Using the spatialwarnings package

The package authors

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Ecosystems can undergo rapid and discontinuous transitions, even after a small change in their control parameters. Arid systems can go extinct, lakes can become eutrophized and forest patches can fail to maintain themselves, even after a small increase in the external pressure they bear. Those sharp transitions after a threshold has been crossed are gathered under the umbrella term of *critical transitions*. Some of them can even show irreversibility, where returning the external conditions to their original values is insufficient to restore the ecosystem to its original state. The latter type of transition is a *catastrophic shift*.

A body of theoretical work suggests that ecosystems should show some deviation in their characteristics before undergoing such a transition, hence the development of *indicators* or *early-warning signals* of critical transitions. These indicators are developed for time-series (package earlywarnings) and spatial data (this package).

The *spatialwarnings* package provides user-friendly tools to compute, test for significance and plot the indicators. This document provides an overview of the package and a possible workflow.

The package provides many indicators, most of which falling into three broad categories, that are detailed thereafter with their corresponding package function:

- "Generic" early-warning signals (`generic_spews`)
- Spectral indicators (`spectral_spews`)
- Patch-based indicators (`patch_spews`)
- Potential-analysis (`potential_analysis`)

This vignette will go through the suggested workflow for all these indicators using an example dataset: the output from Kubo et al's (1996) forest gap model.

Preparing your data

The package assumes on raster-like data, *i.e.* values regularly-spaced point along a 2D grid. Some indicators can work on continuous data, however, some others require binary (1/0) data. Some conversion may thus be required before computing the indicators.

A conversion generic function `as.binary_matrix` is provided and will handle the conversion of discrete data to binary matrices for standard matrices, data frames or list of those (see Fig. 1). However, it is up to the user to convert quantitative data into a binary matrix if necessary (e.g. aerial imagery).

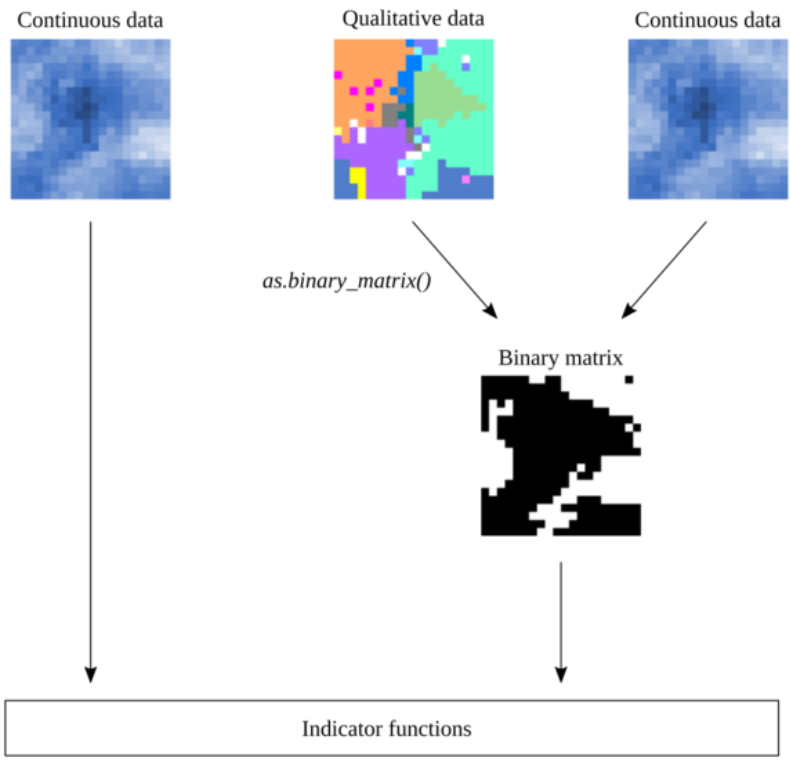

Figure 1. Workflow for data preparation.

Generic spatial early-warning signals

The rationale behind those indicators is a decrease in the return rates of a system (*Critical Slowing Down*, Scheffer et al., 2009) and the assymetry of the underlying potential near a critical point (Guttal et al., 2009).

