Areal Data: Vector Data

HES 505 Fall 2023: Session 8

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Today's Plan

Objectives

By the end of today, you should be able to:

- Understand `predicates` and `measures` in the context of spatial operations in `sf`
- Define valid geometries and approaches for assessing geometries in `R`
- Use `st_*` and `sf_*` to evaluate attributes of geometries and calculate measurements

Understanding the language

Revisiting Simple Features

- The `sf` package relies on a simple feature data model to represent geometries
  - hierarchical
  - standardized methods
  - complementary binary and human-readable encoding

type	description
`POINT`	single point geometry
`MULTIPOINT`	set of points
`LINESTRING`	single linestring (two or more points connected by straight lines)
`MULTILINESTRING`	set of linestrings
`POLYGON`	exterior ring with zero or more inner rings, denoting holes
`MULTIPOLYGON`	set of polygons
`GEOMETRYCOLLECTION`	set of the geometries above

Revisiting Simple Features

- You already know how to access some elements of a simple feature
- `st_crs` - returns the coordinate reference system
- `st_bbox` - returns the bounding box for the simple feature

Standaridized Methods

We can categorize `sf` operations based on what they return and/or how many geometries they accept as input.

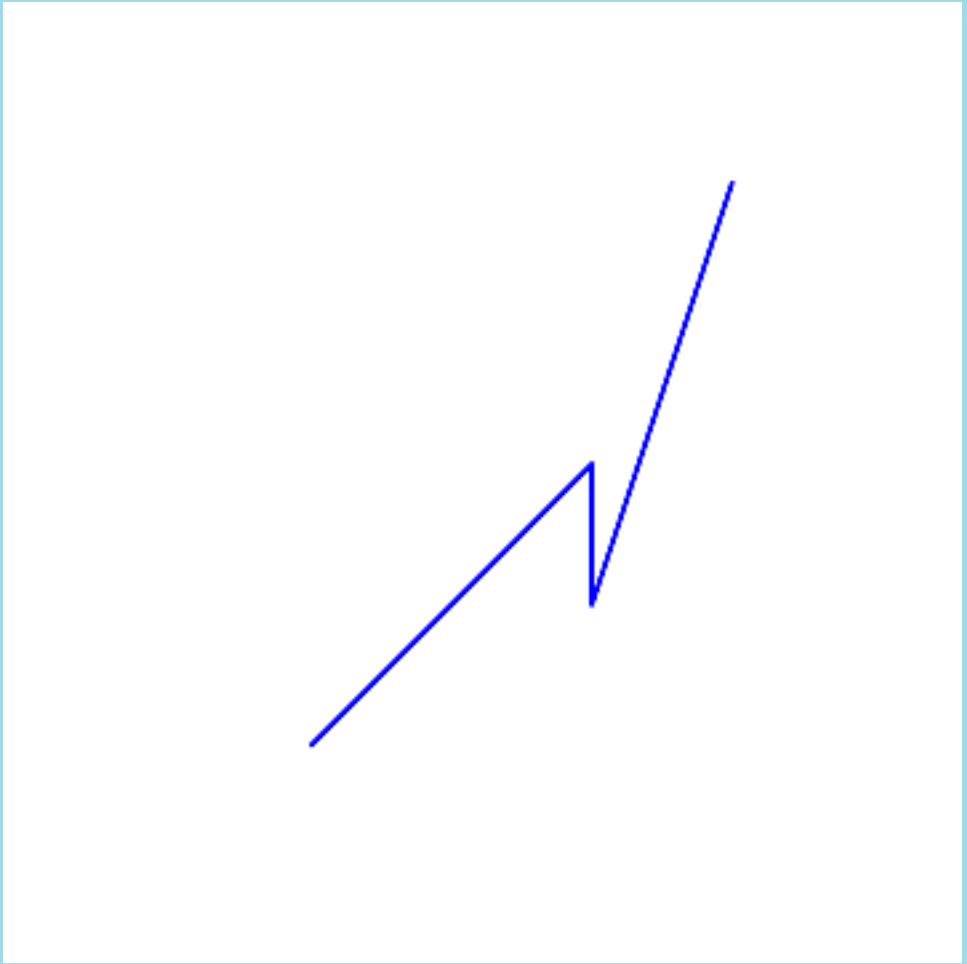
- *Output Categories*
  - **Predicates**: evaluate a logical statement asserting that a property is `TRUE`
  - **Measures**: return a numeric value with units based on the units of the CRS
  - **Transformations**: create new geometries based on input geometries.
- *Input Geometries*
  - **Unary**: operate on a single geometry at a time (meaning that if you have a `MULTI*` object the function works on each geometry individually)
  - **Binary**: operate on pairs of geometries
  - **n-ary**: operate on sets of geometries

