Krigeage avec R

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Résumé

Techniques pour interpoler les valeurs d'une variable continue.

Table des matières

Pour cartographier facilement une variable continue, 4 méthodes sont disponibles, dans les packages *akima*, *spatial*, *gstat* et *automap*.

Des méthodes plus élaborées ne sont pas traitées ici :

- l'estimation d'un modèle de prédiction de la valeur à partir de variables explicatives (krigeage ordinaire ou krigeage universel). Voir l'aide de la fonction `gstat` pour leur utilisation.
- l'estimation bayesienne de ces modèles ou le co-krigeage (estimation de plusieurs variables non indépendantes). Les packages *RGeostats* [1] ou *INLA* [2] permettent une modélisation complexe, mais au prix d'un effort bien supérieur.

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[1] http://rgeostats.free.fr/
[2] http://www.r-inla.org/spde-book
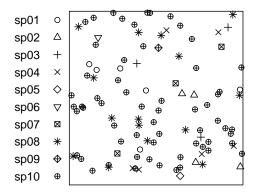
1 Interpolation et cartographie locales

1.1 Création des données

Les données représentent le niveau de la biodiversité locale au voisinages des arbres d'une forêt. La diversité est calculée avec le package *SpatDiv* disponible sur GitHub, à installer. Le package nécessite une compilation, donc les Rtools sont nécessaires sous Windows.

```r
# Package sur GitHub
devtools::install_github("EricMarcon/SpatDiv")
```

Création d'une communauté de 100 individus de 10 espèces dans une placettes carrée de 1x1.

```r
library("SpatDiv")
plot(spCommunity <- rSpCommunity(n = 1, size = 100,
    S = 10), which.marks = "PointType")
```

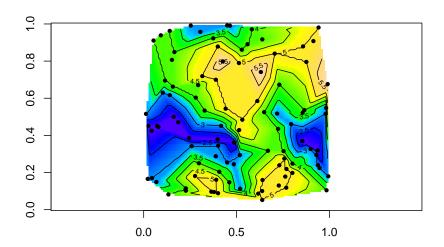**spCommunity <– rSpCommunity(n = 1, size = 100, S = 10)**

Calcul de la SAC (courbe d'accumulation des espèces) en fonction du nombre de voisins. La valeur obtenue est le nombre d'espèces différentes parmi les 10 plus proches voisins de chaque arbre.

```r
divAccum <- DivAccum(spCommunity, n.seq = 1:10, q.seq = 0,
    Individual = TRUE)
```

1.2 Cartographie

1.2.1 akima

La méthode d'Akima est une interpolation entre les valeurs des points, faite dans chaque triangle constitué par les triplets de points les plus proches. La valeur des points est conservée. L'interpolation se limite au polygone convexe contenant les points.
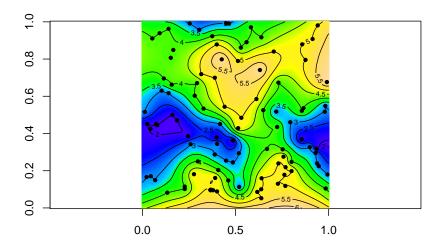
```r
library("akima")
Interpole <- with(divAccum, interp(x = SpCommunity$x,
    y = SpCommunity$y, z = Neighborhoods["0", "10",
        ], xo = seq(from = 0, to = 1, by = 0.01), yo = seq(from = 0,
        to = 1, by = 0.01)))
image(Interpole, col = topo.colors(128, alpha = 1),
    asp = 1)
contour(Interpole, add = TRUE)
with(divAccum, points(x = SpCommunity$x, y = SpCommunity$y,
    pch = 20))
```


1.2.2 spatial

La librairie *spatial* permet krieger, mais renvoie des erreurs si la méthode de calcul de la covariance n'est pas exponentielle. L'ordre du polynome du modèle et la distance de dépendance doivent être choisis explicitement.

```r
library("spatial")
Carte <- with(divAccum, surf.gls(np = 3, covmod = expcov,
    x = SpCommunity$x, y = SpCommunity$y, z = Neighborhoods["0",
        "10", ], d = 0.5))
```

```
Krieg <- prmat(Carte, xl = 0, xu = 1, yl = 0, yu = 1,
    n = 128)
image(Krieg, col = topo.colors(128, alpha = 1), asp = 1)
contour(Krieg, add = TRUE)
with(divAccum, points(x = SpCommunity$x, y = SpCommunity$y,
    pch = 20))
```


