

# Package ‘lulcc’

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**Title** Land Use Change Modelling in R

**Version** 1.0.4

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**Description** Classes and methods for spatially explicit land use change modelling in R.

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**License** GPL (>= 2)

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'class-PredictiveModelList.R' 'class-ExpVarRasterList.R'  
'class-NeighbRasterStack.R' 'class-Model.R'  
'class-ThreeMapComparison.R' 'AgreementBudget.R'  
'ExpVarRasterList.R' 'FigureOfMerit.R' 'Model.R'  
'NeighbRasterStack.R' 'ObsLulcRasterStack.R'  
'class-PerformanceList.R' 'PerformanceList.R'  
'class-PredictionList.R' 'PredictionList.R'  
'ThreeMapComparison.R' 'allocate.R' 'allow.R' 'allowNeighb.R'  
'approxExtrapDemand.R' 'as.data.frame.R'  
'c.PredictiveModelList.R' 'index.R' 'coerce.R' 'compareAUC.R'  
'crossTabulate.R' 'data.R' 'getPredictiveModelInputData.R'  
'length.R' 'lulcc-package.R' 'models.R' 'names.R' 'partition.R'  
'performance.rocr.R' 'plot.AgreementBudget.R'  
'plot.FigureOfMerit.R' 'plot.Performance.R' 'plot.R'  
'predict.R' 'resample.R' 'show.R' 'subset.R' 'summary.R'  
'total.R'

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*lulcc-package*                      *lulcc: land use change modelling in R*

---

## Description

The *lulcc* package is an open and extensible framework for land use change modelling in R.

## Details

The aims of the package are as follows:

1. to improve the reproducibility of scientific results and encourage reuse of code within the land use change modelling community
2. to make it easy to directly compare and combine different model structures
3. to allow users to perform several aspects of the modelling process within the same environment

To achieve these aims the package utilises an object-oriented approach based on the S4 system, which provides a formal structure for the modelling framework. Generic methods implemented for the *lulcc* classes include `summary`, `show`, and `plot`.

Land use change models are represented by objects inheriting from the superclass `Model`. This class is designed to represent general information required by all models while specific models are represented by its subclasses. Currently the package includes two inductive land use change models: the first is an implementation of the Change in Land Use and its Effects at Small Regional extent (CLUE-S) model (Verburg et al., 2002) (class `CluesModel`), while the second is an ordered procedure based on the algorithm described by Fuchs et al. (2013) but modified to allow stochastic transitions (class `OrderedModel`).

The main input to inductive land use change models is a set of predictive models relating observed land use or land use change to spatially explicit explanatory variables. A predictive model is usually obtained for each category or transition. In *lulcc* these models are represented by the class `PredictiveModelList`. Currently *lulcc* supports binary logistic regression, provided by base R (`glm`), recursive partitioning and regression trees, provided by package `rpart` and random forest, provided by package `randomForest`. To a large extent the success of the allocation routine depends on the strength of the predictive models: this is one reason why an R package for land use change modelling is attractive.

To validate model output *lulcc* includes a method developed by Pontius et al. (2011) that simultaneously compares a reference map for time 1, a reference map for time 2 and a simulated map for time 2 at multiple resolutions. In *lulcc* the results of the comparison are represented by the class `ThreeMapComparison`. From objects of this class it is straightforward to extract information about different sources of agreement and disagreement, represented by the class `AgreementBudget`,

which can then be plotted. The results of the comparison are conveniently summarised by the figure of merit, represented by the `classFigureOfMerit`.

In addition to the core functionality described above, `lulcc` includes several utility functions to assist with the model building process. Two example datasets are also included.

### Author(s)

Simon Moulds

### References

Fuchs, R., Herold, M., Verburg, P.H., and Clevers, J.G.P.W. (2013). A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe, *Biogeosciences*, 10:1543-1559.

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., Mastura, S.S. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental management*, 30(3):391-405.

### Examples

```
## Not run:

## Plum Island Ecosystems

## load data
data(pie)

## observed maps
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("Forest","Built","Other"),
                          t=c(0,6,14))

obs

plot(obs)

crossTabulate(obs, times=c(0,14))

## explanatory variables
ef <- ExpVarRasterList(x=pie, pattern="ef")
ef

part <- partition(x=obs[[1]], size=0.1, spatial=TRUE)
train.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part[["train"]])

forms <- list(Built ~ ef_001+ef_002+ef_003,
```

```

Forest ~ ef_001+ef_002,
Other ~ ef_001+ef_002)

glm.models <- glmModels(formula=forms, family=binomial, data=train.data, obs=obs)
rpart.models <- rpartModels(formula=forms, data=train.data, obs=obs)
rf.models <- randomForestModels(formula=forms, data=train.data, obs=obs)

## test ability of models to predict allocation of forest, built and other
## land uses in testing partition
test.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part[["test"]])

glm.pred <- PredictionList(models=glm.models, newdata=test.data)
glm.perf <- PerformanceList(pred=glm.pred, measure="rch")

rpart.pred <- PredictionList(models=rpart.models, newdata=test.data)
rpart.perf <- PerformanceList(pred=rpart.pred, measure="rch")

rf.pred <- PredictionList(models=rf.models, newdata=test.data)
rf.perf <- PerformanceList(pred=rf.pred, measure="rch")

plot(list(glm=glm.perf, rpart=rpart.perf, rf=rf.perf))

## test ability of models to predict location of urban gain 1985 to 1991
part <- rasterToPoints(obs[[1]], fun=function(x) x != 2, spatial=TRUE)
test.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part, t=6)

glm.pred <- PredictionList(models=glm.models[[2]], newdata=test.data)
glm.perf <- PerformanceList(pred=glm.pred, measure="rch")

plot(list(glm=glm.perf))

## obtain demand scenario
dmd <- approxExtrapDemand(obs=obs, tout=0:14)
matplot(dmd, type="l", ylab="Demand (no. of cells)", xlab="Time point",
        lty=1, col=c("Green", "Red", "Blue"))
legend("topleft", legend=obs@labels, col=c("Green", "Red", "Blue"), lty=1)

## get neighbourhood values
w <- matrix(data=1, nrow=3, ncol=3)
nb <- NeighRasterStack(x=obs[[1]], weights=w, categories=2)

## create CLUE-S model object
clues.rules <- matrix(data=1, nrow=3, ncol=3, byrow=TRUE)

clues.parms <- list(jitter.f=0.0002,
                  scale.f=0.000001,
                  max.iter=1000,
                  max.diff=50,
                  ave.diff=50)

clues.model <- CluesModel(obs=obs,
                        ef=ef,
                        models=glm.models,

```

```

        time=0:14,
        demand=dmd,
        elas=c(0.2,0.2,0.2),
        rules=clues.rules,
        params=clues.parms)

## Create Ordered model
ordered.model <- OrderedModel(obs=obs,
                              ef=ef,
                              models=glm.models,
                              time=0:14,
                              demand=dmd,
                              order=c(2,1,3))

## perform allocation
clues.model <- allocate(clues.model)
ordered.model <- allocate(ordered.model, stochastic=TRUE)

## pattern validation

## CLUE-S
clues.tabs <- ThreeMapComparison(x=clues.model,
                                factors=2^(1:8),
                                timestep=14)

plot(clues.tabs)
plot(clues.tabs, category=1, factors=2^(1:8)[c(1,3,5,7)])

## Ordered
ordered.tabs <- ThreeMapComparison(x=ordered.model,
                                  factors=2^(1:8),
                                  timestep=14)

plot(ordered.tabs)
plot(ordered.tabs, category=1, factors=2^(1:8)[c(1,3,5,7)])

## calculate agreement budget and plot

## CLUE-S
clues.agr <- AgreementBudget(x=clues.tabs)
plot(clues.agr, from=1, to=2)

## Ordered
ordered.agr <- AgreementBudget(x=ordered.tabs)
plot(ordered.agr, from=1, to=2)

## calculate Figure of Merit and plot

## CLUE-S
clues.fom <- FigureOfMerit(x=clues.tabs)
p1 <- plot(clues.fom, from=1, to=2)

## Ordered
ordered.fom <- FigureOfMerit(x=ordered.tabs)
p2 <- plot(ordered.fom, from=1, to=2)

```

```
## End(Not run)
```

---

AgreementBudget      *Create an AgreementBudget object*

---

### Description

This function quantifies sources of agreement and disagreement between a reference map for time 1, a reference map for time 2 and a simulated map for time 2 to provide meaningful information about the performance of land use change simulations.