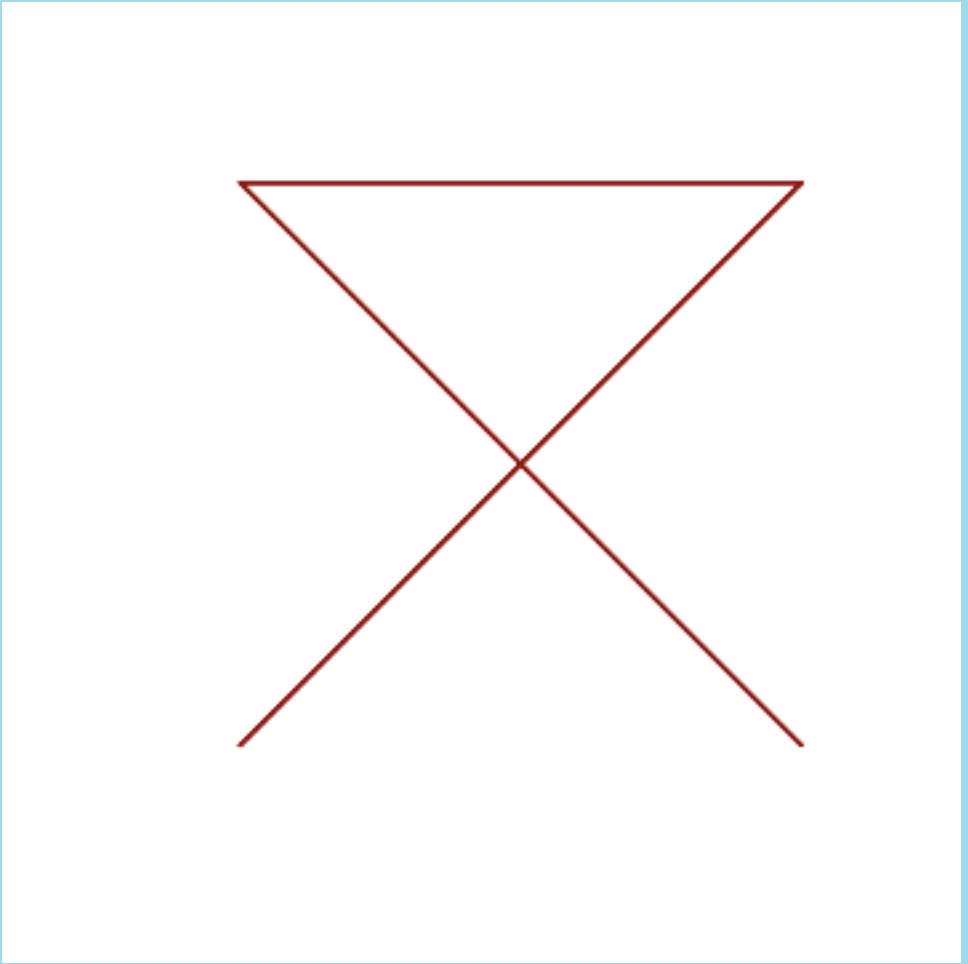
Valid Geometries

Remembering Valid Geometries

- A `linestring` is *simple* if it does not intersect

```
1  library(sf)
2  library(tidyverse)
3  ls = st_linestring(rbind(c(0,0), c(1,1),  c(2,2), c(2,1), c(3,4)))
4
5  ls2 = st_linestring(rbind(c(0,0), c(1,1),  c(2,2), c(0,2), c(1,1), c(2,0)))
```