1.2.3 gstat

La librairie *gstat* étend les possibilités de kriegeage en permettant de spécifier un modèle de tendance pour la variable cartographiée (inutile ici, on utilise `formula=Richness~1`). Le variogramme doit être calculé et un modèle ajusté (dans l'exemple, un modèle gaussien et non exponentiel).

```
library("sp")
# Création d'un SpatialPointsDataFrame avec les
# données
sdfCommunity <- with(divAccum, SpatialPointsDataFrame(coords = data.frame(x = SpCommunity$x,
    y = SpCommunity$y), data = data.frame(Richness = Neighborhoods["0",
    "10", ])))
library("gstat")
# Variogramme empirique
vgmEmpirique <- gstat::variogram(Richness ~ 1, data = sdfCommunity)
# Ajustement d'un modèle gaussien
vgmX <- fit.variogram(vgmEmpirique, vgm("Gau"))
# Objet geostat qui décrit toutes les
# caractéristiques de la modélisation. La formule
# donne le modèle de tendance
geoX <- gstat(formula = Richness ~ 1, locations = sdfCommunity,
    model = vgmX)
# Préparation d'une grille de 128 points de côté
xy <- expand.grid((0:128)/128, (0:128)/128)
```
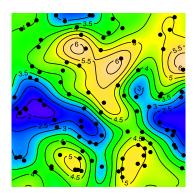
```
names(xy) <- c("x", "y")
gridded(xy) <- ~x + y
# Calcul de la valeur de Richness sur les points de
# la grille (kriegeage)
geoXprd <- predict(geoX, newdata = xy)
```

[using ordinary kriging]

```
# Carte
image(geoXprd, col = topo.colors(128, alpha = 1), asp = 1)
contour(geoXprd, add = TRUE)
with(divAccum, points(x = SpCommunity$x, y = SpCommunity$y,
    pch = 20))
```


1.2.4   automap

La librairie *automap* s'appuie sur *gstat* mais automatise toutes les étapes de sélection du modèle de covariance (celui qui s'ajuste le mieux aux données est choisi). Le modèle sélectionné est affiché dans le variogramme. La grille précédente peut être utilisée, mais une grille calculée à partir de la fenêtre de l'objet *ppp* (librairie *spatstat*) est plutôt utilisée ici.

```
library("spatstat")
# Préparation d'une grille de 128 points de côté
xy <- gridcentres(spCommunity, 128, 128)
# Filtrage des noeuds de la grille à l'intérieur de
# la fenêtre (inutile ici)
ok <- inside.owin(xy$x, xy$y, spCommunity)
# Formatage de la grille
Grille <- SpatialPoints(cbind(xy$x[ok], xy$y[ok]))
```
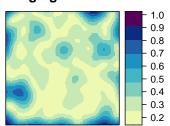
```
gridded(Grille) <- TRUE
# Krigeage du SpatialPointsDataFrame créé à partir
# des données précédemment
library("automap")
AutoKrige <- autoKrige(formula = Richness ~ 1, input_data = sdfCommunity,
    new_data = Grille)
```

```
## [using ordinary kriging]
```
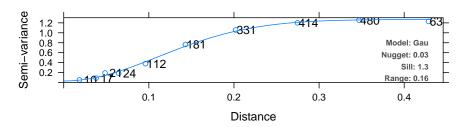
```
# Résultat du krigeage
plot(AutoKrige)
```


Kriging prediction

Kriging standard error

Experimental variogram and fitted variogram model

```
# Carte similaire aux précédentes
image(AutoKrige$krige_output, col = topo.colors(128,
    alpha = 1), asp = 1)
contour(AutoKrige$krige_output, add = TRUE)
with(divAccum, points(x = SpCommunity$x, y = SpCommunity$y,
    pch = 20))
```

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2 Utilisation de fonds de carte

L'objectif est ici d'interpoler une variable continue du même type sur les centroïdes de polygones d'une carte vectorielle (un shapefile) plutôt que sur une grille.

