General Observations:
- Perhaps the single most limiting factor for dissemination of modern spatial statistical procedures is the limited availability of statistical software.
- Writing of statistical software involves the following trade-off:
  - Ease of use
  - Flexibility

Outline: Review software for three areas of spatial statistics.
1. Geostatistics.
2. Spatial Point Patterns.
3. Lattice Data.

Geostatistics
South Florida Ecosystem Assessment.
Sample Sites
Predicted Total Mercury
Geostatistical Software:
- SAS
- Surfer
- ArcGIS Geostatistical Analyst
- S-SpatialStats
- R

SAS: Variogram Model Fitting

SAS: REML Estimation of Variogram Model Parameters

SAS: Kriging
Comments: SAS Geostatistics
- SAS is not menu driven. Analysis is carried out by writing SAS programs in the SAS editor.
  - For those who have experience with SAS, the geostatistical procedures are easy to apply.
  - Harder to use than menu-driven software.
- SAS has procedures for:
  - Isotropic and anisotropic variogram estimation (proc variog);
  - Variogram model fitting:
    - Weighted Least Squares (proc nlin);
    - Maximum Likelihood and REML (proc mixed).
  - Ordinary Kriging (proc kriged).
  - Universal Kriging (proc mixed).
- Generalized Mixed Models (proc glimmix).
- Limitations:
  - Limited choice of variogram models.
  - Cannot draw good contour maps.

Comments: Surfer
- Menu Driven
- Surfer has procedures for:
  - Variogram Estimation;
  - Least Squares Estimation of Variogram Model Parameters
  - Wide Variety of Variogram Models: exponential, Gaussian, linear, log, power, quadratic, rational quadratic, spherical, wave, pentaspherical, cubic.
  - Ordinary Kriging
  - Excellent mapping capabilities: contour maps; 3D surface maps; wireframe maps; vector maps; shaded relief maps.
- Limitations:
  - Cannot fit Matern variogram;
  - Universal kriging not available.
**Comments:** ArcGIS Geostatistical Analyst
- Menu Driven
- Geostatistical Analyst has procedures for:
  - Isotropic and anisotropic variogram estimation;
  - Least squares estimation of variogram parameters;
  - Wide variety of variogram models: circular, spherical, tetraspherical, pentaspherical, exponential, Gaussian, rational quadratic, hole effect, k-bessel, stable.
- Variety of kriging methods:
  - Ordinary kriging
  - Universal kriging
  - Indicator kriging (Binary Variables)
  - Disjunctive kriging (Nonlinear Geostatistics)
  - Cokriging (Multivariate Geostatistics)
- Crossvalidation for model diagnostics.
- Limitation: Expensive ($2,500 for Geostatistical Analyst, $1,500 for ArcView 9.1)

**Definition:** Crossvalidation.
- Remove the data at site $s_i$ from the data set;
  - Use the remaining data to obtain the kriging predictor $\hat{Z}(s_i)$ of the data at site $s_i$;
  - Compute the corresponding kriging variance $\sigma^2(s_i)$
- Repeat the above procedure for all sites.
- Compare observed values $Z(s_i)$ with predicted values $\hat{Z}(s_i)$
  - Bias Measure
    \[
    CV_1 = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{Z(s_i) - \hat{Z}(s_i)}{\sigma(s_i)} \right)
    \]
  - Uncertainty Assessment
    \[
    CV_2 = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{Z(s_i) - \hat{Z}(s_i)}{\sigma^2(s_i)} \right)^2
    \]
- For a valid model, we should have
  \[
  CV_1 \leq 0 \text{ and } CV_2 \leq 1
  \]
Comments: S+SPATIALSTATS
- Menu Driven
- S+SPATIALSTATS has procedures for:
  - Isotropic and Anisotropic Variogram Estimation
  - Least Squares Estimation of Variogram Parameters (Weighted least squares with some work)
  - Limited variogram models: Spherical, exponential, Gaussian
  - Ordinary and Universal Kriging
  - Good quality contour maps
- Software has not been kept up to date.
  - Effort has been made to improve user interface.
  - No effort has been made to include modern methods.

R
http://www.r-project.org/

Geostatistical Packages
- geoR http://www.est.ufpr.br/geoR/
  Frequentist and Bayesian geostatistics.
- geoRglm http://www.daimi.au.dk/~olefc/geoRglm/
  Geostatistics for counts data. Poisson and binomial models.
- fields http://www.image.ucar.edu/GSP/Software/Fields/
  Best for global data. Includes great circle distance.
- gstat http://www.gstat.org/
- RandomFields
  Spatial simulation.
Comments: R
- Public domain software;
- Packages contributed by statistical researchers keep the software up to date;
- Command driven and interactive;
- GeoR has procedures for:
  - Variogram estimation;
  - Least squares, weighted least squares, REML estimation of variogram parameters;
  - Bayesian inference for model parameters;
  - Diverse variety of variogram models including the Matérn class;
  - Ordinary, universal and Bayesian kriging.
- GeoRglm has procedures for binomial and Poisson models for counts data;
- Fields includes great circle distance for investigating global data;
- Limitation: Not well documented.

Lattice Model Software
- S+SPATIALSTATS
- BUGS
- R package: spdep

Lattice Data
Sudden Infant Death Rates in North Carolina

S+SPATIALSTATS
Lattice Models
Moran’s Index   CAR Model
**Comments: S+SPATIALSTATS**
- Menu Driven
- S+SPATIALSTATS has procedures for:
  - Defining neighborhood matrices
  - Defining spatial weights matrices
  - Computing Moran’s I
  - Fitting spatial regression models:
    - Conditional AutoRegressive
    - Simultaneous AutoRegressive
    - Moving Average

**GeoBUGS**
http://www.mrc-bsu.cam.ac.uk/bugs/winbugs/geobugs.shtml

**Comments: GeoBUGS**
- Public domain software;
- Bayesian inference for lattice models:
  - CAR models
  - Poisson and binomial models with spatially dependent random effects.
- Data interface can use some work.

**Spatial Point Pattern**
California Earthquakes
Point Pattern Software:
- S+SPATIALSTATS
- R

Comments: S+SPATIALSTATS
- Menu Driven;
- S+SPATIALSTATS has procedures for:
  - Computing F-, G- and K-functions;
  - Testing complete spatial randomness;
  - Nonparametric estimation of the intensity function;
  - Fitting the point cluster process model.

R: Point Pattern Packages:
- spatstat http://www.spatstat.org/
  Analysis of spatial point patterns.
- splancs http://www.maths.lancs.ac.uk/~rowlings/Splancs/
  Analysis of spatial and spatiotemporal point patterns.
- MarkedPointProcess
  http://www2.hsu-hh.de/schlath/schlather.html#Software
  Analysis of marked point patterns.
Comments: R
- Public domain software;
- Packages contributed by statistical researchers keep the software up to date;
- Command driven and interactive;
- Spastat has procedures for:
  - Computing F-, G- and K-functions;
  - Testing complete spatial randomness;
  - Fitting the point cluster process model;
  - Simulating a variety of point process models;
  - Estimating parameters of modulated Poisson process model (covariates must be observed at all locations).

General Summary
- ArcGIS Geostatistical Analyst:
  - Menu driven;
  - A comprehensive collection of geostatistical methods;
  - Expensive.
- R:
  - Up-to-date methods for geostatistical and point pattern analyses;
  - Public domain;
  - Command driven and interactive.
- S+SPATIALSTATS:
  - Best for analysis of lattice data;
  - Menu driven.