These indicators can be applied both on continuous data and binary data (`binary matrix`). If the user supplies the latter, then an intermediate matrix is computed by coarse-graining (binning) the binary data into larger cells.

```
library(spatialwarnings)
library(ggplot2)

# Load and make data available
attach(forestdat) # make variable matrices and parameters available
```

```
## The following objects are masked from forestdat (pos = 3):
##
##     matrices, parameters
##
## The following objects are masked from forestdat (pos = 4):
##
##     matrices, parameters
```

```r
# Compute generic early warning signals
test.dat <- generic_spews(matrices)
test.summary <- summary(test.dat)
```

```
## [1] "plop"

## Warning in FUN(X[[i]], ...): Testing of variance and skewness is not
## implemented yet

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## implemented yet
```
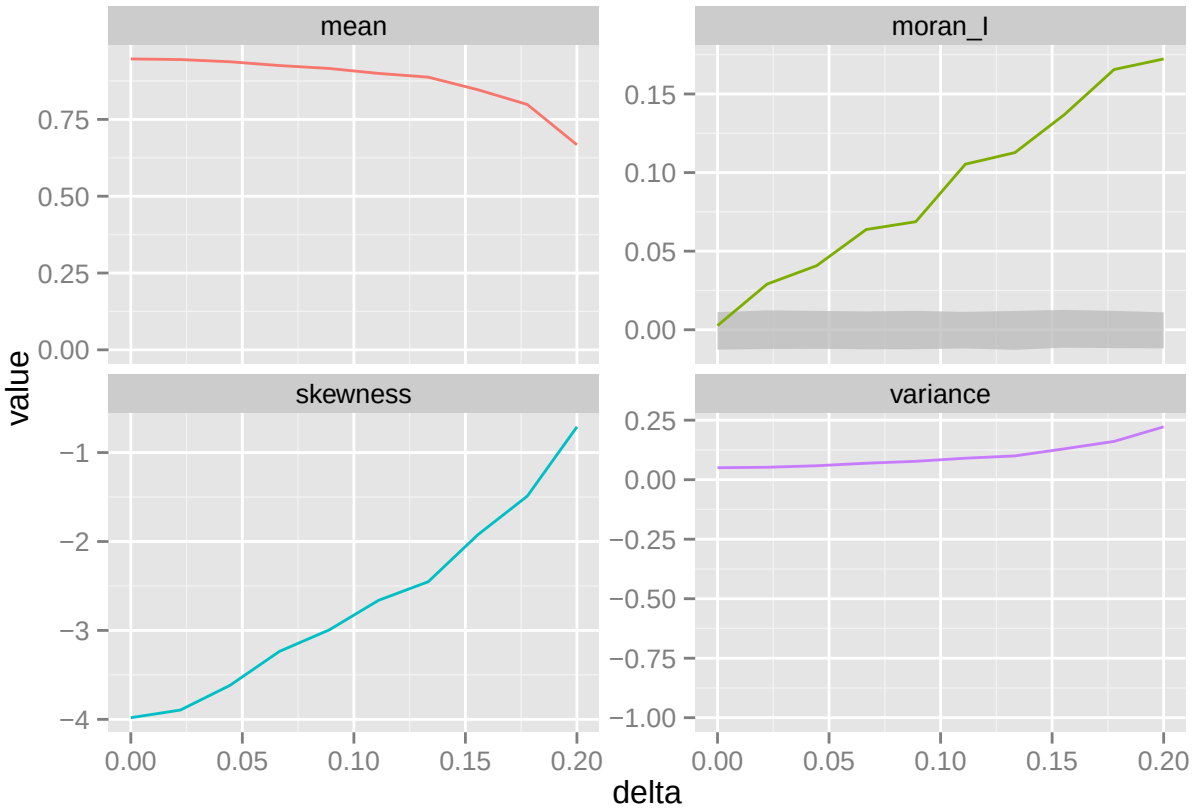

```r
# Plot along the replicate number
plot(test.summary, along = parameters[ ,"delta"]) + xlab('delta')
```



References

Guttal, V., & Jayaprakash, C. (2009). Spatial variance and spatial skewness: Leading indicators of regime shifts in spatial ecological systems. Theoretical Ecology, 2(1), 3–12. http://doi.org/10.1007/s12080-008-0033-1

Kubo, T., Iwasa, Y., & Furumoto, N. (1996). Forest spatial dynamics with gap expansion: Total gap area and gap size distribution. Journal of Theoretical Biology, 180(3), 229–246. http://doi.org/10.1006/jtbi.1996.0099

Scheffer, M., Bascompte, J., Brock, W. a, Brovkin, V., Carpenter, S. R., Dakos, V., … Sugihara, G. (2009). Early-warning signals for critical transitions. Nature, 461(7260), 53–9. http://doi.org/10.1038/nature08227