2.1 Obtention des cartes

Le package *raster* permet de télécharger des fonds de carte administratifs, des modèles numériques de terrain, des cartes de climat : voir l'aide de la fonction getData.

```r
library("raster")
# Récupération du shapefile des limites de régions
# de France
France <- raster::getData("GADM", country = "FRA",
    level = 3)
# Projection de France en Lambert 93
France <- spTransform(France, CRS("+init=epsg:2154"))
```

```
## Warning in showSRID(uprojargs, format = "PROJ",
## multiline = "NO", prefer_proj = prefer_proj):
## Discarded datum Reseau_Geodesique_Francais_1993 in
## CRS definition
```
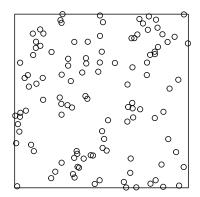
```
plot(France)
```


2.2 Fabrication des données

Les données sont 100 points placés aléatoirement dans un rectangle contenant la France. Leur marque est une valeur numérique continue, augmentant linéairement de l'ouest vers l'est et avec la distance à la latitude moyenne, et contenant un bruit gaussien.

```
library("spatstat")
# Tirage d'un processus de Poisson, 1000 points
# attendus, dans une fenêtre de 1x1
plot(X <- rpoispp(100))
```

X <- rpoispp(100)


```r
# Valeur de la marque
X$marks <- X$x + 3 * abs(X$y - 0.5) + rnorm(X$n, sd = 0.1)
# Calage sur Lambert 93 (pas très propre, la
# fenêtre n'est pas modifiée...)
X$x <- 8e+05 * X$x + 3e+05
X$y <- 9e+05 * X$y + 6200000
```
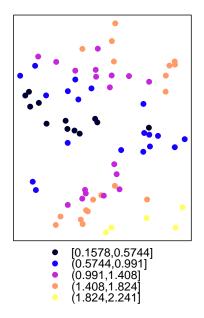
2.3 Interpolation

Les valeurs de x, y et z doivent être intégrées dans un objet *Spatial*.

```r
# Nécessite un dataframe avec les colonnes x et y
# plus un dataframe avec la valeur à cartographier
SpatialX <- SpatialPointsDataFrame(coords = data.frame(x = X$x,
    y = X$y), data = data.frame(m = X$marks))
# Le système de projection doit être le même
proj4string(SpatialX) <- proj4string(France)
```

```
## Warning in proj4string(France): CRS object has
## comment, which is lost in output

## Warning in showSRID(uprojargs, format = "PROJ",
## multiline = "NO", prefer_proj = prefer_proj):
## Discarded datum Unknown based on GRS80 ellipsoid
## in CRS definition
```

```r
# Découpe
SpatialX <- SpatialX[France, ]
# Carte des points
spplot(SpatialX, "m")
```

- ● [0.1578,0.5744]
- ● (0.5744,0.991]
- ● (0.991,1.408]
- ● (1.408,1.824]
- ● (1.824,2.241]

L'interpolation est faite avec *gstat*.

```r
library("gstat")
# Variogramme empirique
vgmEmpirique <- variogram(m ~ 1, data = SpatialX)
# Ajustement d'un modèle gaussien
vgmX <- fit.variogram(vgmEmpirique, vgm("Gau"))
# Objet geostat qui décrit toutes les
# caractéristiques de la modélisation
geoX <- gstat(formula = m ~ 1, locations = SpatialX,
    model = vgmX)
# Calcul de la valeur de m sur les centroides des
# polygones
geoXprd <- predict(geoX, newdata = France)
```

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## [using ordinary kriging]

## Warning in proj4string(newdata): CRS object has
## comment, which is lost in output

## Warning in showSRID(uprojargs, format = "PROJ",
## multiline = "NO", prefer_proj = prefer_proj):
## Discarded datum Unknown based on GRS80 ellipsoid
## in CRS definition
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## Warning in proj4string(obj): CRS object has
## comment, which is lost in output
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# Carte finale
spplot(geoXprd, "var1.pred")
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## Warning in SpatialPointsDataFrame(spp, data.frame(Lines.NR = L3, Lines.ID = L2, : If the
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