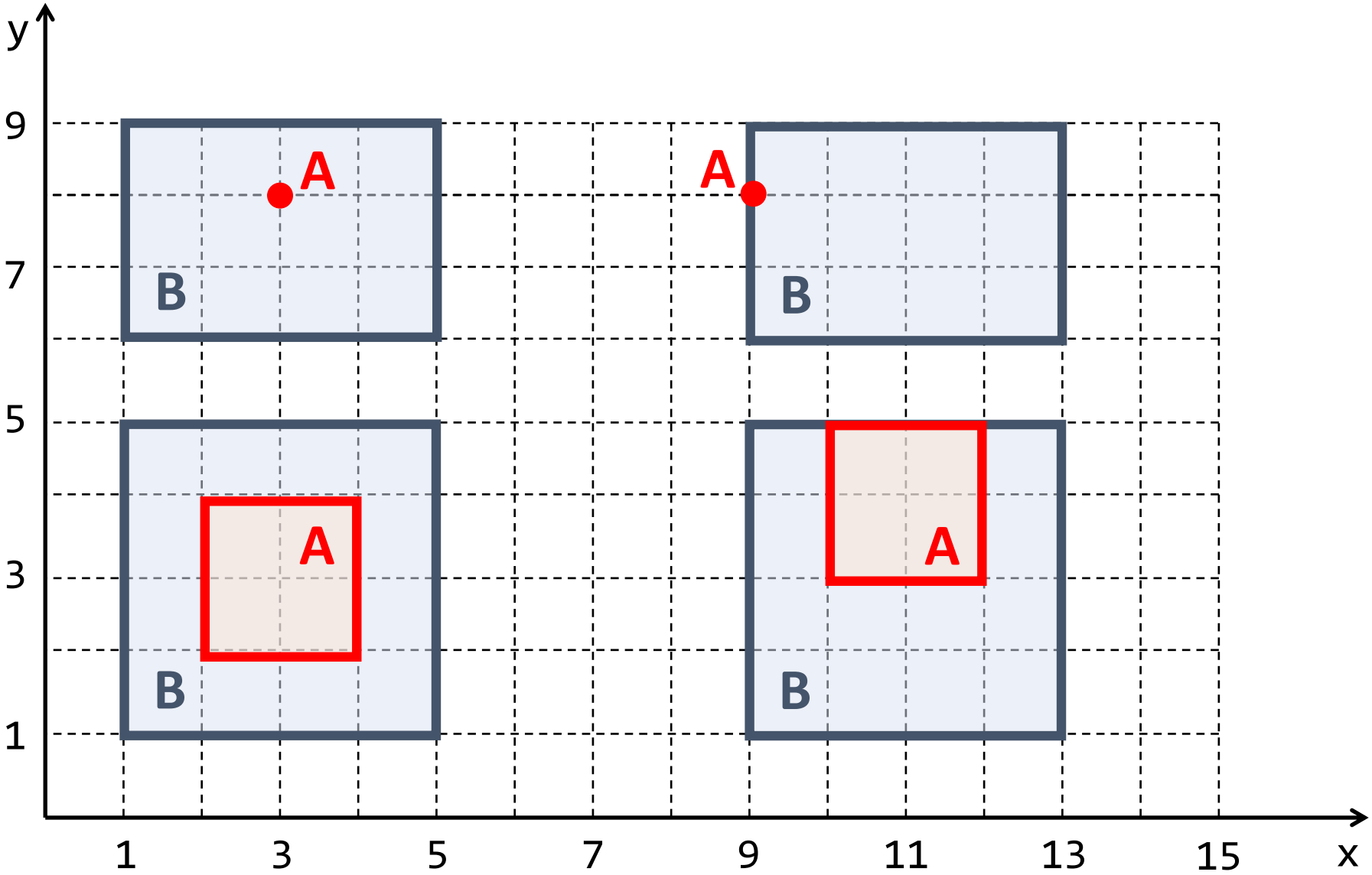
A geometria A sobrepõe B?



