Spatial Autocorrelation in SEMs

1. Detecting spatial autocorrelation
2. Adjusting for Spatial Autocorrelation with spatial correlation
3. Lagged neighbor Spatial Autoregressive (SAR) models

Spatial modelling of forest community features in the Volzhsko-Kamsky reserve

Example data from Zuur’s books

Example: NDVI in a Boreal System
Data Contains Spatial Information

```r
> boreal <- read.csv("../Data/boreal.csv")
> head(boreal)

   x   y richness NDVI   temp   wet
 1 2109.70 2093.52    13 0.480180 23.217 -0.0264378
 2 2190.18 2105.71    21 0.483990 23.217 -0.0234048
 3 2064.48 2052.77    30 0.489213 23.217 -0.0189264
 4 2277.34 2103.42    13 0.473226 23.217 -0.0280431
 5 2347.91 2074.81    13 0.405898 23.635 -0.0292287
 6 2437.21 2086.95     6 0.424769 23.217 -0.0229209
```

Example: NDVI in a Boreal System

The Model

```
> rich_lm <- lm(richness ~ temp, data = boreal)
> ndvi_lm <- lm(NDVI ~ richness + temp + wet, data=boreal)
> boreal.sem <- psem(rich_lm, ndvi_lm, temp %~~% wet, data = boreal)
```
SEM Example. “Independent”

Tests of directed separation:

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>richness ~ wet</td>
<td>-35.13</td>
<td>33.71</td>
<td>530</td>
<td>-1.0421</td>
<td>0.2979</td>
</tr>
</tbody>
</table>

Global goodness-of-fit:

Fisher’s C = 2.422 with P-value = 0.298 and on 2 degrees of freedom

Coefficients:

<table>
<thead>
<tr>
<th>Response</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>richness</td>
<td>temp</td>
<td>1.1707</td>
<td>0.3470</td>
<td>531</td>
<td>3.2401</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>NDVI</td>
<td>-0.0004</td>
<td>0.0002</td>
<td>529</td>
<td>2.0862</td>
<td>0.0374</td>
</tr>
<tr>
<td></td>
<td>NDVI</td>
<td>-0.0355</td>
<td>0.0023</td>
<td>529</td>
<td>-15.6364</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>--temp</td>
<td>--wet</td>
<td>0.2961</td>
<td>NA</td>
<td>7.1436</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

What about the residuals?

```
source("./residuals.R")
res <- residuals.psem(boreal.sem)
boreal <- cbind(boreal, res)
```

Spatial Correlation in Residuals?

Cool colors cluster in Center

Spatial Correlation in Residuals?
library(ape)
distMat <- as.matrix(dist(cbind(boreal$x, boreal$y)))

distsInv <- 1/distMat
diag(distsInv) <- 0

1. Distance matrices tell us how close points are in space
   • ape library calculates matrix and Moran’s I

2. We take the inverse, as closer points have greater similarity
   • The diagonal is 0, as there is no correlation within a point

> Moran.I(boreal$richness_residuals, distsInv)
$observed
 [1] 0.03853411

$expected
 [1] -0.001879699

$sd
 [1] 0.003998414

$p.value
 [1] 0

Data is more spatially correlated than expected – need a correction

> mi.ndvi <- Moran.I(boreal$ndvi_residuals, distsInv)
> mi.ndvi
$observed
 [1] 0.08014145

$expected
 [1] -0.001879699

$sd
 [1] 0.003986118

$p.value
 [1] 0

Data is more spatially correlated than expected – need a correction

Variograms to Examine Correlation
library(nlme)
ndvi_gls<- gls(NDVI ~ richness + temp + wet, data=boreal)
plot(Variogram(ndvi_gls, form=~x+y, robust=T, maxDist=2000, resType="normalized"))

#Fit using spatial autocorrelation
spaceCor <- corExp(form =~ x+y, nugget=T)
ndvi_gls_space <- gls(NDVI ~ richness + temp + wet, correlation = spaceCor, data=boreal)
rich_gls_space <- gls(richness ~ temp, correlation = spaceCor, data = boreal)

1. Detecting spatial autocorrelation
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boreal_space.sem <- psem(
  ndvi_gls_space,
  rich_gls_space,
  temp %~~% wet,
  data = boreal
)

> dSep(boreal_space.sem)

<table>
<thead>
<tr>
<th>Independ.Claim</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 richness ~ wet + ...</td>
<td>-35.20974</td>
<td>42.07507</td>
<td>533</td>
<td>-0.8368315</td>
<td>0.4030645</td>
</tr>
</tbody>
</table>

> coefs(boreal_space.sem)

