

# Spatial analysis

Huge topic!

## Key references

Diggle (point patterns); Cressie (everything); Diggle and Ribeiro (geostatistics); Dormann et al (GLMMs for species presence/abundance), Haining

## Point processes

- just looking at the distribution of (“unmarked”) points, asking whether they are clustered, random, regular (“overdispersed” [!!])
- standard summary: Ripley’s  $K$  (number of points within radius  $r$  of a randomly chosen point, divided by the overall density);  $L = \sqrt{K/\pi}$  should be linear ...
  - have to deal with *edge corrections*: corrected estimators, null distributions via permutation tests
- tests of *complete spatial randomness* (CSR)

## Lattices

I don’t have much to say here: data are often *sampled* this way but we more typically model them in continuous space, or on a graph

## Graphs/networks

- Really more general than space: don’t even need to satisfy “spatial” properties (e.g. could be a social network rather than a spatial graph)
- different ways to represent spatial networks
  - neighbor list (with weights)
  - adjacency matrix (weighted)
- Deriving weights matrix  $W$  from spatial data (from [Bannerjee presentation](#)):
  - =1 if nearest neighbor (or  $n^{\text{th}}$  nearest neighbor?), 0 otherwise
  - polygons: “neighbor”=“share a boundary”, then as above?
  - =1 if distance < threshold
  - inverse-distance weighted (cutoff beyond some distance to make the matrix *sparse*?)
  - exponential weighting (but need to choose decay parameter ...)

- $W$  doesn't need to be symmetric
- Voronoi diagrams/Delaunay/Dirichlet tessellations

### Random fields

- Random fields
- Point samples of a continuously varying field
- *Gaussian* random fields (multivariate normal with specified spatial correlation function)
- build non-Gaussian random fields on top of Gaussian RF; hierarchical models

### Trend vs correlation

- stationarity, isotropy
- large- vs small-scale patterns
- (fitting small-scale spatial pattern via splines)

### Not-really-spatial models

Two kinds of models that I don't classify as spatial models:

- Models where the samples are taken spatially (i.e. measuring diversity vs rainfall from a bunch of plots, or environment and community samples in many plots (ordination etc.), but we just use space as a grouping factor, not considering which plots are closer to each other
- As above, but with  $x/y$  (lat/long, eastings/northings etc.) included as input variables, possibly with quadratic terms (`poly(x,y,degree=2)`) - in spatial statistics this is called *trend surface analysis*.
- in other words, truly spatial analyses take spatial *relationships* among points into account

### Avoiding spatial analysis

- Non-spatial analysis; show that residual pattern is insignificant, biologically and statistically (maps, or e.g. Moran's  $I$ )
- Aggregate data (buffering etc.) until aggregated observations are approximately independent
- Claim that spatial correlations don't bias your estimates (true for *linear* models) and that the adjustment to the confidence intervals is not important (McGill)
- Dutilleul's method?

## Spatial diagnostics

- graphical: maps of residuals (e.g. size=absolute magnitude, red vs blue = positive/negative, or diverging color scale)
- semi-graphical: *semivariogram* or *autocorrelation function*