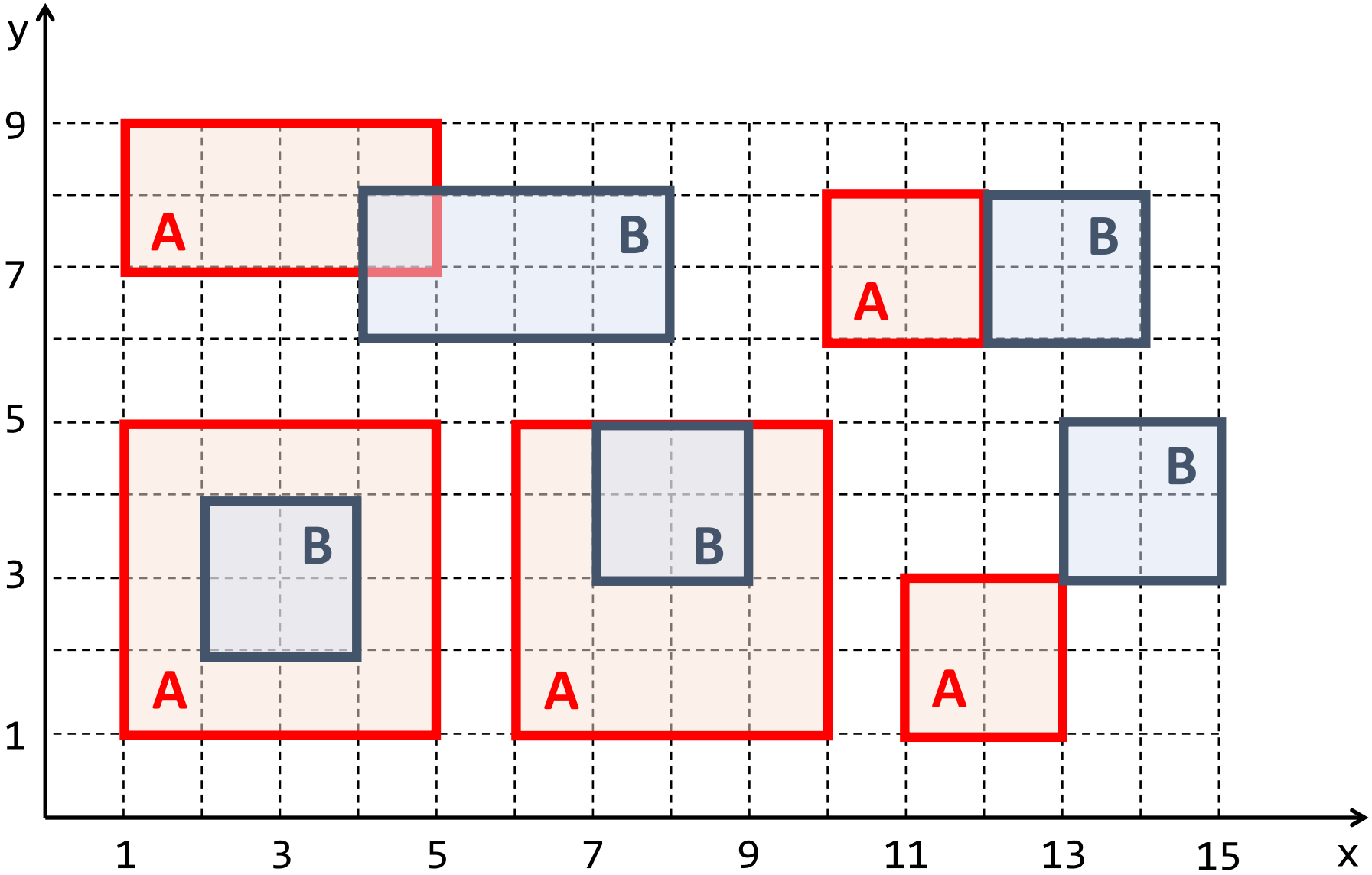
A geometria A contém B?



A geometria A está dentro de B?



A geometria A intersecta B?