### Usage

```
AgreementBudget(x, ...)  
  
## S4 method for signature 'ThreeMapComparison'  
AgreementBudget(x, ...)  
  
## S4 method for signature 'RasterLayer'  
AgreementBudget(x, ...)
```

### Arguments

x                    a ThreeMapComparison object or RasterLayer  
...                    additional arguments to ThreeMapComparison. Only required if x is not a ThreeMapComparison object

### Details

The types of agreement and disagreement considered are those described in Pontius et al. (2011):

1. Persistence simulated correctly (agreement)
2. Persistence simulated as change (disagreement)
3. Change simulated incorrectly (disagreement)
4. Change simulated correctly (agreement)
5. Change simulated as persistence (disagreement)

### Value

An AgreementBudget object.

## References

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

## See Also

[AgreementBudget-class](#), [plot.AgreementBudget](#), [ThreeMapComparison](#), [FigureOfMerit](#)

## Examples

```
## see lulcc-package examples
```

---

AgreementBudget-class *Class AgreementBudget*

---

## Description

An S4 class for information about sources of agreement and disagreement between three categorical raster maps.

## Slots

`tables` list of data.frames that depict the three dimensional table described by Pontius et al. (2011) at different resolutions

`factors` numeric vector of aggregation factors

`maps` list of RasterStack objects containing land use maps at different resolutions

`categories` numeric vector of land use categories

`labels` character vector corresponding to categories

`overall` data.frame containing the overall agreement budget

`category` list of data.frames showing the agreement budget for each category

`transition` list of data.frames showing the agreement budget for all possible transitions

---

allocate	<i>Allocate land use change spatially</i>
----------	---

---

### Description

Perform spatially explicit allocation of land use change using different models. Currently the function provides an implementation of the Change in Land Use and its Effects at Small regional extent (CLUE-S) model (Verburg et al., 2002) and an ordered procedure based on the algorithm described by Fuchs et al., (2013), modified to allow stochastic transitions.

### Usage

```
allocate(model, ...)  
  
## S4 method for signature 'CluesModel'  
allocate(model, ...)  
  
## S4 method for signature 'OrderedModel'  
allocate(model, stochastic = TRUE, ...)
```

### Arguments

model	an object inheriting from class <code>Model</code>
...	additional arguments for specific methods
stochastic	logical indicating whether the model should be run stochastically. Only used if model is an <code>OrderedModel</code> object

### Value

An updated `Model` object.

### References

Fuchs, R., Herold, M., Verburg, P.H., and Clevers, J.G.P.W. (2013). A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe, *Biogeosciences*, 10:1543-1559.

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., Mastura, S.S. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental management*, 30(3):391-405.

### See Also

[CluesModel](#), [OrderedModel](#)

### Examples

```
## see lulcc-package examples
```

---

allow *Implement decision rules for land use change*

---

### Description

Identify legitimate transitions based on land use history and specific transition rules.

### Usage

```
allow(x, categories, cd, rules, hist = NULL, ...)
```

### Arguments

x	numeric vector containing the land use pattern for the current timestep
categories	numeric vector containing land use categories in the study region
cd	numeric vector indicating the direction of change for each land use category. A value of 1 means demand is increasing (i.e. the number of cells belonging to the category must increase), -1 means decreasing demand and 0 means demand is static
rules	matrix. See details
hist	numeric vector containing land use history (values represent the number of timesteps the cell has contained the current land use category). Only required for rules 2 and 3
...	additional arguments (none)

### Details

Decision rules are based on those described by Verburg et al. (2002). The rules input argument is a square matrix with dimensions equal to the number of land use categories in the study region where rows represent the current land use and columns represent future transitions. The value of each element should represent a rule from the following list:

1. rule == 0 | rule == 1: this rule concerns specific land use transitions that are allowed (1) or not (0)
2. rule > 100 & rule < 1000: this rule imposes a time limit (rule - 100) on land use transitions, after which land use change is not allowed. Time is taken from hist
3. rule > 1000: this rule imposes a minimum period of time (rule-1000) before land use is allowed to change

allow should be called from [allocate](#) methods. The output is a matrix with the same dimensions as the matrix used internally by allocation functions to store land use suitability. Thus, by multiplying the two matrices together, disallowed transitions are removed from the allocation procedure.

### Value

A matrix.

## References

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., Mastura, S.S. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental management*, 30(3):391-405.

## See Also

[allowNeighb](#)

## Examples

```
## Plum Island Ecosystems

## load observed land use data
obs <- ObsLulcRasterStack(x=pie,
                        pattern="lu",
                        categories=c(1,2,3),
                        labels=c("forest","built","other"),
                        t=c(0,6,14))

## get land use values
x <- getValues(obs[[1]])
x <- x[!is.na(x)]

## create vector of arbitrary land use history values
hist <- sample(1:10, length(x), replace=TRUE)

## calculate demand and get change direction for first timestep
dmd <- approxExtrapDemand(obs=obs, tout=0:14)
cd <- dmd[2,] - dmd[1,]

## create rules matrix, only allowing forest to change if the cell has
## belonged to forest for more than 8 years
rules <- matrix(data=c(1,1008,1008,
                      1,1,1,
                      1,1,1), nrow=3, ncol=3, byrow=TRUE)

allow <- allow(x=x,
              hist=hist,
              categories=obs@categories,
              cd=cd,
              rules=rules)

## create raster showing cells that are allowed to change from forest to built
r <- obs[[1]]
r[!is.na(r)] <- allow[,2]
r[obs[[1]] != 1] <- NA
plot(r)

## NB output is only useful when used within allocation routine
```

---

allowNeighb

*Implement neighbourhood decision rules*


---

### Description

Identify legitimate transitions for each cell according to neighbourhood decision rules.

### Usage

```
allowNeighb(neighb, x, categories, rules, ...)
```

### Arguments

neighb	a NeighbRasterStack object
x	a categorical RasterLayer to which neighbourhood rules should be applied. If neighb is supplied it is updated with this map
categories	numeric vector containing land use categories. If allowNeighb is called from an allocation model this argument should contain all categories in the simulation, regardless of whether they're associated with a neighbourhood decision rule
rules	a numeric vector with neighbourhood decision rules. Each rule is a value between 0 and 1 representing the threshold neighbourhood value above which change is allowed. Rules should correspond with x@categories
...	additional arguments (none)

### Value

A matrix.

### See Also

[allow](#), [NeighbRasterStack](#)

### Examples

```
## Plum Island Ecosystems

## load observed land use data
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("forest","built","other"),
                          t=c(0,6,14))

## create a NeighbRasterStack object for forest only
w <- matrix(data=1, nrow=3, ncol=3)
nb <- NeighbRasterStack(x=obs[[1]], weights=w, categories=1)
```

```

## only allow change to forest within neighbourhood of current forest cells
## note that rules can be any value between zero (less restrictive) and one
## (more restrictive)
nb.allow <- allowNeighb(neighb=nb,
                        x=obs[[1]],
                        categories=obs@categories,
                        rules=0.5)

## create raster showing cells allowed to change to forest
r <- obs[[1]]
r[!is.na(r)] <- nb.allow[,1]
plot(r)

## NB output is only useful when used within an allocation routine

```

---

approxExtrapDemand      *Extrapolate land use area in time*

---

### Description

Extrapolate land use area from two or more observed land use maps to provide a valid (although not necessarily realistic) demand scenario.

### Usage

```
approxExtrapDemand(obs, tout, ...)
```

### Arguments

obs	an ObsLulcRasterStack object containing at least two maps
tout	numeric vector specifying the timesteps where interpolation is to take place. Comparable to the xout argument of <code>Hmisc::approxExtrap</code>
...	additional arguments to <code>Hmisc::approxExtrap</code>

### Details

Many allocation routines, including the two included with `lulcc`, require non-spatial estimates of land use demand for every timestep in the study period. Some routines are coupled to complex economic models that predict future or past land use demand based on economic considerations; however, linear extrapolation of trends remains a useful technique.

### Value

A matrix.

### See Also

`Hmisc::approxExtrap`

**Examples**

```
## Plum Island Ecosystems

## load observed land use maps
obs <- ObsLulcRasterStack(x=pie,
  pattern="lu",
  categories=c(1,2,3),
  labels=c("forest","built","other"),
  t=c(0,6,14))

## obtain demand scenario by interpolating between observed maps
dmd <- approxExtrapDemand(obs=obs, tout=c(0:14))

## plot
matplot(dmd, type="l", ylab="Demand (no. of cells)", xlab="Time point",
  lty=1, col=c("Green","Red","Blue"))
legend("topleft", legend=obs@labels, col=c("Green","Red","Blue"), lty=1)

## linear extrapolation is also possible
dmd <- approxExtrapDemand(obs=obs, tout=c(0:50))

## plot
matplot(dmd, type="l", ylab="Demand (no. of cells)", xlab="Time point",
  lty=1, col=c("Green","Red","Blue"))
legend("topleft", legend=obs@labels, col=c("Green","Red","Blue"), lty=1)
```

---

```
as.data.frame.ExpVarRasterList
  Coerce objects to data.frame
```

---

**Description**

This function extracts data from all raster objects in [ObsLulcRasterStack](#) or [ExpVarRasterList](#) objects for a specified timestep.