<table>
<thead>
<tr>
<th>Response</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
<th>Std.Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 NDVI</td>
<td>richness</td>
<td>-0.0002</td>
<td>0.0002</td>
<td>533</td>
<td>-1.6250</td>
<td>0.1047</td>
<td>-0.0030</td>
</tr>
<tr>
<td>2 NDVI</td>
<td>temp</td>
<td>-0.0282</td>
<td>0.0033</td>
<td>533</td>
<td>-8.4356</td>
<td>0.0000</td>
<td>-0.2746 ***</td>
</tr>
<tr>
<td>3 NDVI</td>
<td>wet</td>
<td>-3.4060</td>
<td>0.1590</td>
<td>533</td>
<td>-21.4266</td>
<td>0.0000</td>
<td>-0.5636 ***</td>
</tr>
<tr>
<td>4 richness</td>
<td>temp</td>
<td>0.0357</td>
<td>0.0459</td>
<td>533</td>
<td>-0.0459</td>
<td>0.9634</td>
<td>-0.0028</td>
</tr>
<tr>
<td>5 ~temp</td>
<td>~wet</td>
<td>0.2961</td>
<td>NA</td>
<td>531</td>
<td>7.1436</td>
<td>0.0000</td>
<td>0.2961 ***</td>
</tr>
</tbody>
</table>

1. Detecting spatial autocorrelation
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library(sp)
library(spdep)

# Determine nearest neighbors
boreal_sp <- boreal
coordinates(boreal_sp) <- ~x+y

# get neighbors
# many functions if using # regions instead of points
nb <- tri2nb(boreal_sp)
plot(nb, coordinates(boreal_sp))

# Run regression models (with spatial weights)
spatial_weights <- nb2listw(nb)

rich_lag <- lagsarlm(richness ~ temp,
                      data = boreal_sp,
                      listw = spatial_weights,
                      tol.solve = 1e-11)

ndvi_lag <- lagsarlm(NDVI ~ richness + temp + wet,
                      data = boreal_sp,
                      listw = spatial_weights,
                      tol.solve = 1e-11)

boreal_space_lag.sem <- psem(
    rich_lag, 
nov_lag, 
    temp %~~% wet, 
data = boreal_sp 
)
SAR Approach

---
Tests of directed separation:

<table>
<thead>
<tr>
<th>Independ.Claim Estimate Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>richness ~ wet + ...</td>
<td>-25.6601</td>
<td>31.2746 NA</td>
<td>-0.8205 0.4119</td>
</tr>
</tbody>
</table>

Global goodness-of-fit:

Fisher’s C = 1.774 with P-value = 0.412 and on 2 degrees of freedom

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Coefficients:

<table>
<thead>
<tr>
<th>Response</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>Crit.Value</th>
<th>P.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>richness</td>
<td>temp</td>
<td>0.6808</td>
<td>0.5094</td>
<td>NA</td>
<td>1.3364</td>
<td>0.0538</td>
</tr>
<tr>
<td>NDVI</td>
<td>richness</td>
<td>-0.0003</td>
<td>0.0001</td>
<td>NA</td>
<td>-1.8619</td>
<td>0.0626</td>
</tr>
<tr>
<td>NDVI</td>
<td>wet</td>
<td>-0.0207</td>
<td>0.0021</td>
<td>NA</td>
<td>-9.1514</td>
<td>0.0000  ***</td>
</tr>
<tr>
<td>--temp</td>
<td>--wet</td>
<td>0.2961</td>
<td>0.1519</td>
<td>NA</td>
<td>20.4340</td>
<td>0.0000  ***</td>
</tr>
</tbody>
</table>

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

SAR Approach

Why not to think about autocorrelation

There are two key issues regarding space:

1. Are there things to learn about the other factors that could explain variations in the data that vary spatially?
2. Do we have nonindependence in our residuals?

Recent reference on the subject:

Historic Range
Expanded Range
Since 2001

Driven by Prey?

Humboldt Squid SPUE (#/h)

Stewart et al. 2014 GCB

Climate Drivers
Physical Environment

SEM and So Can YOU!

Adapted from Richard Young

Humboldt Squid SPUE (#/h)

Stewart et al. 2014 GCB

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Humboldt Squid SPUE (#/h)

Stewart et al. 2014 GCB

Driven by Prey?
Both Indirect Effects and Spurious Correlations with Prey

The Data

```
SqMonth SqYear Distkm ROV_ID   chla tcline   tcstren     tcval    tcoxy ocline    ocval
1       5   2009  5.229      3 1.5889     22 0.3874163 10.378564 5.247444   34.5 4.584194
2       5   2009  2.581      3 1.7582     22 0.5015197 10.230897 4.763088   38.5 3.948747
3       5   2009  7.450      3 1.5723     31 0.2943885  9.695900 4.646011   27.5 4.443057
4       5   2009  0.136      3 1.0145     33 0.2439991  9.322700 3.369191   35.0 3.445972
5       5   2009  1.550      3 1.1726     34 0.2833411  9.589154 3.925325   35.0 3.832471
6       5   2009  2.395      3 1.0132     52 0.1746201  9.456108 3.950209   56.0 3.479309
```

Exercise: Use Space, Time, or Both

```
squid <- read.csv("../Data/goodsquid.csv")
```

1. Is there temporal or spatial autocorrelation (SqYear, LatN?)
2. Attempt to handle any correlation using either random effects, spatial, or temporal autocorrelation.