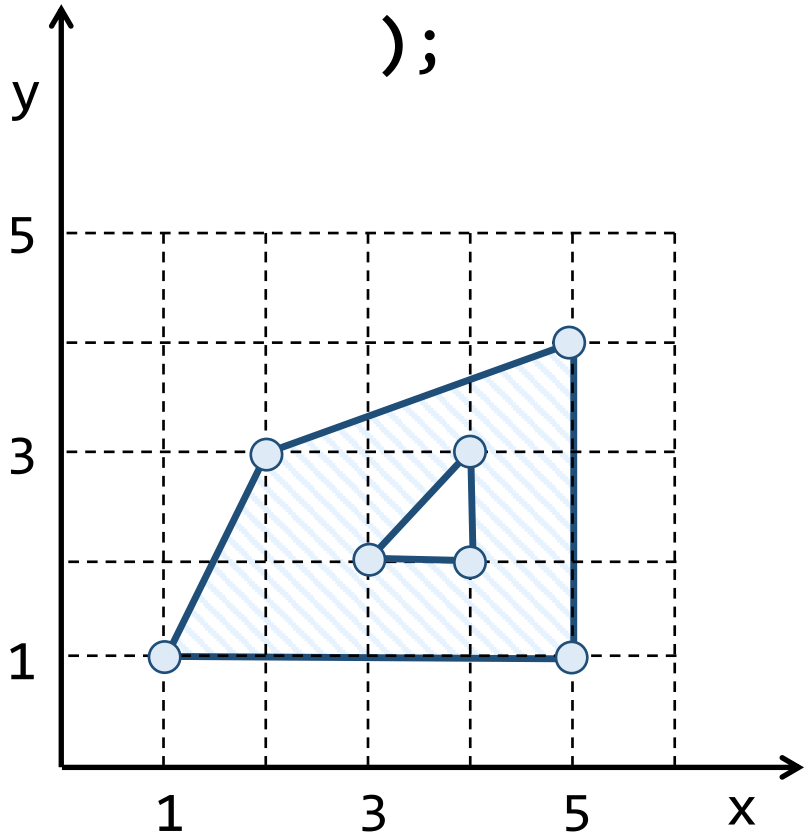
Operadores PostGIS

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

Operadores Métricos

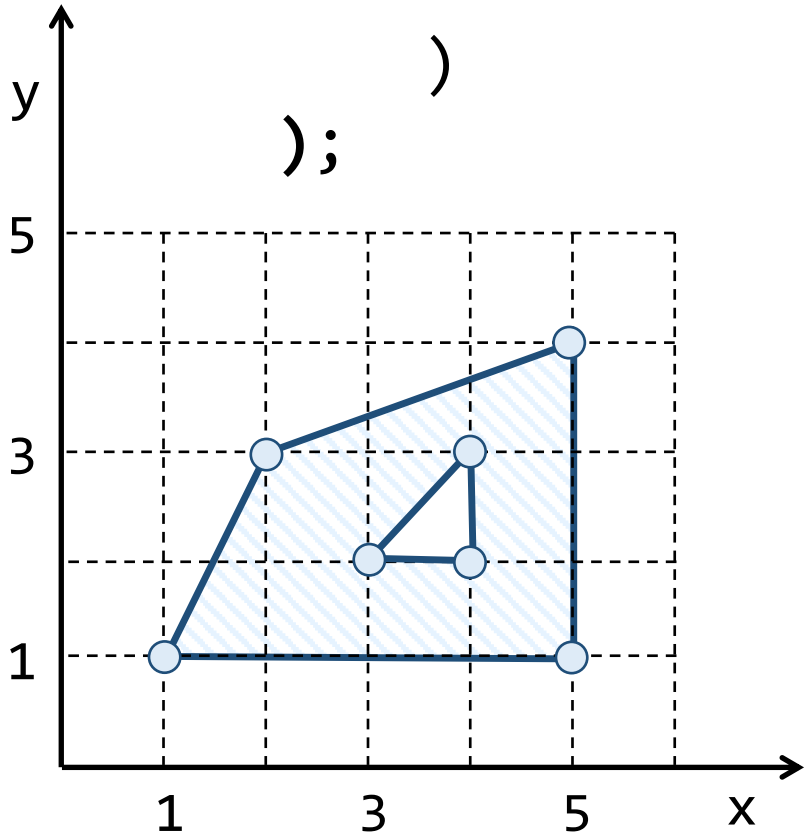
Qual a área do polígono?

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



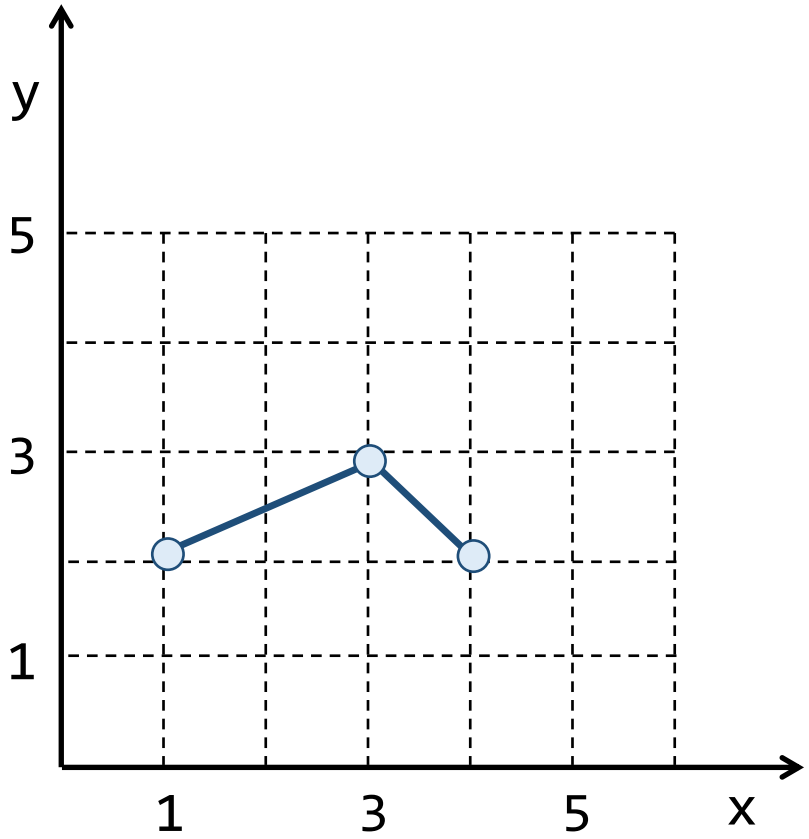
Qual o perímetro da geometria?

