

# Package ‘xegaDerivationTrees’

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**Title** Generating and Manipulating Derivation Trees

**Version** 1.0.0.6

**Description** Derivation tree operations are needed for implementing grammar-based genetic programming and grammatical evolution: Generating a random derivation trees of a context-free grammar of bounded depth, decoding a derivation tree, choosing a random node in a derivation tree, extracting a tree whose root is a specified node, and inserting a subtree into a derivation tree at a specified node. These operations are necessary for the initialization and for decoders of a random population of programs, as well as for implementing crossover and mutation operators. Depth-bounds are guaranteed by switching to a grammar without recursive production rules. For executing the examples, the package 'BNF' is needed. The basic tree operations for generating, extracting, and inserting derivation trees as well as the conditions for guaranteeing complete derivation trees have been presented in Geyer-Schulz (1997, ISBN:978-3-7908-0830-X). The use of random integer vectors for the generation of derivation trees has been introduced in Ryan, C., Collins, J. J., and O'Neill, M. (1998) <[doi:10.1007/BFb0055930](https://doi.org/10.1007/BFb0055930)> for grammatical evolution.

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**URL** <https://github.com/ageyerschulz/xegaDerivationTrees>

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---

addE *Add an edge or a list of edges to the data frame for edges.*

---

**Description**

Adds the edges of the kids of a node to the edge list.

**Usage**

```
addE(df, from, to)
```

**Arguments**

df	Data frame for edges.
from	Integer (numerical identifier of vertex).
to	Vector of integers (numerical identifiers of kids of vertex).

**Value**

A Data frame for edges.

**See Also**

Other Data frames for igraph: [addV\(\)](#), [newE\(\)](#), [newV\(\)](#)

**Examples**

```
df<-addE(newE(), 1, c(2, 3, 4))
print(df)
```

---

addV *Add a vertex to the data frame for vertices.*

---

**Description**

Add a vertex to the data frame for vertices.

**Usage**

```
addV(df, id, name)
```

**Arguments**

df	Data frame for vertices.
id	Integer (numerical identifier of vertex).
name	Name of grammar symbol of of vertex.

**Value**

A Data frame for vertices.

**See Also**

Other Data frames for igraph: [addE\(\)](#), [newE\(\)](#), [newV\(\)](#)

**Examples**

```
df<-addV(newV(), 1, "<fe>")
print(df)
```

---

booleanGrammar	<i>A constant function which returns the BNF (Backus-Naur Form) of a context-free grammar for the XOR problem.</i>
----------------	--

---

**Description**

A constant function which returns the BNF (Backus-Naur Form) of a context-free grammar for the XOR problem.

**Usage**

```
booleanGrammar()
```

**Details**

Imported from package xegaBNF for use in examples.

**Value**

A named list with elements \$filename and \$BNF representing the grammar of a boolean grammar with two variables and the boolean functions AND, OR, and NOT.

**See Also**

Other Grammar: [compileBNF\(\)](#)

**Examples**

```
booleanGrammar()
```

---

chooseNode	<i>Randomly selects an attributed node in an attributed node list.</i>
------------	--

---

**Description**

chooseNode() returns a random attributed node from an attributed node list.

**Usage**

```
chooseNode(ANL)
```

**Arguments**

ANL                    Attributed node list.

**Details**

An attributed node has the following elements:

- ID
- NonTerminal
- Pos
- Depth
- Rdepth
- subtreedepth
- Index

These elements can be used e.g.

- for inserting and extracting subtrees (Pos or node\$Index),
- for checking the feasibility of subtree substitution (ID),
- for checking depth bounds (Depth, RDepth, and subtreedepth), ...

**Value**

An attributed node.