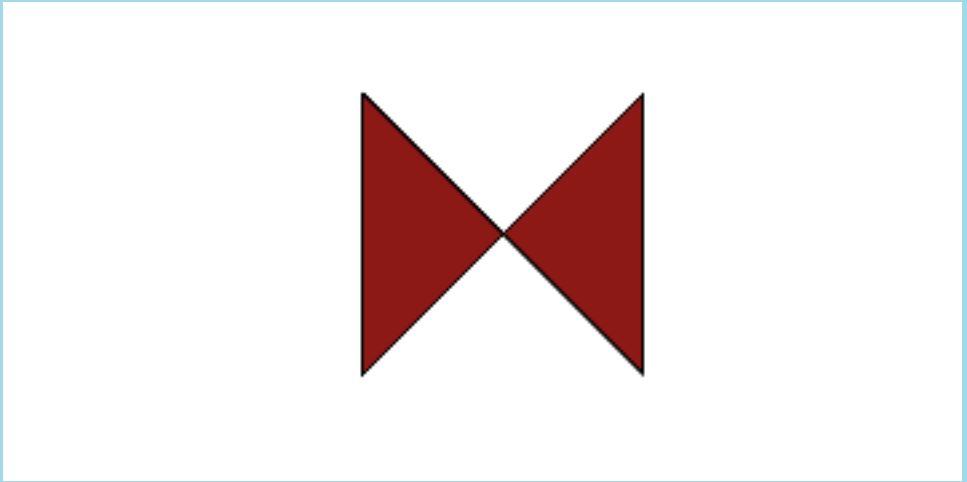


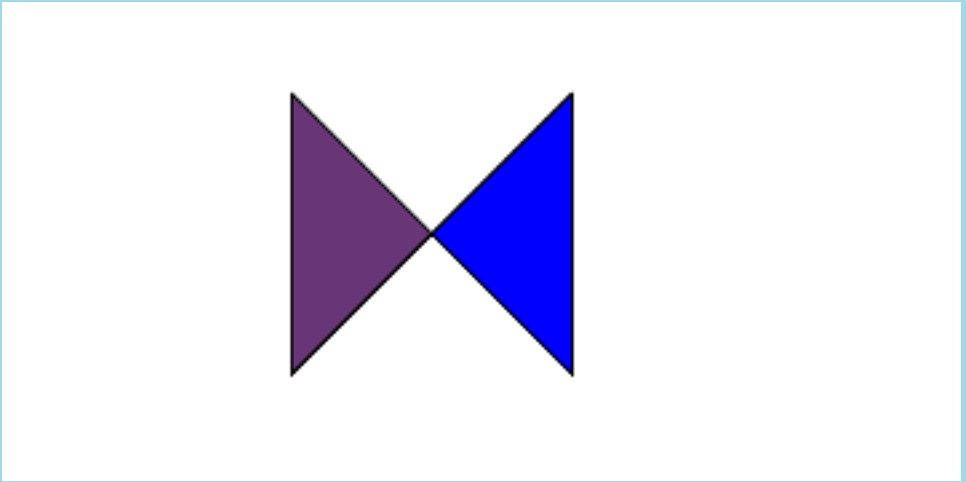
Remembering Valid Geometries

- Valid polygons
  - Are closed (i.e., the last vertex equals the first)
  - Have holes (inner rings) that inside the the exterior boundary
  - Have holes that touch the exterior at no more than one vertex (they don't extend across a line)
    - For multipolygons, adjacent polygons touch only at points
  - Do not repeat their own path

Remembering Valid Geometries

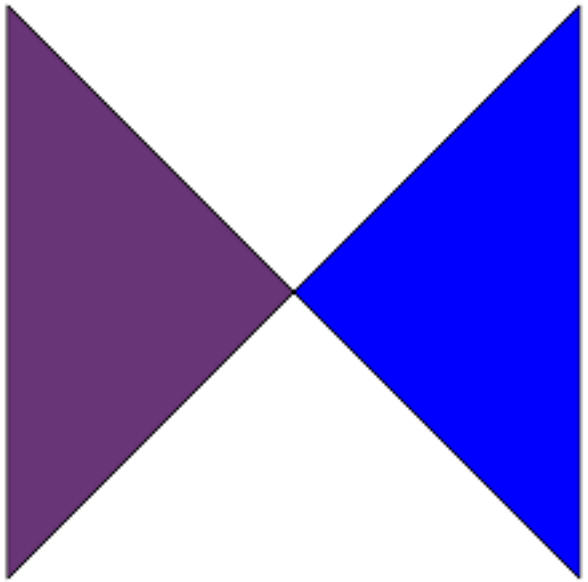
```
1  p1 = st_as_sfc("POLYGON((0 0, 0 10, 10 0, 10 10, 0 0))")
2  p2 = st_as_sfc("POLYGON((0 0, 0 10, 5 5,  0 0))")
3  p3 = st_as_sfc("POLYGON((5 5, 10 10, 10 0, 5 5))")
```