## Analyses based on weight matrices

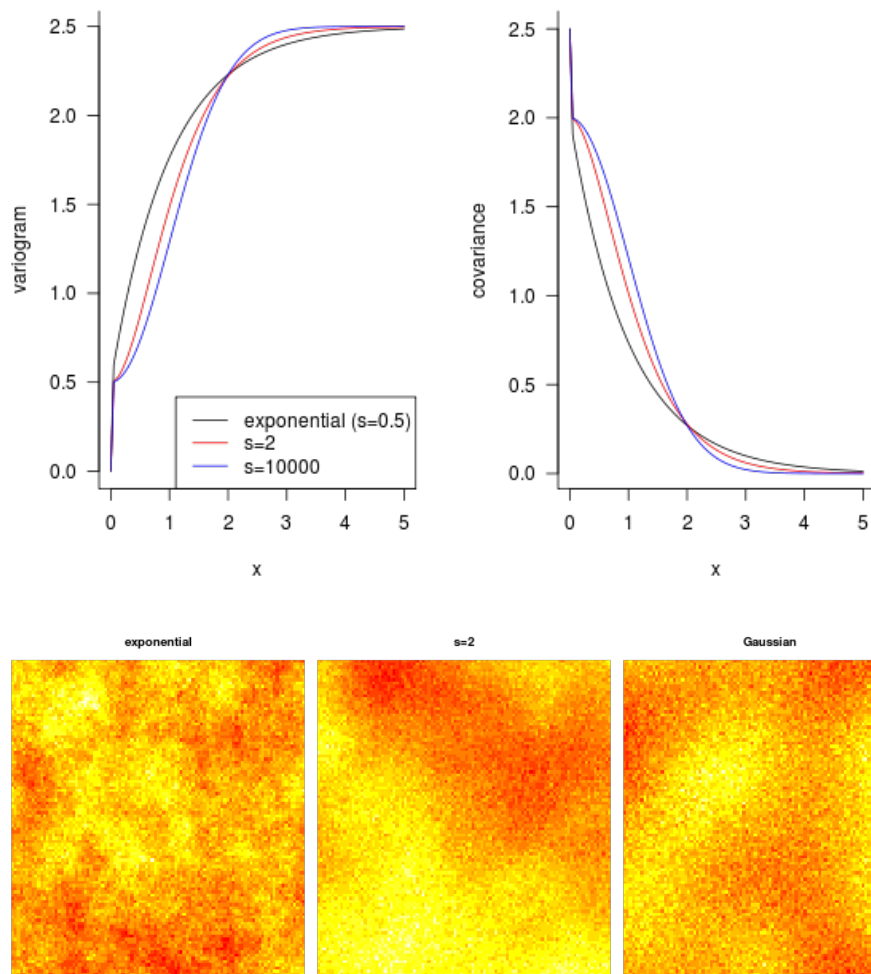
- Moran's  $I$  (analogue of lagged autocorrelation), Geary's  $C$
- Assume we are willing to specify the weight matrix  $W$  *a priori*
- Efficient matrix-based solutions: [Conditional and simultaneous autoregression](#):
  - *Non-spatial model*: my house value is a function of my home gardening investment.
  - *Conditional autoregression*: my house value is a function of the gardening investment of my neighbours.
  - *Simultaneous autoregression*: my house value is a function of the house values of my neighbours.

## Geostatistical models

### Correlation models

(Semi)variance:  $S(r_{ij}) = (x_i - \bar{x})(x_j - \bar{x})/2$ .

- starts at the *nugget*; continues out to the *sill*
- Useful for exploration (mostly not for model fitting nowadays)
- Usually makes a giant, uninterpretable point cloud unless one bins the data or fits some kind of smooth curve



- must obey constraints: *positive definiteness* (equivalent to ‘no negative variances’ or ‘no impossible correlation geometries’)
- typically use a small set of well-studied possibilities
  - classical: spherical, linear, exponential, Gaussian: each have a
  - newer: Matérn (includes exponential and Gaussian as special cases), powered exponential
  - all start at 1 (unless there’s a *nugget effect*), decrease eventually to zero; most are positive everywhere
  - spatial *variogram* or *semivariogram*; equivalent information but easier to compute

## R packages

- **spdep**: weight matrices, Moran's I, CAR/SAR
- **RandomFields**: simulating Gaussian RF of all types
- **nlme**: `g[n]ls` and `[n]lme` can handle standard spatial autocorrelation structures
- **ramps**: Bayesian MCMC fitting of geostatistical models. Also lots of additional spatial correlation structures, including basing correlation on great-circle distances
- **geoR**: spatial LMs and GLMMs (but without additional grouping structures)
- **ape**: correlation classes for phylogenetic correlations
- **INLA**: complex but powerful package for spatial (among others) fitting