**Usage**

```
## S3 method for class 'ExpVarRasterList'
as.data.frame(x, row.names = NULL,
  optional = FALSE, cells, t = 0, ...)

## S3 method for class 'ObsLulcRasterStack'
as.data.frame(x, row.names = NULL,
  optional = FALSE, cells, t = 0, ...)

## S4 method for signature 'ExpVarRasterList'
as.data.frame(x, row.names = NULL,
```

```

optional = FALSE, cells, t = 0, ...)

## S4 method for signature 'ObsLulcRasterStack'
as.data.frame(x, row.names = NULL,
  optional = FALSE, cells, t = 0, ...)

```

### Arguments

x	an ExpVarRasterList or ObsLulcRasterStack object
row.names	NULL or a character vector giving the row.names for the data.frame. Missing values are not allowed
optional	logical. If TRUE, setting row names and converting column names (to syntactic names: see make.names) is optional
cells	index of cells to be extracted, which may be a SpatialPoints* object or a numeric vector representing cell numbers (see raster::extract)
t	numeric indicating the time under consideration
...	additional arguments (none)

### Details

If x is an ObsLulcRasterStack object the raster corresponding to t is first transformed to a Raster-Brick with a boolean layer for each class with raster::layerize.

### Value

A data.frame.

### See Also

[as.data.frame](#), [ObsLulcRasterStack](#), [ExpVarRasterList](#), [partition](#)

### Examples

```

## Not run:

## Plum Island Ecosystems

## observed maps
obs <- ObsLulcRasterStack(x=pie,
  pattern="lu",
  categories=c(1,2,3),
  labels=c("Forest", "Built", "Other"),
  t=c(0,6,14))

## explanatory variables
ef <- ExpVarRasterList(x=pie, pattern="ef")

## separate data into training and testing partitions
part <- partition(x=obs[[1]], size=0.1, spatial=TRUE)

```

```
df1 <- as.data.frame(x=obs, cells=part[["all"]], t=0)
df2 <- as.data.frame(x=ef, cells=part[["all"]], t=0)

## End(Not run)
```

---

### c.PredictiveModelList *Merge PredictiveModelList objects*

---

#### Description

Combine different PredictiveModelList objects into one

#### Usage

```
## S3 method for class 'PredictiveModelList'
c(..., recursive = FALSE)
```

#### Arguments

```
...          two or more PredictiveModelList objects
recursive    for consistency with generic method (ignored)
```

#### Value

a PredictiveModelList object

#### Examples

```
## Not run:

## Plum Island Ecosystems

## load data
data(pie)

## observed maps
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("Forest","Built","Other"),
                          t=c(0,6,14))

## explanatory variables
ef <- ExpVarRasterList(x=pie, pattern="ef")

part <- partition(x=obs[[1]], size=0.1, spatial=TRUE)
train.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part[["train"]], t=0)
```

```

forms <- list(Built ~ ef_001+ef_002+ef_003,
             Forest ~ 1,
             Other ~ ef_001+ef_002)

glm.models <- glmModels(formula=forms, family=binomial, data=train.data, obs=obs)
glm.models

## separate glm.models into two PredictiveModelList objects
mod1 <- glm.models[[1]]
mod2 <- glm.models[[2:3]]

## put them back together again
glm.models <- c(mod1, mod2)
glm.models

## End(Not run)

```

---

CategoryLabel-class     *Virtual class CategoryLabel*

---

### Description

A virtual S4 class to represent information about categorical Raster\* objects.

### Slots

categories numeric vector of land use categories  
labels character vector corresponding to categories

---

CluesModel                     *Create a CluesModel object*

---

### Description

Methods to create a CluesModel object to supply to [allocate](#).

### Usage

```
CluesModel(obs, ef, models, ...)
```

```

## S4 method for signature
## 'ObsLulcRasterStack,ExpVarRasterList,PredictiveModelList'
CluesModel(obs,
           ef, models, time, demand, hist, mask, neighb = NULL, elas, rules = NULL,
           nb.rules = NULL, params, output = NULL, ...)

```

**Arguments**

<code>obs</code>	an <code>ObsLulcRasterStack</code>
<code>ef</code>	an <code>ExpVarRasterList</code> object
<code>models</code>	a <code>PredictiveModelList</code> object
<code>...</code>	additional arguments (none)
<code>time</code>	numeric vector containing timesteps over which simulation will occur
<code>demand</code>	matrix with demand for each land use category in terms of number of cells to be allocated. The first row should be the number of cells allocated to the initial observed land use map (i.e. the land use map for time 0)
<code>hist</code>	<code>RasterLayer</code> containing land use history (values represent the number of years the cell has contained the current land use category)
<code>mask</code>	<code>RasterLayer</code> containing binary values where 0 indicates cells that are not allowed to change
<code>neighb</code>	an object of class <code>NeighbRasterStack</code>
<code>elas</code>	numeric indicating the elasticity of each land use category to change. Elasticity varies between 0 and 1, with 0 indicating a low resistance to change and 1 indicating a high resistance to change
<code>rules</code>	matrix with land use change decision rules
<code>nb.rules</code>	numeric with neighbourhood decision rules
<code>params</code>	list with model parameters
<code>output</code>	either a <code>RasterStack</code> containing output maps or <code>NULL</code>

**Details**

The `params` argument is a list of parameter values which should contain the following components:

`jitter.f` Parameter controlling the amount of perturbation applied to the probability surface prior to running the CLUE-S iterative algorithm. Higher values result in more perturbation. Default is 0.0001

`scale.f` Scale factor which controls the amount by which suitability is increased if demand is not met. Default is 0.0005

`max.iter` The maximum number of iterations in the simulation

`max.diff` The maximum allowed difference between allocated and demanded area of any land use type. Default is 5

`ave.diff` The average allowed difference between allocated and demanded area. Default is 5

Note that, in order to achieve convergence, it is likely that some adjustment of these parameters will be required.

**Value**

A `CluesModel` object.

**References**

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., Mastura, S.S. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental management*, 30(3):391-405.

**See Also**

[CluesModel-class, allocate](#)

**Examples**

```
## see lulcc-package examples
```

---

CluesModel-class	<i>Class CluesModel</i>
------------------	-------------------------

---

**Description**

An S4 class to represent inputs to the CLUE-S land use change model.

**Slots**

**obs** an ObsLulcRasterStack object  
**ef** an ExpVarRasterList object  
**models** a PredictiveModelList object  
**time** numeric vector of timesteps over which simulation will occur  
**demand** matrix containing demand scenario  
**hist** RasterLayer showing land use history or NULL  
**mask** RasterLayer showing masked areas or NULL  
**neighb** NeighbRasterStack object or NULL  
**categories** numeric vector of land use categories  
**labels** character vector corresponding to categories  
**rules** matrix with land use change decision rules  
**nb.rules** numeric with neighbourhood decision rules  
**elas** numeric indicating elasticity to change (only required for  
**params** list with model parameters  
**output** RasterStack containing simulated land use maps or NULL

---

`compareAUC`*Calculate the area under the ROC curve (AUC)*

---

**Description**

Estimate the AUC for each ROCR: `:prediction` object in a `PredictionList` object.

**Usage**

```
compareAUC(pred, ...)  
  
## S4 method for signature 'PredictionList'  
compareAUC(pred, digits = 4, ...)  
  
## S4 method for signature 'list'  
compareAUC(pred, digits = 4, ...)
```

**Arguments**

<code>pred</code>	a <code>PredictionList</code> object or a list of these
<code>...</code>	additional arguments (none)
<code>digits</code>	numeric indicating the number of digits to be displayed after the decimal point for AUC values

**Details**

The user can compare the performance of different statistical models by providing a list of `PredictionList` objects. Note that `compareAUC` should be used in conjunction with other comparison methods because the AUC does not contain as much information as, for instance, the ROC curve itself (Pontius and Parmentier, 2014).

**Value**

A `data.frame`.

**References**

Sing, T., Sander, O., Beerenwinkel, N., Lengauer, T. (2005). ROCR: visualizing classifier performance in R. *Bioinformatics* 21(20):3940-3941.