Remembering Valid Geometries

```
1  p4 = st_as_sfc(c("POLYGON((0 0, 0 10, 5 5,  0 0))", "POLYGON((5 5, 10 10, 1
2  plot(p4, col=c( "#7C4A89", "blue"))
```



Empty Geometries

- Empty geometries arise when an operation produces `NULL` outcomes (like looking for the intersection between two non-intersecting polygons)
- `sf` allows empty geometries to make sure that information about the data type is retained
- Similar to a `data.frame` with no rows or a `list` with `NULL` values
- Most vector operations require simple, valid geometries

Predicates

Using Unary Predicates

- Unary predicates accept single geometries (or geometry collections)
- Provide helpful ways to check whether your data is ready to analyze
- Use the `st_` prefix and return `TRUE/FALSE`

predicate	asks…
`is_simple`	is the geometry self-intersecting (i.e., simple)?
`is_valid`	is the geometry valid?
`is_empty`	is the geometry column of an object empty?
`is_longlat`	does the object have geographic coordinates? (`FALSE` if coords are projected, `NA` if no `crs`)
`is(geometry, class)`	is the geometry of a particular class?

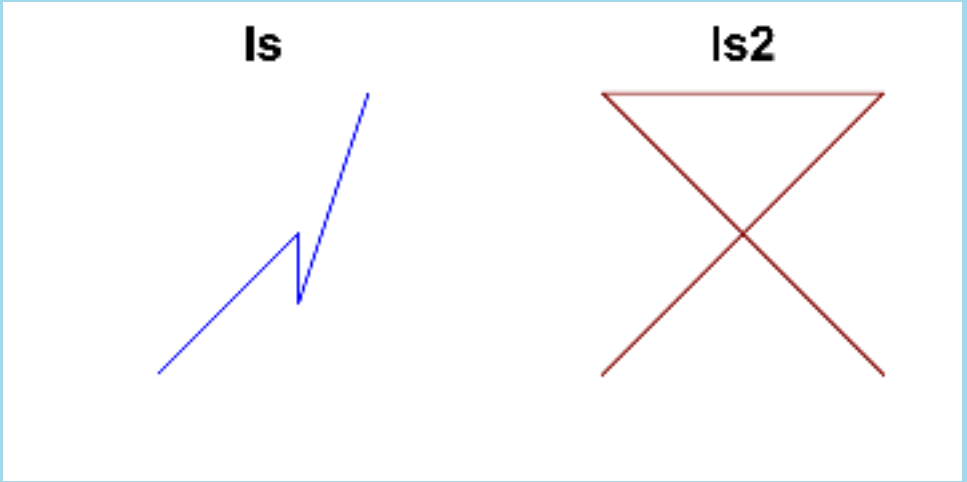
Checking Geometries With Unary Predicates

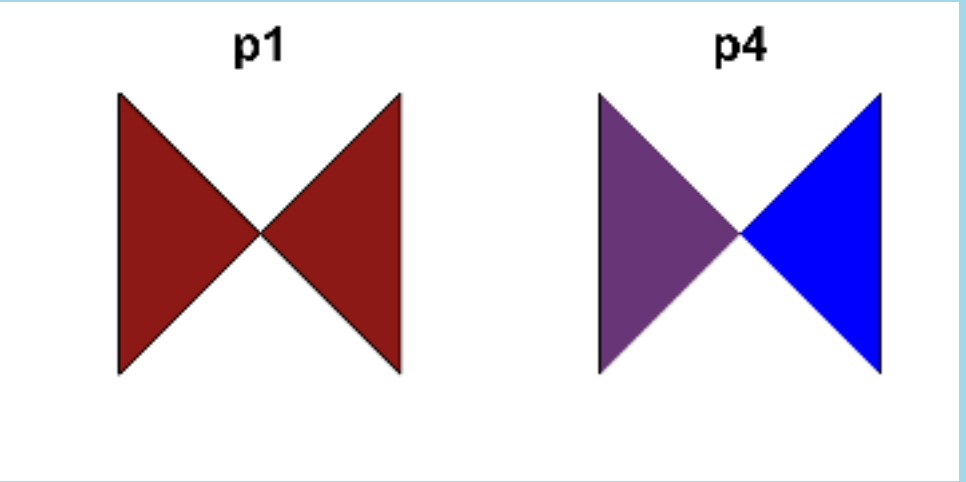
- Before conducting costly analyses, it's worth checking for:

1. empty geometries, using `any(st_is_empty(x)))`
2. corrupt geometries, using `any(is.na(st_is_valid(x)))`
3. invalid geometries, using `any(na.omit(st_is_valid(x)) == FALSE)`; in case of corrupt and/or invalid geometries,
4. in case of invalid geometries, query the reason for invalidity by `st_is_valid(x, reason = TRUE)`

Invalid geometries will require **transformation** (next week!)

Checking Geometries With Unary Predicates






```
1 st_is_simple(ls)
```

```
[1] TRUE
```

```
1 st_is_simple(ls2)
```

```
[1] FALSE
```

```
1 st_is_valid(p1)
```

```
[1] FALSE
```

```
1 st_is_valid(p4)
```

```
[1] TRUE TRUE
```

Unary Predicates and Real Data

```
1  library(tigris)
2  id.cty <- counties("ID",
3                     progres
4  st_crs(id.cty)$input
```

```
[1] "NAD83"
```

```
1  st_is_longlat(id.cty)
```

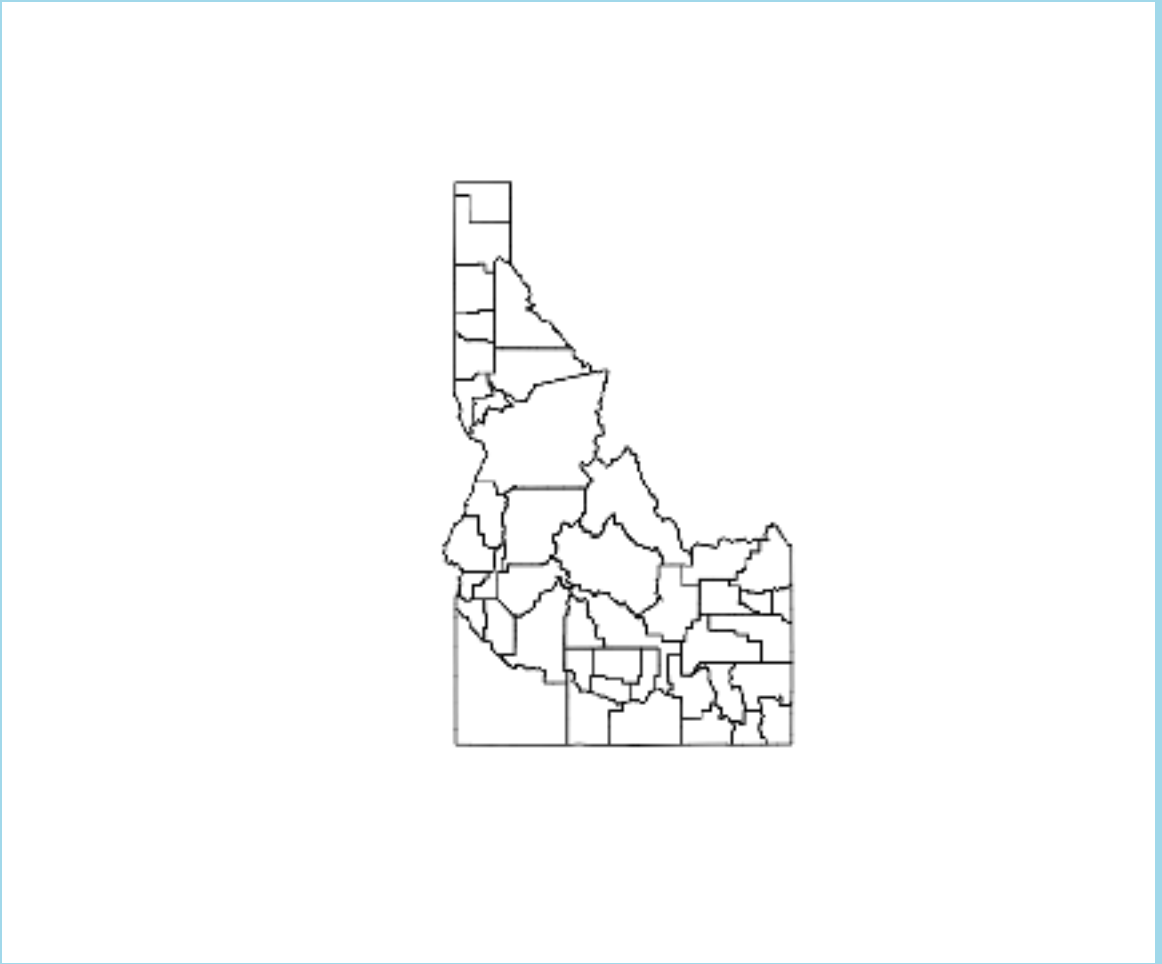
```
[1] TRUE
```

```
1  st_is_valid(id.cty)[1:5]
```

```
[1] TRUE TRUE TRUE TRUE TRUE
```

```
1  all(st_is_valid(id.cty))
```

```
[1] TRUE
```