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



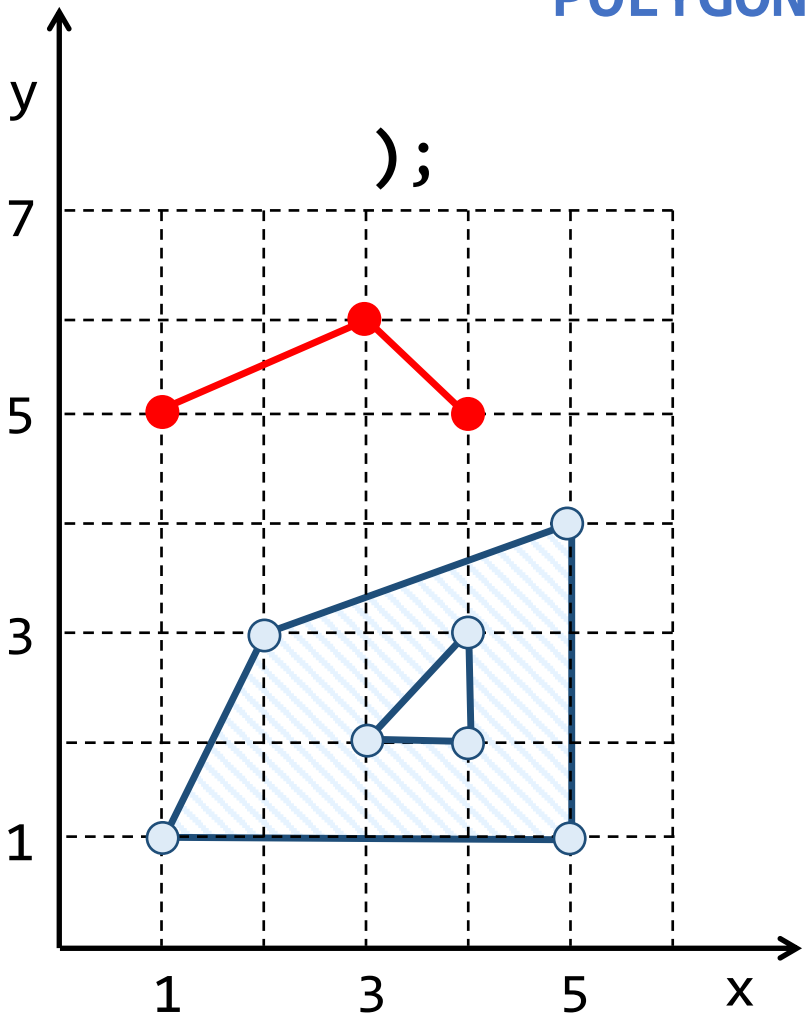
Qual o comprimento da geometria?

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



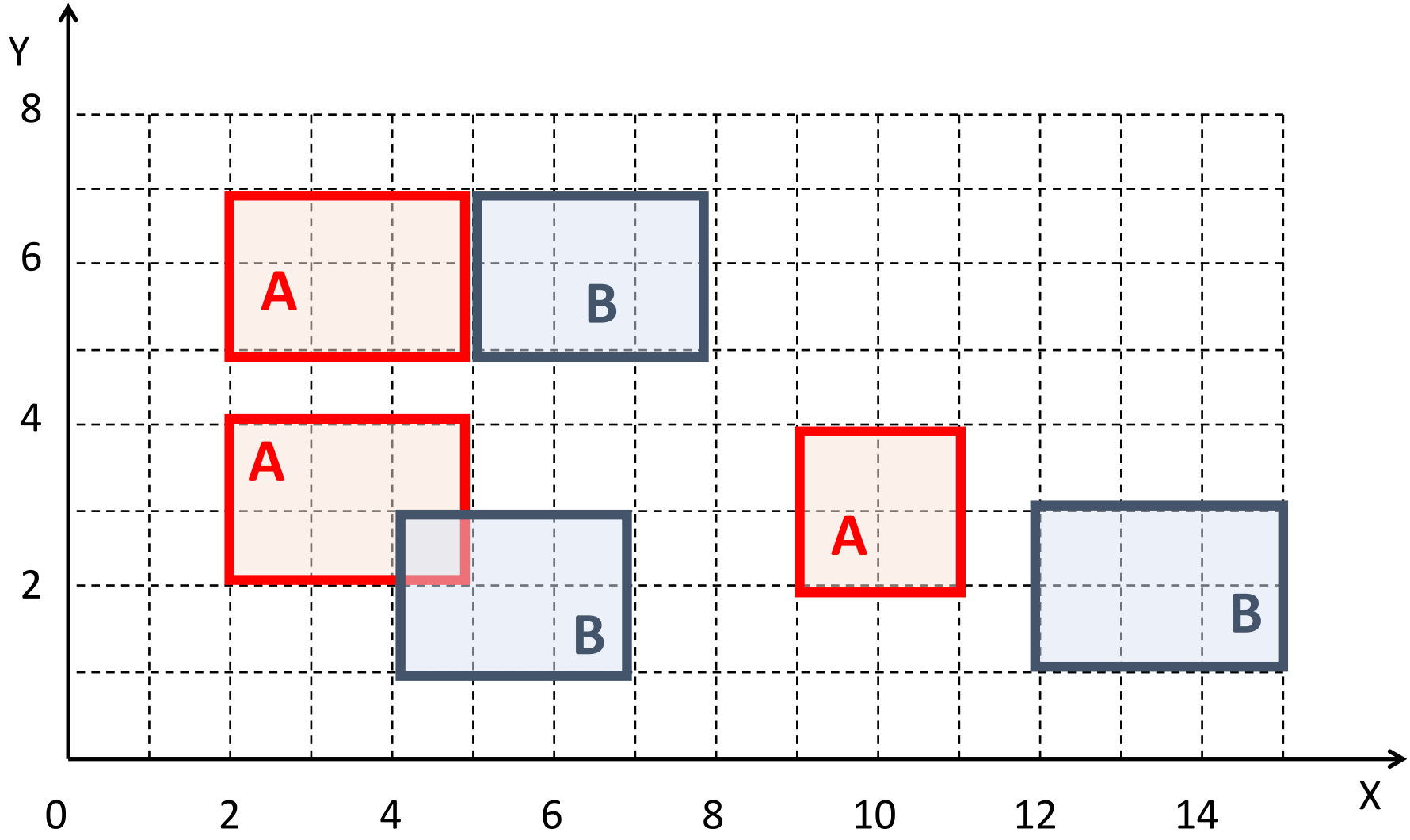
Qual a distância entre A e B?

```
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) )'
);
```