Pontius Jr, R. G., & Parmentier, B. (2014). Recommendations for using the relative operating characteristic (ROC). *Landscape ecology*, 29(3), 367-382.

**See Also**

`PredictionList`, `ROCR::performance`

**Examples**

```
## see PredictiveModelList examples
```

---

crossTabulate	<i>Cross tabulate land use transitions</i>
---------------	--

---

**Description**

Cross tabulate land use transitions using raster::[crosstab](#). This step should form the basis of further research into the processes driving the most important transitions in the study region (Pontius et al., 2004).

**Usage**

```
crossTabulate(x, y, ...)

## S4 method for signature 'RasterLayer,RasterLayer'
crossTabulate(x, y, categories,
  labels = as.character(categories), ...)

## S4 method for signature 'ObsLulcRasterStack,ANY'
crossTabulate(x, y, times, ...)
```

**Arguments**

x	RasterLayer representing land use map from an earlier timestep or an ObsLulcRasterStack object containing at least two land use maps for different points in time
y	RasterLayer representing land use map from a later timestep. Not used if x is an ObsLulcRasterStack object
...	additional arguments to raster:: <a href="#">crosstab</a>
categories	numeric vector containing land use categories to consider. Not used if x is an ObsLulcRasterStack object
labels	character vector (optional) with labels corresponding to categories. Not used if x is an ObsLulcRasterStack object
times	numeric vector representing the time points of two land use maps from ObsLulcRasterStack

**Value**

A data.frame.

**References**

Pontius Jr, R.G., Shusas, E., McEachern, M. (2004). Detecting important categorical land changes while accounting for persistence. *Agriculture, Ecosystems & Environment* 101(2):251-268.

**See Also**

[ObsLulcRasterStack](#), [raster::crosstab](#)

**Examples**

```
## Plum Island Ecosystems

## Load observed land use maps
obs <- ObsLulcRasterStack(x=pie,
  pattern="lu",
  categories=c(1,2,3),
  labels=c("forest","built","other"),
  t=c(0,6,14))

crossTabulate(x=obs, times=c(0,14))

## RasterLayer input
crossTabulate(x=obs[[1]],
  y=obs[[3]],
  categories=c(1,2,3),
  labels=c("forest","built","other"))
```

---

ExpVarRasterList	<i>Create an ExpVarRasterList object</i>
------------------	--

---

**Description**

Methods to load maps of explanatory variables, which may be created from file, an existing Raster\* object or a list of Raster\* objects.

**Usage**

```
ExpVarRasterList(x, ...)
```

## S4 method for signature 'missing'

```
ExpVarRasterList(x, pattern = NULL, ...)
```

## S4 method for signature 'character'

```
ExpVarRasterList(x, pattern = NULL, ...)
```

## S4 method for signature 'RasterStack'

```
ExpVarRasterList(x, pattern = NULL, ...)
```

## S4 method for signature 'list'

```
ExpVarRasterList(x, pattern = NULL, ...)
```

## Arguments

x	path (character) to directory containing observed land use maps, a Raster* object or a list of Raster* objects
...	additional arguments to raster::stack
pattern	regular expression (character). Only filenames (if x is a path) or Raster* objects (if x is a list) matching the regular expression will be returned. See raster::raster for more information about supported filetypes

## Details

Explanatory variables should follow a naming convention to identify them as static (one map provided for the study period) or dynamic (one map provided for each year of the study period). The name should consist of two (static) or three (dynamic) parts: firstly, the prefix should differentiate explanatory variables from other maps in the directory, list or RasterStack. This should be followed by a unique number to differentiate the explanatory variables (note that the order of variables in the ExpVarRasterList object is determined by this value) If the variable is dynamic this number should be followed by a second number representing the timestep to which the map applies. Dynamic variables should include a map for time 0 (corresponding to the initial observed map) and every subsequent timestep in the simulation. The different parts should be separated by a period or underscore.

Maps of different explanatory variables should have the same coordinate reference system but do not have to have the same extent and resolution as long as the minimum extent is that of the study region defined by an ObsLulcRasterStack object. However, maps for different timesteps of the same dynamic variable should have the same extent and resolution because these are stored as RasterStack objects.

## Value

An ExpVarRasterList object.

## See Also

raster::stack

## Examples

```
## Plum Island Ecosystems
ef <- ExpVarRasterList(x=pie, pattern="ef")

## Sibuyan
ef <- ExpVarRasterList(x=sibuyan$maps, pattern="ef")
```

---

ExpVarRasterList-class

*Class ExpVarRasterList*

---

### Description

An S4 class for explanatory variables.

### Slots

maps list of RasterStack objects. The length of the list corresponds to the number of explanatory variables and the number of layers in each RasterStack represents time

names character vector with the name of each variable in maps

dynamic logical indicating whether dynamic variables are present

---

Extract by index

*Extract by index*

---

### Description

object[[i]] can be used to extract individual objects from container classes such as ExpVarRasterList, PredictiveModelList, PredictionList and PerformanceList.

### Usage

```
## S4 method for signature 'ExpVarRasterList,ANY,ANY'
x[[i, j, ...]]
```

```
## S4 method for signature 'CategoryLabel,ANY,ANY'
x[[i, j, ...]]
```

### Arguments

x	an object of class ExpVarRasterList or any object inheriting from the virtual class CategoryLabel
i	layer number (if 'x' inherits from a RasterStack) or list index (if 'x' stores data as a list)
j	numeric (not used)
...	additional arguments (none)

**Examples**

```
## Plum Island Ecosystems

## Load observed land use maps
obs <- ObsLulcRasterStack(x=pie,
  pattern="lu",
  categories=c(1,2,3),
  labels=c("forest","built","other"),
  t=c(0,6,14))

summary(obs[[1]])
summary(obs[[1:2]])
```

---

FigureOfMerit	<i>Create a FigureOfMerit object</i>
---------------	--------------------------------------

---

**Description**

Calculate the figure of merit at different levels and at different resolutions for a reference map at time 1, a reference map at time 2 and a simulated map at time 2.

**Usage**

```
FigureOfMerit(x, ...)

## S4 method for signature 'RasterLayer'
FigureOfMerit(x, ...)

## S4 method for signature 'ThreeMapComparison'
FigureOfMerit(x, ...)
```

**Arguments**

**x** a ThreeMapComparison object or RasterLayer  
**...** additional arguments to ThreeMapComparison. Only required if x is not a ThreeMapComparison object

**Details**

In land use change modelling the figure of merit is the intersection of observed change and simulated change divided by the union of these, with a range of 0 (perfect disagreement) to 1 (perfect agreement). It is useful to calculate the figure of merit at three levels: (1) considering all possible transitions from all land use categories, (2) considering all transitions from specific land use categories and (3) considering a specific transition from one land use category to another.

**Value**

A FigureOfMerit object.

**References**

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

**See Also**

[plot.FigureOfMerit, ThreeMapComparison](#)

**Examples**

```
## see lulcc-package examples
```

---

FigureOfMerit-class    *Class FigureOfMerit*

---

**Description**

An S4 class for different figure of merit scores.

**Slots**

`tables` list of data.frames that depict the three dimensional table described by Pontius et al. (2011) at different resolutions

`factors` numeric vector of aggregation factors

`maps` list of RasterStack objects containing land use maps at different resolutions

`categories` numeric vector of land use categories

`labels` character vector corresponding to categories

`overall` list containing the overall figure of merit score for each aggregation factor

`category` list of numeric vectors containing category specific scores

`transition` list of matrices containing transition specific scores

---

```
getPredictiveModelInputData
```

*Extract data to fit predictive models*

---

### Description

Extract a data.frame containing variables required for fitting predictive models.

### Usage

```
getPredictiveModelInputData(obs, ef, cells, ...)
```

### Arguments

obs	an ObsLulcRasterStack object
ef	an ExpVarRasterList object
cells	index of cells to be extracted, which may be a SpatialPoints* object or a numeric vector representing cell numbers (see raster::extract)
...	additional arguments to <a href="#">as.data.frame</a>

### Value

A data.frame.

### See Also

[as.data.frame](#), [ObsLulcRasterStack](#), [ExpVarRasterList](#), [partition](#)

### Examples

```
## TODO
```

---

Model fitting

*Fit predictive models*

---

### Description

These functions fit parametric and non-parametric models to data.