Binary Predicates

Binary Predicates

- Accept exactly two geometries (or collections)
- Also return `logical` outcomes
- Based on the Dimensionally Extended 9-Intersection Model (DE-9IM)

predicate	meaning	inverse of
`contains`	None of the points of A are outside B	`within`
`contains_properly`	A contains B and B has no points in common with the boundary of A	
`covers`	No points of B lie in the exterior of A	`covered_by`
`covered_by`	Inverse of `covers`	
`crosses`	A and B have some but not all interior points in common	
`disjoint`	A and B have no points in common	`intersects`
`equals`	A and B are topologically equal: node order or number of nodes may differ; identical to A contains B AND A within B	
`equals_exact`	A and B are geometrically equal, and have identical node order	
`intersects`	A and B are not disjoint	`disjoint`
`is_within_distance`	A is closer to B than a given distance	
`within`	None of the points of B are outside A	`contains`
`touches`	A and B have at least one boundary point in common, but no interior points	
`overlaps`	A and B have some points in common; the dimension of these is identical to that of A and B	
`relate`	given a mask pattern, return whether A and B adhere to this pattern	

Binary Predicates

```
id <- states(progress_bar=
  filter(STUSPS == "ID")
or <- states(progress_bar=
  filter(STUSPS == "OR")
ada.cty <- id.cty %>%
  filter(NAME == "Ada")
```

```
st_covers(id, ada.cty)
```

```
Sparse geometry binary predicate list of
length 1, where the predicate
was `covers'
 1: 1
```

```
st_covers(id, ada.cty, sparse=FALSE)
```

```
     [,1]
[1,] TRUE
```

```
st_within(ada.cty, or)
```

```
Sparse geometry binary predicate list of
length 1, where the predicate
was `within'
 1: (empty)
```

```
st_within(ada.cty, or, sparse=FALSE)
```

```
      [,1]
[1,] FALSE
```

Measures

Measures

Unary Measures

- Return quantities of individual geometries

measure	returns
`dimension`	0 for points, 1 for linear, 2 for polygons, possibly `NA` for empty geometries
`area`	the area of a geometry
`length`	the length of a linear geometry

Unary Measures

```
1 st_area(id)
```

```
2.15994e+11 [m^2]
```

```
1 st_area(id.cty[1:5,])
```

```
Units: [m^2]
[1] 2858212132 3380630278 1459359818 1726660484 1223521586
```

```
1 st_dimension(id.cty[1:5,])
```

```
[1] 2 2 2 2 2
```

Binary Measures

- `st_distance` returns the distance between pairs of geometries

```
kootenai.cty <- id.cty %>%
  filter(NAME == "Kootenai")
st_distance(kootenai.cty, ada.cty)
```

```
Units: [m]
         [,1]
[1,] 396433.8
```

```
st_distance(id.cty)[1:5, 1:5]
```

```
Units: [m]
         [,1]     [,2]     [,3]     [,4]     [,5]
[1,]      0.0 467635.7 277227.0 132998.0      0.0
[2,] 467635.7      0.0 319706.4 656056.0 514306.9
[3,] 277227.0 319706.4      0.0 377105.4 336146.8
[4,] 132998.0 656056.0 377105.4      0.0 133045.5
[5,]      0.0 514306.9 336146.8 133045.5      0.0
```