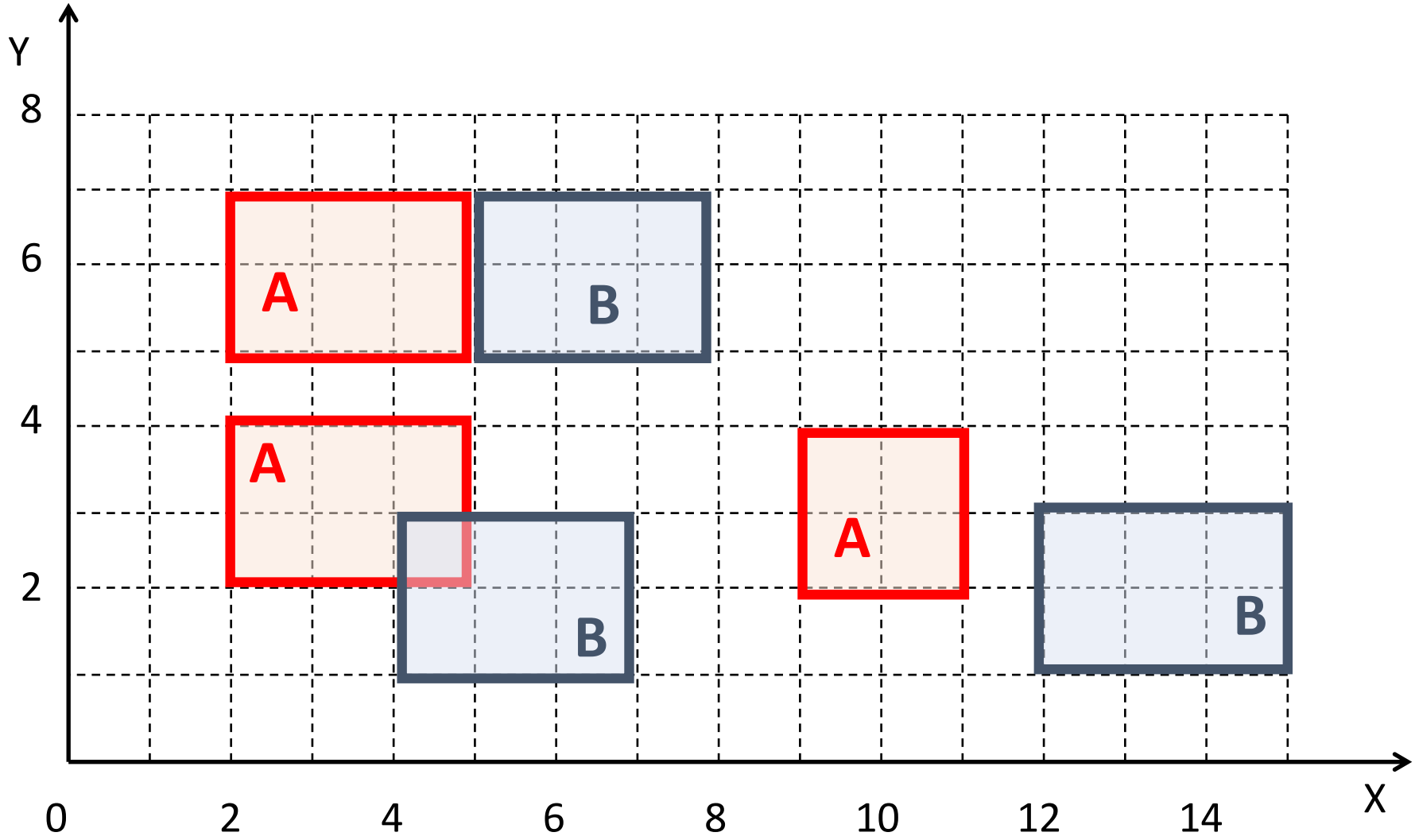


Operadores Conjunto

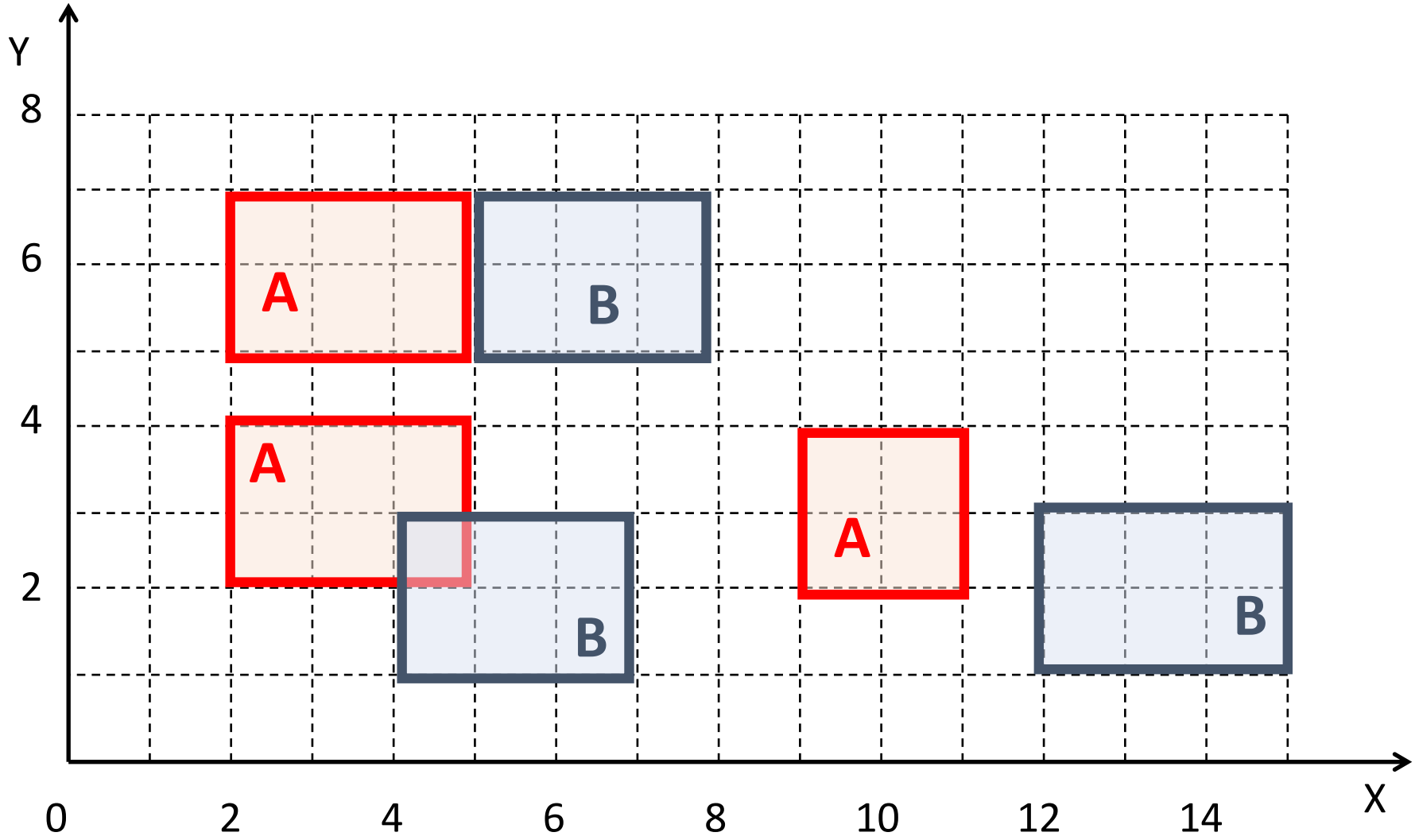