### Usage

```
glmModels(formula, family = binomial, model = FALSE, ..., obs,
           categories = NA, labels = NA)
```

```
randomForestModels(formula, ..., obs, categories = NA, labels = NA)
```

```
rpartModels(formula, ..., obs, categories = NA, labels = NA)
```

**Arguments**

formula	list containing formula objects
family	see <a href="#">glm</a> . Default is 'binomial'. Only used by <code>glmModels</code>
model	see <a href="#">glm</a> . Default is FALSE. Only used by <code>glmModels</code>
...	additional arguments to specific functions
obs	an <code>ObsLulcRasterStack</code> object
categories	numeric vector of land use categories in observed maps. Only required if 'obs' is missing
labels	character vector (optional) with labels corresponding to categories. Only required if 'obs' is missing

**Value**

A `PredictiveModelList` object.

**See Also**

[glm](#), `rpart::rpart`, `randomForest::randomForest`

**Examples**

```
## see lulcc-package examples
```

---

Model-class

*Virtual class Model*

---

**Description**

A virtual S4 class to represent land use change models.

**Slots**

output `RasterStack` containing simulated land use maps or `NULL`

---

NeighbRasterStack      *Create a NeighbRasterStack object*

---

### Description

Methods to calculate neighbourhood values for cells in raster maps using `raster::focal`. By default the fraction of non-NA cells within the moving window (i.e. the size of the weights matrix) devoted to each land use category is calculated. This behaviour can be changed by altering the weights matrix or providing an alternative function. The resulting object can be used as the basis of neighbourhood decision rules.

### Usage

```
NeighbRasterStack(x, weights, neighb, ...)

## S4 method for signature 'RasterLayer,list,ANY'
NeighbRasterStack(x, weights, neighb,
  categories, fun = mean, ...)

## S4 method for signature 'RasterLayer,matrix,ANY'
NeighbRasterStack(x, weights, neighb,
  categories, fun = mean, ...)

## S4 method for signature 'RasterLayer,ANY,NeighbRasterStack'
NeighbRasterStack(x, weights,
  neighb)
```

### Arguments

<code>x</code>	RasterLayer containing categorical data
<code>weights</code>	list containing a matrix of weights (the <code>w</code> argument in <code>raster::focal</code> ) for each land use category. The order of list or vector elements should correspond to the order of land use categories in <code>categories</code>
<code>neighb</code>	NeighbRasterStack object. Only used if <code>categories</code> and <code>weights</code> are not provided. This option can be useful when existing NeighbRasterStack objects need to be updated because a new land use map is available, such as during the allocation procedure.
<code>...</code>	additional arguments to <code>raster::focal</code>
<code>categories</code>	numeric vector containing land use categories for which neighbourhood values should be calculated
<code>fun</code>	function. Input argument to <code>focal</code> . Default is <code>mean</code>

### Value

A NeighbRasterStack object.

**See Also**

[NeighbRasterStack-class](#), [allowNeighb](#), [raster::focal](#)

**Examples**

```
## Plum Island Ecosystems

## observed data
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("forest", "built", "other"),
                          t=c(0,6,14))

## create a NeighbRasterStack object for 1985 land use map
w1 <- matrix(data=1, nrow=3, ncol=3, byrow=TRUE)
w2 <- w1
w3 <- w1

nb1 <- NeighbRasterStack(x=obs[[1]],
                        categories=c(1,2,3),
                        weights=list(w1,w2,w3))

## update nb2 for 1991
nb2 <- NeighbRasterStack(x=obs[[2]],
                        neighb=nb1)

## plot neighbourhood map for forest
plot(nb2[[1]])
```

---

NeighbRasterStack-class

*Class NeighbRasterStack*

---

**Description**

An S4 class for neighbourhood maps.

**Slots**

filename see [raster::Raster-class](#)

layers see [raster::Raster-class](#)

title see [raster::Raster-class](#)

extent see [raster::Raster-class](#)

rotated see [raster::Raster-class](#)

rotation see [raster::Raster-class](#)

ncols see raster::[Raster-class](#)  
 nrows see raster::[Raster-class](#)  
 crs see raster::[Raster-class](#)  
 history see raster::[Raster-class](#)  
 z see raster::[Raster-class](#)  
 calls list containing each call to raster::[focal](#)  
 categories numeric vector of land use categories for which neighbourhood maps exist

---

ObsLulcRasterStack      *Create an ObsLulcRasterStack object*

---

### Description

Methods to create an ObsLulcRasterStack object, which may be created from file, an existing Raster\* object or a list of Raster\* objects.

### Usage

```
ObsLulcRasterStack(x, pattern, ...)

## S4 method for signature 'missing,character'
ObsLulcRasterStack(x, pattern, ...)

## S4 method for signature 'character,character'
ObsLulcRasterStack(x, pattern, ...)

## S4 method for signature 'list,character'
ObsLulcRasterStack(x, pattern, ...)

## S4 method for signature 'RasterLayer,ANY'
ObsLulcRasterStack(x, pattern, ...)

## S4 method for signature 'RasterStack,ANY'
ObsLulcRasterStack(x, pattern, categories, labels,
  t)
```

### Arguments

x	path (character), Raster* object or list of Raster* objects. Default behaviour is to search for files in the working directory
pattern	regular expression (character). Only filenames (if x is a path) or Raster* objects (if x is a list) matching the regular expression will be returned. See raster:: <a href="#">raster</a> for more information about supported filetypes
...	additional arguments to raster:: <a href="#">stack</a>

categories	numeric vector of land use categories in observed maps
labels	character vector (optional) with labels corresponding to categories
t	numeric vector containing the timestep of each observed map. The first timestep must be 0

### Details

Observed land use maps should have the same extent and resolution. The location of non-NA cells in ObsLulcRasterStack objects defines the region for subsequent analysis.

### Value

An ObsLulcRasterStack object.

### See Also

[ObsLulcRasterStack-class](#), [raster::stack](#)

### Examples

```
## Plum Island Ecosystems
obs <- ObsLulcRasterStack(x=pie,
  pattern="lu",
  categories=c(1,2,3),
  labels=c("forest","built","other"),
  t=c(0,6,14))

## Sibuyan Island
obs <- ObsLulcRasterStack(x=sibuyan$maps,
  pattern="lu",
  categories=c(1,2,3,4,5),
  labels=c("forest","coconut","grass","rice","other"),
  t=c(0,14))
```

---

ObsLulcRasterStack-class

*Class ObsLulcRasterStack*

---

### Description

An S4 class for observed land use maps.

**Slots**

filename see raster::[Raster-class](#)  
 layers see raster::[Raster-class](#)  
 title see raster::[Raster-class](#)  
 extent see raster::[Raster-class](#)  
 rotated see raster::[Raster-class](#)  
 rotation see raster::[Raster-class](#)  
 ncols see raster::[Raster-class](#)  
 nrows see raster::[Raster-class](#)  
 crs see raster::[Raster-class](#)  
 history see raster::[Raster-class](#)  
 z see raster::[Raster-class](#)  
 t numeric vector with timesteps corresponding to each observed map  
 categories numeric vector of land use categories  
 labels character vector corresponding to categories

---

 OrderedModel

*Create an OrderedModel object*


---

**Description**

Methods to create a OrderedModel object to supply to [allocate](#).

**Usage**

```
OrderedModel(obs, ef, models, ...)
```

```

## S4 method for signature
## 'ObsLulcRasterStack,ExpVarRasterList,PredictiveModelList'
OrderedModel(obs,
  ef, models, time, demand, hist, mask, neighb = NULL, rules = NULL,
  nb.rules = NULL, order, params, output = NULL, ...)

```

**Arguments**

obs	an ObsLulcRasterStack object
ef	an ExpVarRasterList object
models	a PredictiveModelList object
...	additional arguments (none)
time	numeric vector containing timesteps over which simulation will occur

demand	matrix with demand for each land use category in terms of number of cells to be allocated. The first row should be the number of cells allocated to the initial observed land use map (i.e. the land use map for time 0)
hist	RasterLayer containing land use history (values represent the number of years the cell has contained the current land use category)
mask	RasterLayer containing binary values where 0 indicates cells that are not allowed to change
neighb	an object of class NeighbRasterStack
rules	matrix with land use change decision rules
nb.rules	numeric with neighbourhood decision rules
order	numeric vector of land use categories in the order that change should be allocated. See Details
params	list with model parameters
output	either a RasterStack containing output maps or NULL

### Details

The `params` argument is a list of parameter values which should contain the following components:

`max.diff` The maximum allowed difference between allocated and demanded area of any land use type. Default is 5

### Value

An `OrderedModel` object.

### References

Fuchs, R., Herold, M., Verburg, P.H., and Clevers, J.G.P.W. (2013). A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe, *Biogeosciences*, 10:1543-1559.