Intersecção entre as geometrias A e B



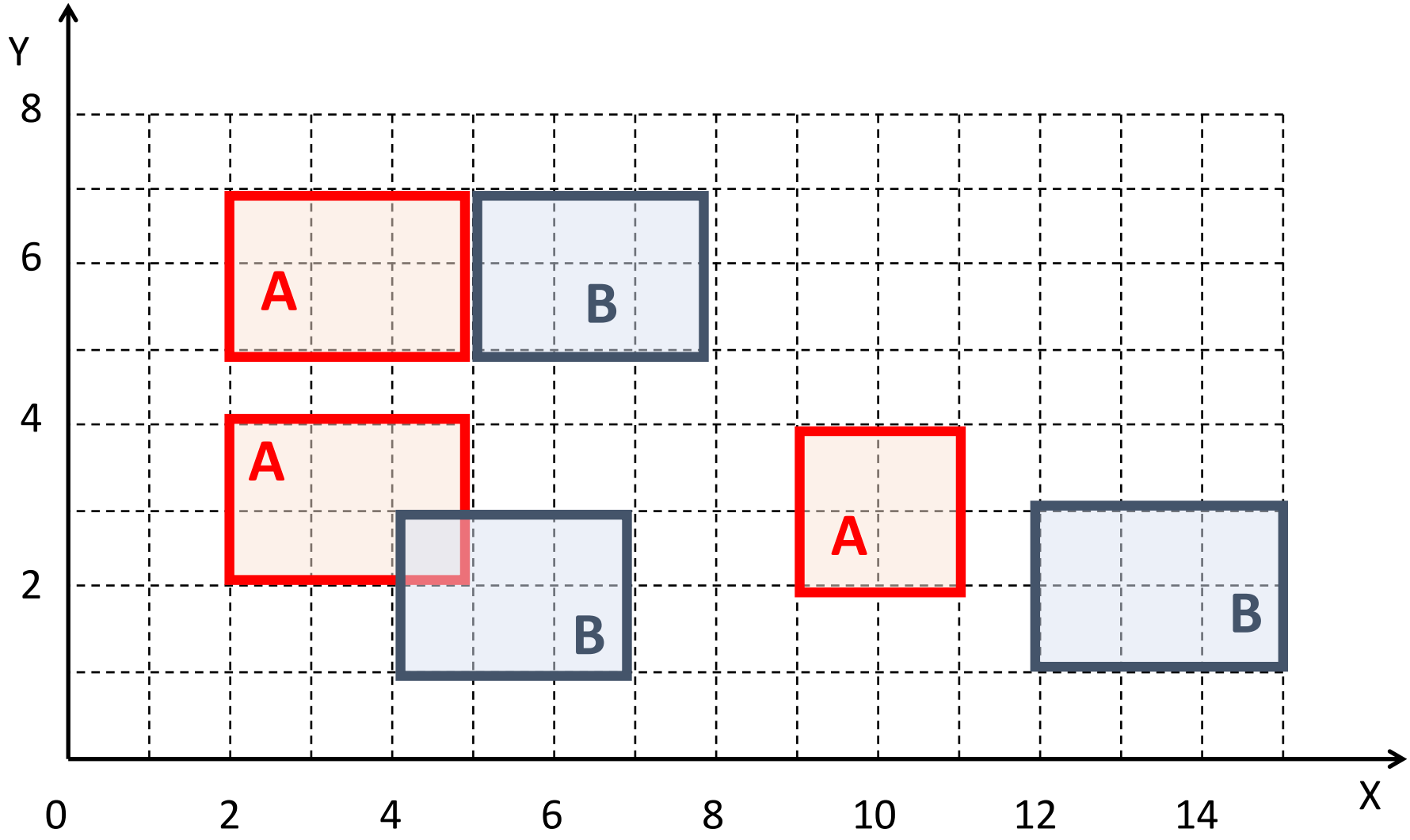
União entre as geometrias A e B