### See Also

[OrderedModel-class](#), [allocate](#)

### Examples

```
## see lulcc-package examples
```

---

OrderedModel-class	<i>Class OrderedModel</i>
--------------------	---------------------------

---

**Description**

An S4 class to represent inputs to the Ordered allocation procedure

**Slots**

obs an ObsLulcRasterStack object  
 ef an ExpVarRasterList object  
 models a PredictiveModelList object  
 time numeric vector of timesteps over which simulation will occur  
 demand matrix containing demand scenario  
 hist RasterLayer showing land use history or NULL  
 mask RasterLayer showing masked areas or NULL  
 neighb NeighbRasterStack object or NULL  
 categories numeric vector of land use categories  
 labels character vector corresponding to categories  
 rules matrix with land use change decision rules  
 nb.rules numeric with neighbourhood decision rules  
 order numeric vector of land use categories in the order that change should be allocated  
 params list with model parameters  
 output RasterStack containing simulated land use maps or NULL

---

partition	<i>Partition raster data</i>
-----------	------------------------------

---

**Description**

Divide a categorical raster map into training and testing partitions. A wrapper function for `caret::createDataPartition` (Kuhn, 2008) to divide a categorical raster map into training and testing partitions.

**Usage**

```
partition(x, size = 0.5, spatial = TRUE, ...)
```

**Arguments**

<code>x</code>	RasterLayer with categorical data
<code>size</code>	numeric value between zero and one indicating the proportion of non-NA cells that should be included in the training partition. Default is 0.5, which results in equally sized partitions
<code>spatial</code>	logical. If TRUE, the function returns a SpatialPoints object with the coordinates of cells in each partition. If FALSE, the cell numbers are returned
<code>...</code>	additional arguments (none)

**Value**

A list containing the following components:

`train` a SpatialPoints object or numeric vector indicating the cells in the training partition

`test` a SpatialPoints object or numeric vector indicating the cells in the testing partition

`all` a SpatialPoints object or numeric vector indicating all non-NA cells in the study region

**References**

Kuhn, M. (2008). Building predictive models in R using the caret package. *Journal of Statistical Software*, 28(5), 1-26.

**See Also**

`caret::createDataPartition`

**Examples**

```
## Not run:

## Plum Island Ecosystems

## Load observed land use maps
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("forest","built","other"),
                          t=c(0,6,14))

## create equally sized training and testing partitions
part <- partition(x=obs[[1]], size=0.1, spatial=FALSE)
names(part)

## End(Not run)
```

---

performance	<i>Create ROCR performance objects</i>
-------------	--

---

## Description

A wrapper function for `ROCR::performance` (Sing et al, 2005) to create performance objects from a list of prediction objects.

## Usage

```
performance(prediction.obj, ...)  
  
## S4 method for signature 'list'  
performance(prediction.obj, measure, x.measure = "cutoff",  
            ...)
```

## Arguments

<code>prediction.obj</code>	a list of <code>ROCR::prediction</code> objects
<code>...</code>	additional arguments to <code>ROCR::performance</code>
<code>measure</code>	performance measure to use for the evaluation. See <code>ROCR::performance</code>
<code>x.measure</code>	a second performance measure. See <code>ROCR::performance</code>

## Value

A list of performance objects.

## References

Sing, T., Sander, O., Beerenwinkel, N., Lengauer, T. (2005). ROCR: visualizing classifier performance in R. *Bioinformatics* 21(20):3940-3941.

## See Also

`ROCR::prediction`, `ROCR::performance`

---

PerformanceList	<i>Create a PerformanceList object</i>
-----------------	--

---

### Description

This function uses different measures to evaluate multiple `ROCR::prediction` objects stored in a `PredictionList` object.

### Usage

```
PerformanceList(pred, measure, x.measure = "cutoff", ...)
```

### Arguments

<code>pred</code>	an object of class <code>PredictionList</code>
<code>measure</code>	performance measure to use for the evaluation. See <code>ROCR::performance</code>
<code>x.measure</code>	a second performance measure. See <code>ROCR::performance</code>
<code>...</code>	additional arguments to <code>ROCR::performance</code>

### Value

A `PerformanceList` object.

### References

Sing, T., Sander, O., Beerenwinkel, N., Lengauer, T. (2005). ROCr: visualizing classifier performance in R. *Bioinformatics* 21(20):3940-3941.

### See Also

[performance](#), [PredictionList](#)

### Examples

```
## see lulcc-package examples
```

---

PerformanceList-class *Class PerformanceList*

---

### Description

An S4 class that extends ROCR: [:performance-class](#) to hold the results of multiple model evaluations.

### Slots

`performance` list of ROCR performance objects. Each object is calculated for the corresponding ROCR prediction object held in the PredictionList object supplied to the constructor function  
`auc` numeric vector containing the area under the curve for each performance object  
`categories` numeric vector of land use categories for which performance objects were created  
`labels` character vector with labels corresponding to `categories`

---

`pie` *Land use change dataset for Plum Island Ecosystem*

---

### Description

Dataset containing land use maps for 1985, 1991 and 1999 and several explanatory variables derived from Pontius and Parmentier (2014).

### Usage

```
pie
```

### Format

A list containing the following elements:

**lu\_pie\_1985** RasterLayer showing land use in 1985 (forest, built, other)

**lu\_pie\_1991** RasterLayer showing land use in 1991

**lu\_pie\_1999** RasterLayer showing land use in 1999

**ef\_001** RasterLayer showing elevation

**ef\_002** RasterLayer showing slope

**ef\_003** RasterLayer showing distance to built land in 1985

### References

Pontius Jr, R. G., & Parmentier, B. (2014). Recommendations for using the relative operating characteristic (ROC). *Landscape ecology*, 29(3), 367-382.

### Examples

```
data(pie)
```

---

plot

*Plot method for objects based on Raster\* data*

---

### Description

Plot lulcc objects based on Raster\* data

### Usage

```
## S3 method for class 'ObsLulcRasterStack'  
plot(x, y, ...)
```

```
## S3 method for class 'Model'  
plot(x, y, ...)
```

```
## S3 method for class 'ThreeMapComparison'  
plot(x, y, category, factors, ...)
```

```
## S4 method for signature 'ObsLulcRasterStack,ANY'  
plot(x, y, ...)
```

```
## S4 method for signature 'Model,ANY'  
plot(x, y, ...)
```

```
## S4 method for signature 'ThreeMapComparison,ANY'  
plot(x, y, category, factors, ...)
```

### Arguments

x	an object from lulcc containing Raster data
y	not used
...	additional arguments to rasterVis:: <a href="#">levelplot</a>
category	numeric
factors	numeric

### Value

A trellis object.

### See Also

rasterVis::[levelplot](#)

### Examples

```
## see lulcc-package examples
```

---

plot.AgreementBudget *Plot method for AgreementBudget objects*

---

### Description

Plot an [AgreementBudget](#) object.

### Usage

```
## S3 method for class 'AgreementBudget'  
plot(x, y, from, to,  
     col = RColorBrewer::brewer.pal(5, "Set2"), key, scales, xlab, ylab, ...)  
  
## S4 method for signature 'AgreementBudget,ANY'  
plot(x, y, from, to,  
     col = RColorBrewer::brewer.pal(5, "Set2"), key, scales, xlab, ylab, ...)
```

### Arguments

x	an <a href="#">AgreementBudget</a> object
y	not used
from	optional numeric value representing a land use category. If provided without to the figure of merit for all transitions from this category will be plotted
to	similar to from. If provided with a valid from argument the transition defined by these two arguments (i.e. from -> to) will be plotted
col	character specifying the plotting colour. Default is to use the 'Set2' palette from <a href="#">RColorBrewer</a>
key	list. See <a href="#">lattice::xyplot</a>
scales	list. See <a href="#">lattice::xyplot</a>
xlab	character or expression. See <a href="#">lattice::xyplot</a>
ylab	character or expression. See <a href="#">lattice::xyplot</a>
...	additional arguments to <a href="#">lattice::xyplot</a>

### Details

The plot layout is based on work presented in Pontius et al. (2011)

### Value

A trellis object.

### References

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

**See Also**

[AgreementBudget](#), [lattice::xyplot](#)

**Examples**

```
## see lulcc-package examples
```

---

```
plot.FigureOfMerit      Plot method for FigureOfMerit objects
```

---

**Description**

Plot the overall, category-specific or transition-specific figure of merit at different resolutions.

**Usage**

```
## S3 method for class 'FigureOfMerit'
plot(x, y, ..., from, to,
     col = RColorBrewer::brewer.pal(8, "Set2"), type = "b", key, scales, xlab,
     ylab)

## S4 method for signature 'FigureOfMerit,ANY'
plot(x, y, ..., from, to,
     col = RColorBrewer::brewer.pal(8, "Set2"), type = "b", key, scales, xlab,
     ylab)
```

**Arguments**

x	a FigureOfMerit object
y	not used
...	additional arguments to <a href="#">lattice::xyplot</a>
from	optional numeric value representing a land use category. If provided without to the figure of merit for all transitions from this category will be plotted
to	similar to from. If provided with a valid from argument the transition defined by these two arguments (i.e. from -> to) will be plotted. It is possible to include more than one category in which case the different transitions will be included on the same plot
col	character specifying the plotting colour. Default is to use the 'Set2' palette from RColorBrewer
type	character. See <a href="#">lattice::panel.xyplot</a>
key	list. See <a href="#">lattice::xyplot</a>
scales	list. See <a href="#">lattice::xyplot</a>
xlab	character or expression. See <a href="#">lattice::xyplot</a>
ylab	character or expression. See <a href="#">lattice::xyplot</a>

**Value**

A trellis object.

**See Also**

[FigureOfMerit](#), [lattice::xyplot](#), [lattice::panel.xyplot](#)

**Examples**

```
## see lulcc-package examples
```

---

`plot.PerformanceList` *Plot method for PerformanceList objects*

---

**Description**

Plot the the ROC curve for each performance object in a [PerformanceList](#) object. If more than one PerformanceList objects are provided ROC curves for the same land use category from different objects are included on the same plot for model comparison.

**Usage**

```
## S3 method for class 'PerformanceList'
plot(x, y, multipanel = TRUE, type = "l",
     abline = list(c(0, 1), col = "grey"), col = RColorBrewer::brewer.pal(9,
     "Set1"), key.args = NULL, ...)

## S4 method for signature 'list,ANY'
plot(x, y, multipanel = TRUE, type = "l",
     abline = list(c(0, 1), col = "grey"), col = RColorBrewer::brewer.pal(9,
     "Set1"), key.args = NULL, ...)
```

**Arguments**

<code>x</code>	either a single PerformanceList object or a list of these. If a list is provided it must be named.
<code>y</code>	not used
<code>multipanel</code>	logical. If TRUE, create a trellis plot where the number of panels equals the number of PerformanceList objects. Otherwise, create a single plot for each PerformanceList object
<code>type</code>	character. See <a href="#">lattice::panel.xyplot</a>
<code>abline</code>	list. See <a href="#">lattice::panel.xyplot</a>
<code>col</code>	character. Plotting colour
<code>key.args</code>	list containing additional components to be passed to the key argument of <a href="#">lattice::xyplot</a>
<code>...</code>	additional arguments to <a href="#">lattice::xyplot</a>

**Value**

A trellis object.

**See Also**

[PerformanceList](#), [lattice::xyplot](#)

**Examples**

```
## see lulcc-package examples
```

---

```
predict.PredictiveModelList
      Predict location suitability
```

---

**Description**

Estimate location suitability with predictive models.

**Usage**

```
## S3 method for class 'PredictiveModelList'
predict(object, newdata, data.frame = FALSE,
        ...)

## S4 method for signature 'PredictiveModelList'
predict(object, newdata, data.frame = FALSE,
        ...)
```

**Arguments**

object	a PredictiveModelList object
newdata	data.frame containing new data
data.frame	logical indicating whether the function should return a matrix (default) or data.frame
...	additional arguments to predict methods

**Details**

This function is usually called from `allocate` to calculate land use suitability at each timestep. However, it may also be used to produce suitability maps (see examples).

**Value**

A matrix.

**See Also**

[Model fitting, allocate](#)

**Examples**

```
## Not run:

## Sibuyan Island

## load observed land use data
obs <- ObsLulcRasterStack(x=sibuyan$maps,
                          pattern="lu",
                          categories=c(1,2,3,4,5),
                          labels=c("Forest", "Coconut", "Grass", "Rice", "Other"),
                          t=c(0,14))

## load explanatory variables
ef <- ExpVarRasterList(x=sibuyan$maps, pattern="ef")

## separate data into training and testing partitions
part <- partition(x=obs[[1]], size=0.1, spatial=TRUE)
train.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part[["train"]])
all.data <- getPredictiveModelInputData(obs=obs, ef=ef, cells=part[["all"]])

## get glm.models from data
forms <- list(Forest ~ ef_001+ef_002+ef_003+ef_004+ef_005+ef_006+ef_007+ef_008+ef_010+ef_012,
              Coconut ~ ef_001+ef_002+ef_005+ef_007+ef_008+ef_009+ef_010+ef_011+ef_012,
              Grass~ef_001+ef_002+ef_004+ef_005+ef_007+ef_008+ef_009+ef_010+ef_011+ef_012+ef_013,
              Rice~ef_009+ef_010+ef_011,
              Other~1)

glm.models <- glmModels(formula=forms, family=binomial, data=train.data, obs=obs)

## create suitability maps
suitability.maps <- predict(object=glm.models, newdata=all.data, data.frame=TRUE)
points <- rasterToPoints(obs[[1]], spatial=TRUE)
suitability.maps <- SpatialPointsDataFrame(coords=points, data=suitability.maps)
r <- stack(rasterize(x=suitability.maps, y=obs[[1]], field=names(suitability.maps)))
plot(r)

## library(rasterVis)
## levelplot(r)

## End(Not run)
```

**Description**

This function creates a `ROCR::prediction` object for each predictive model in a `PredictiveModelList` object. It should be used with `PerformanceList` to evaluate multiple models with exactly the same criteria while keeping track of which model corresponds to which land use category.

**Usage**

```
PredictionList(models, newdata, ...)
```

**Arguments**

<code>models</code>	a <code>PredictiveModelList</code> object
<code>newdata</code>	a <code>data.frame</code> containing new data
<code>...</code>	additional arguments to <code>ROCR::prediction</code>

**Value**

A `PredictionList` object.

**References**

Sing, T., Sander, O., Beerenwinkel, N., Lengauer, T. (2005). ROCr: visualizing classifier performance in R. *Bioinformatics* 21(20):3940-3941.

**See Also**

`link{PerformanceList}`, `ROCR::prediction`

**Examples**

```
## see lulcc-package examples
```

PredictionList-class *Class PredictionList*

**Description**

An S4 class that extends `ROCR::prediction-class` to hold the results of multiple model predictions.

**Slots**

<code>prediction</code>	a list of <code>ROCR::prediction-class</code> objects. These objects are calculated for each statistical model in the <code>PredictiveModelList</code> object supplied to the constructor function
<code>categories</code>	numeric vector of land use categories for which prediction objects were created
<code>labels</code>	character vector with labels corresponding to categories

---

 PredictiveModelList-class

*Class PredictiveModelList*


---

### Description

An S4 class to hold multiple mathematical models for different land use categories belonging to the same map.

### Slots

models list of predictive models

categories numeric vector of land use categories

labels character vector with labels corresponding to categories

---

 resample,ExpVarRasterList,Raster-method

*Resample maps in ExpVarRasterList object or list*


---

### Description

A wrapper function for raster::resample to resample raster objects in an ExpVarRasterList object or list.

### Usage

```
## S4 method for signature 'ExpVarRasterList,Raster'
resample(x, y, method = "ngb", ...)
```

```
## S4 method for signature 'list,Raster'
resample(x, y, method = "ngb", ...)
```

### Arguments

x	an ExpVarRasterList object or list of Raster* maps to be resampled
y	Raster* object with parameters that x should be resampled to
method	method used to compute values for the new RasterLayer, should be "bilinear" for bilinear interpolation, or "ngb" for nearest neighbour
...	additional arguments to raster::resample

### Value

An ExpVarRasterList object or list, depending on x.

**See Also**

[ExpVarRasterList](#), `raster::resample`

**Examples**

```
## Not run:

## Plum Island Ecosystems

## observed data
obs <- ObsLulcRasterStack(x=pie,
                          pattern="lu",
                          categories=c(1,2,3),
                          labels=c("forest","built","other"),
                          t=c(0,6,14))

## explanatory variables
ef <- ExpVarRasterList(x=pie, pattern="ef")

## resample to ensure maps have same characteristics as observed maps
ef <- resample(x=ef, y=obs, method="ngb")

## End(Not run)
```

---

roundSum

*Round elements in matrix or data.frame rows*

---

**Description**

Round all numbers in a matrix or data.frame while ensuring that all rows sum to the same value.

**Usage**

```
roundSum(x, ncell, ...)
```

**Arguments**

x	matrix or data.frame
ncell	numeric specifying the target sum for each row in x
...	additional arguments (none)

**Details**

The main application of roundSum is to ensure that each row in the demand matrix specifies exactly the number of cells to be allocated to each land use category for the respective timestep. It may also be used to convert the units of demand to number of cells.