Diferença entre as geometrias A e B



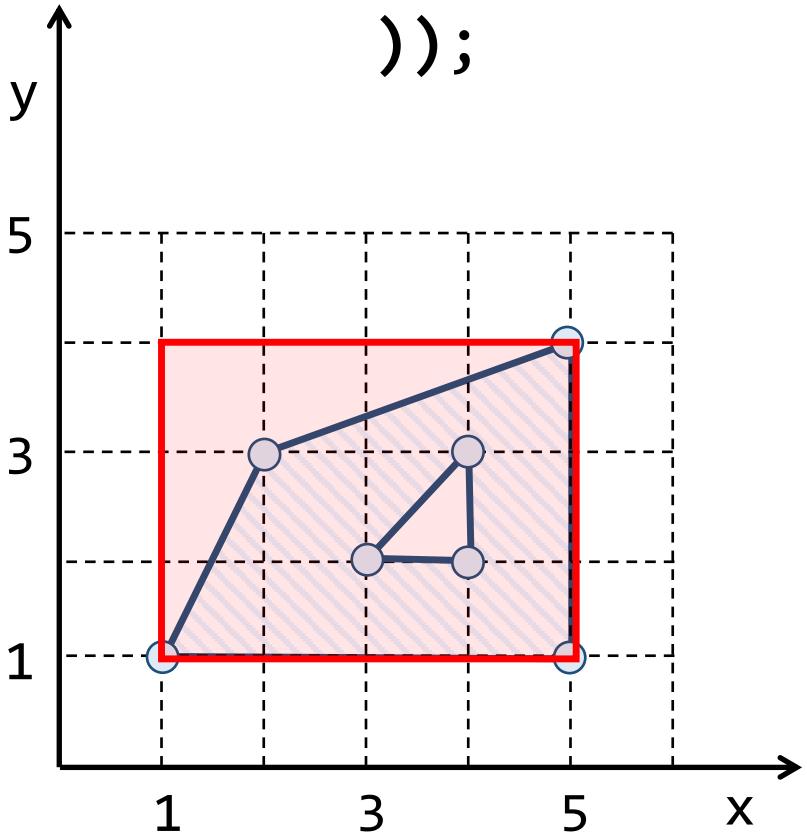
Diferença Simétrica entre as geometrias A e B