**Value**

A matrix.

**Examples**

```
## Sibuyan Island

## load observed land use data and create demand scenario
obs <- ObsLulcRasterStack(x=sibuyan$maps,
                          pattern="lu",
                          categories=c(1,2,3,4,5),
                          labels=c("Forest", "Coconut", "Grass", "Rice", "Other"),
                          t=c(0,14))

dmd <- approxExtrapDemand(obs, tout=0:14)
apply(dmd, 1, sum)

## artificially perturb for illustration purposes
dmd <- dmd * runif(1)
apply(dmd, 1, sum)

## use roundSum to correct demand scenario
ncell <- length(which(!is.na(getValues(sibuyan$maps$lu_sib_1997))))
ncell
dmd <- roundSum(dmd, ncell=ncell)
apply(dmd, 1, sum)
```

---

show,ExpVarRasterList-method

*Show*

---

**Description**

Show objects

**Usage**

```
## S4 method for signature 'ExpVarRasterList'
show(object)

## S4 method for signature 'PredictiveModelList'
show(object)

## S4 method for signature 'PredictionList'
show(object)

## S4 method for signature 'PerformanceList'
show(object)
```

```
## S4 method for signature 'Model'
show(object)

## S4 method for signature 'ThreeMapComparison'
show(object)
```

### Arguments

**object** an object belonging to one of the classes in lulcc

---

sibuyan *Land use change dataset for Sibuyan Island*

---

### Description

Dataset containing land use map for 1997 and several explanatory variables for Sibuyan Island derived from Verburg et al. (2002). Data are modified by Peter Verburg to demonstrate the CLUE-s model; as such the dataset should not be used for purposes other than demonstration.

### Usage

sibuyan

### Format

A list containing the following components:

**maps** list containing the following RasterLayers:

- lu\_sib\_1997** RasterLayer with land use in 1997 (forest, coconut, grassland, rice, other)
- ef\_001** RasterLayer showing distance to sea
- ef\_002** RasterLayer showing mean population density
- ef\_003** RasterLayer showing occurrence of diorite rock
- ef\_004** RasterLayer showing occurrence of ultramafic rock
- ef\_005** RasterLayer showing occurrence of sediments
- ef\_006** RasterLayer showing areas with no erosion
- ef\_007** RasterLayer showing areas with moderate erosion
- ef\_008** RasterLayer showing elevation
- ef\_009** RasterLayer showing slope
- ef\_010** RasterLayer showing aspect
- ef\_011** RasterLayer showing distance to roads in 1997
- ef\_012** RasterLayer showing distance to urban areas in 1997
- ef\_013** RasterLayer showing distance to streams
- restr1** RasterLayer showing location of current national park
- restr2** RasterLayer showing location of proposed national park

**demand** list of matrices with different demand scenarios:

**demand1** data.frame with demand scenario representing slow growth scenario

**demand2** data.frame with demand scenario representing fast growth scenario

**demand3** data.frame with demand scenario representing land use change primarily for food production

## References

Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., Mastura, S.S (2002). Modeling the Spatial Dynamics of Regional Land Use: The CLUE-S Model. *Environmental Management* 30(3): 391-405.

## Examples

```
data(sibuyan)
```

---

```
subset,ExpVarRasterList-method
```

*Subset*

---

## Description

Extract a subset of objects from container classes such as ExpVarRasterList, PredictiveModelList, PredictionList and PerformanceList.

## Usage

```
## S4 method for signature 'ExpVarRasterList'
```

```
subset(x, subset, ...)
```

```
## S4 method for signature 'PredictiveModelList'
```

```
subset(x, subset, ...)
```

```
## S4 method for signature 'PerformanceList'
```

```
subset(x, subset, ...)
```

```
## S4 method for signature 'PredictionList'
```

```
subset(x, subset, ...)
```

## Arguments

x an object of class ExpVarRasterList, PredictiveModelList, PredictionList or PerformanceList

subset integer or character indicating the objects to be extracted

... additional arguments (none)

**Examples**

```
## Sibuyan Island

## load observed land use data
obs <- ObsLulcRasterStack(x=sibuyan$maps,
                          pattern="lu",
                          categories=c(1,2,3,4,5),
                          labels=c("Forest","Coconut","Grass","Rice","Other"),
                          t=c(0,14))

summary(obs)
obs <- subset(obs, subset=names(obs)[1])
summary(obs)

## load explanatory variables
ef <- ExpVarRasterList(x=sibuyan$maps, pattern="ef")

summary(ef)
ef <- subset(ef, subset=1:5)
summary(ef)
```

---

summary

*Summary*


---

**Description**

Summarise lulcc objects containing Raster\* data or predictive models

**Usage**

```
summary(object, ...)

## S4 method for signature 'ObsLulcRasterStack'
summary(object, ...)

## S4 method for signature 'ExpVarRasterList'
summary(object, ...)

## S4 method for signature 'NeighbRasterStack'
summary(object, ...)

## S4 method for signature 'PredictiveModelList'
summary(object, ...)

## S4 method for signature 'Model'
summary(object, ...)
```

**Arguments**

object            an object belonging to one of the classes in lulcc  
 ...                additional arguments (none)

**Value**

A matrix, data.frame or list

---

ThreeMapComparison     *Evaluate allocation performance with three maps*

---

**Description**

An implementation of the method described by Pontius et al. (2011), which compares a reference map at time 1, a reference map at time 2 and a simulated map at time 2 to evaluate allocation performance at multiple resolutions while taking into account persistence. The method quantifies disagreement within coarse squares (minor allocation disagreement), disagreement between coarse squares (major allocation disagreement), disagreement about the quantity of land use change and agreement.

**Usage**

```
ThreeMapComparison(x, x1, y1, ...)

## S4 method for signature 'Model,ANY,ANY'
ThreeMapComparison(x, x1, y1, factors, timestep, ...)

## S4 method for signature 'RasterLayer,RasterLayer,RasterLayer'
ThreeMapComparison(x, x1, y1,
  factors, categories, labels, ...)
```

**Arguments**

x                    either a RasterLayer of observed land use at time 0 or an object inheriting from class Model

x1                   a RasterLayer of observed land use at a subsequent time. Only required if x is also a RasterLayer

y1                   a RasterLayer of simulated land use corresponding to x1. Only required if x is also a RasterLayer

...                   additional arguments to raster::aggregate

factors              numeric vector of aggregation factors (equivalent to the 'fact' argument to raster::aggregate representing the resolutions at which model performance should be tested)

timestep             numeric value indicating the timestep of the simulated land use map. Only required if x is a Model object

categories	numeric vector of land use categories in observed maps. Only required if x is a RasterLayer
labels	character vector (optional) with labels corresponding to categories. Only required if x is a RasterLayer

**Value**

A ThreeMapComparison object.

**References**

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

**See Also**

[AgreementBudget](#), [FigureOfMerit](#), [raster::aggregate](#)

**Examples**

```
## see lulcc-package examples
```

---

ThreeMapComparison-class

*Class ThreeMapComparison*

---

**Description**

An S4 class to hold results of a comparison between a reference map for time 1, a reference map for time 2 and a simulation map for time 2 using the the method described by Pontius et al. (2011).

**Slots**

tables list of data.frames that depict the three dimensional table described by Pontius et al. (2011) at different resolutions

factors numeric vector of aggregation factors

maps list of RasterStack objects containing land use maps at different resolutions

categories numeric vector of land use categories

labels character vector corresponding to categories

**References**

Pontius Jr, R.G., Peethambaram, S., Castella, J.C. (2011). Comparison of three maps at multiple resolutions: a case study of land change simulation in Cho Don District, Vietnam. *Annals of the Association of American Geographers* 101(1): 45-62.

---

total	<i>Total number of cells in a categorical Raster* object</i>
-------	--

---

**Description**

Count the number of cells belonging to each category in a Raster\* object.

**Usage**

```
total(x, categories)
```

**Arguments**

x	Raster* object
categories	numeric vector containing land use categories. Only cells belonging to these categories will be counted

**Value**

A list containing the following components:

`total` a matrix containing the total number of cells belonging to each category. Rows represent layers in the input Raster\* object

`categories` the categories included in the calculation

**Examples**

```
## Sibuyan Island

## load observed land use data
obs <- ObsLulcRasterStack(x=sibuyan$maps,
                          pattern="lu",
                          categories=c(1,2,3,4,5),
                          labels=c("Forest", "Coconut", "Grass", "Rice", "Other"),
                          t=c(0,14))

total(x=obs)
total(x=obs[[1]])
total(x=obs[[2]])
```

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