Operações Geração Geometrias

Retângulo Envolvente da Geometria

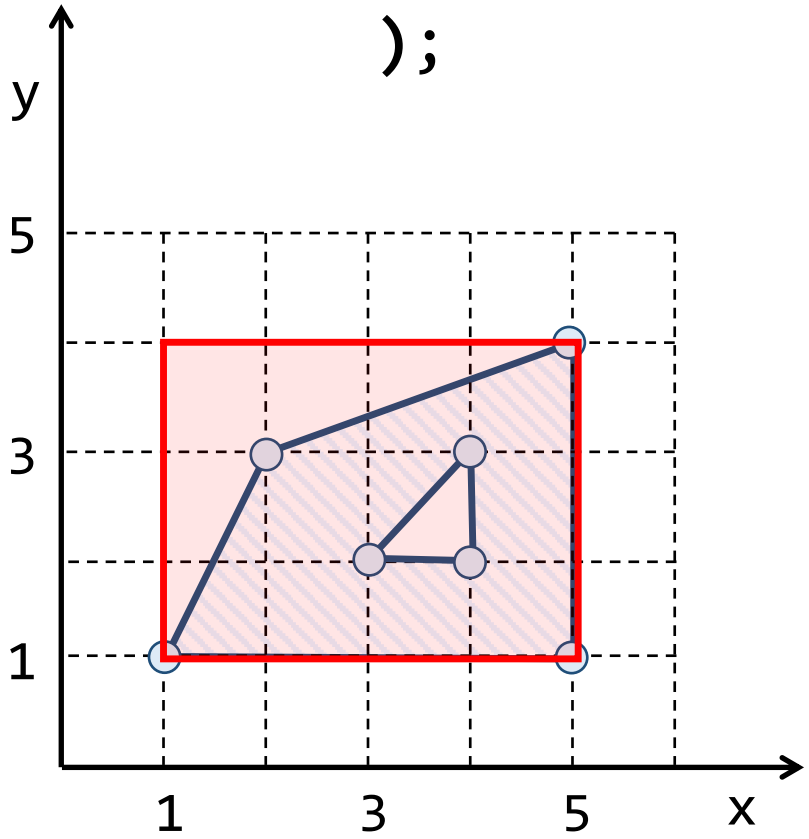
```
SELECT ST_Envelope( ST_GeomFromText(
            'POLYGON( (1 1, 2 3, 5 4, 5 1, 1 1),
                      (3 2, 4 3, 4 2, 3 2) )'
        ));
```



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

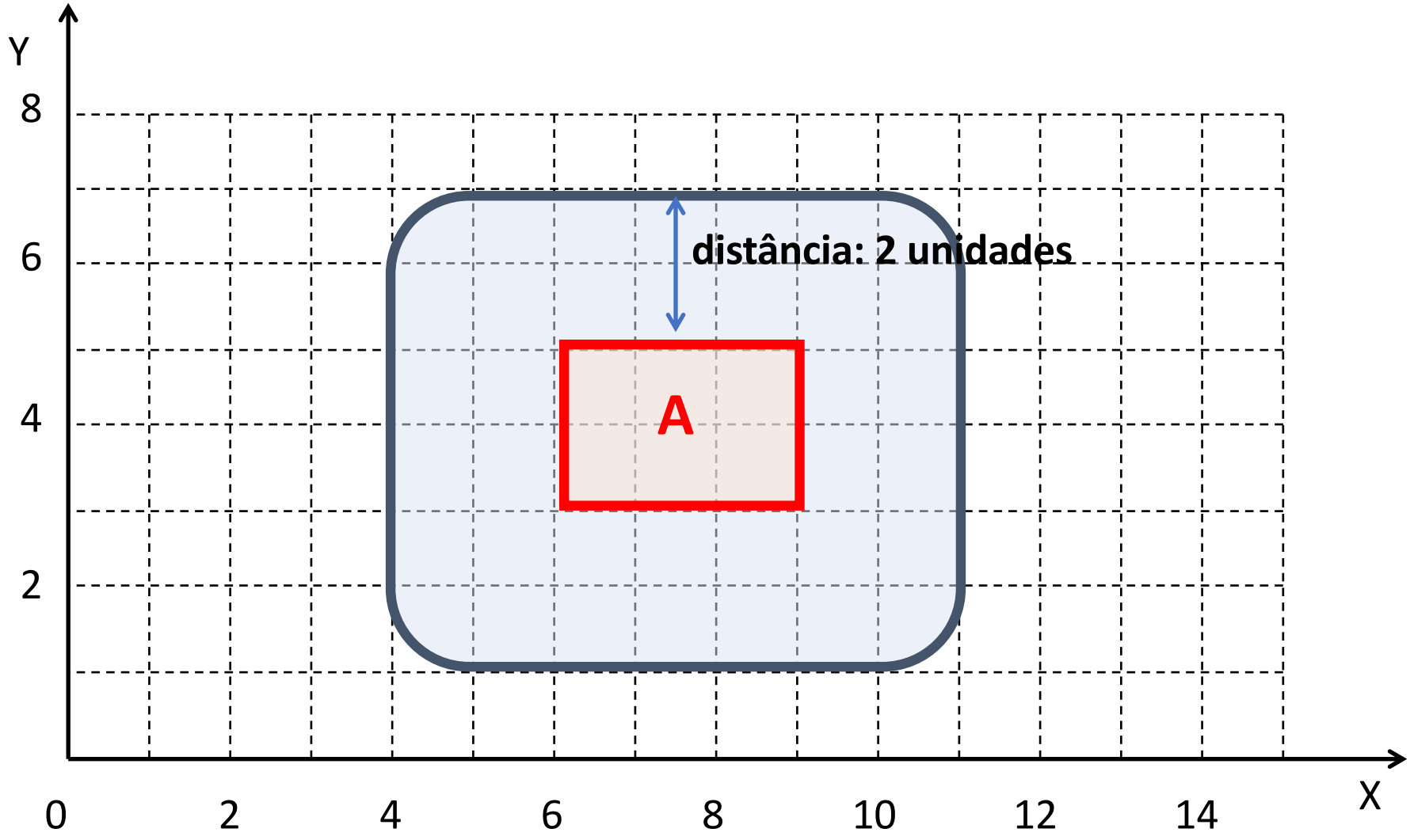
Retângulo Envolvente da Geometria

```
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 tabla 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