**See Also**

Other Random Choice: [chooseRule\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
b<-treeANL(a, g$ST)
c<-chooseNode(b$ANL)
```

chooseRule                    *Selects a production rule index at random from a vector of production rules.*

---

**Description**

chooseRule() selects a production rule index from the vector of production rule indices in the g\$PT\$LHS for a non-terminal symbol.

**Usage**

```
chooseRule(riv)
```

**Arguments**

riv                    Vector of production rules indices for a non-terminal symbol.

**Value**

Integer. Index of the production rule.

**See Also**

Other Random Choice: [chooseNode\(\)](#)

**Examples**

```
chooseRule(c(7, 8, 9))  
chooseRule(as.vector(1))
```

---

chooseRulek                    *Selects k-th production rule index from a vector of production rules.*

---

**Description**

chooseRulek() selects the k-th production rule index from the vector of production rule indices in the g\$PT\$LHS for a non-terminal symbol.

**Usage**

```
chooseRulek(riv, k)
```

**Arguments**

riv                    Vector of production rule indices for a non-terminal symbol.  
k                      Integer.

**Value**

The index of the production rule.

**Examples**

```
chooseRulek(c(7, 8, 9), 9)
chooseRulek(as.vector(1), 9)
```

---

compatibleSubtrees      *Test the compatibility of subtrees.*

---

**Description**

compatibleSubtrees() tests the compatibility of two subtrees.

**Usage**

```
compatibleSubtrees(n1, n2, maxdepth = 5, DepthBounded = TRUE)
```

**Arguments**

n1	Attributed node of the root of subtree 1.
n2	Attributed node of the root of subtree 2.
maxdepth	Integer. Maximal derivation depth.
DepthBounded	<ul style="list-style-type: none"> <li>• TRUE: Only subtrees with the same root symbol that respect the depth restrictions are compatible.</li> <li>• FALSE: The depth restrictions are not checked.</li> </ul>

**Details**

compatibleSubtrees() tests the compatibility of two subtrees:

1. The root symbol of the two subtrees must be identical: (n1\$ID==n2\$ID).
2. The depth restrictions must hold:
  - (a)  $\text{depth}(n1) + \text{depth}(\text{subtree2}) \leq \text{maxdepth} + \text{maxSPT}$
  - (b)  $\text{depth}(n2) + \text{depth}(\text{subtree1}) \leq \text{maxdepth} + \text{maxSPT}$

maxSPT is the maximal number of derivations needed to generate a complete derivation tree.

**Value**

TRUE or FALSE

**See Also**

Other Tree Operations: [treeExtract\(\)](#), [treeInsert\(\)](#)

## Examples

```
g<-compileBNF(booleanGrammar())
t1<-randomDerivationTree(g$Start, g)
t1anl<-treeANL(t1, g$ST)
t2<-randomDerivationTree(g$Start, g)
t2anl<-treeANL(t2, g$ST)
n1<-chooseNode(t1anl$ANL)
n2<-chooseNode(t2anl$ANL)
compatibleSubtrees(n1, n2)
compatibleSubtrees(n1, n2, maxdepth=1)
compatibleSubtrees(n1, n2, DepthBounded=FALSE)
```

---

compileBNF

*Compile a BNF (Backus-Naur Form) of a context-free grammar.*

---

## Description

compileBNF() produces a context-free grammar from its specification in Backus-Naur form (BNF).  
Warning: No error checking is implemented.

## Usage

```
compileBNF(g, verbose = FALSE)
```

## Arguments

g	A character string with a BNF.
verbose	Boolean. TRUE: Show progress. Default: FALSE.

## Details

A grammar consists of the symbol table ST, the production table PT, the start symbol Start, and the short production table SPT.

The function performs the following steps:

1. Make the symbol table.
2. Make the production table.
3. Extract the start symbol.
4. Compile a short production table.
5. Return the grammar.

**Value**

A grammar object (list) with the attributes

- name: Filename of the grammar.
- ST: Symbol table.
- PT: Production table.
- Start: Start symbol of the grammar.
- SPT: Short production table.

**See Also**

Other Grammar: [booleanGrammar\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
g$ST
g$PT
g$Start
g$SPT
```

---

decodeAndFixDT

*Decodes (and completes) a derivation tree into a working program.*

---

**Description**

The program is guaranteed to work.

**Usage**

```
decodeAndFixDT(tree, G, kvec)
```

**Arguments**

tree	Derivation tree.
G	A Grammar object.
kvec	A random integer vector.

**Value**

A program

**See Also**

Other Decoder: [decodeCDT\(\)](#), [decodeDT\(\)](#), [decodeDTsym\(\)](#), [decodeTree\(\)](#), [leavesIncompleteDT\(\)](#)

**Examples**

```

g<-compileBNF(booleanGrammar())
complete<-TRUE
while (complete) {
t1<-generateDerivationTree(sym=g$Start, kvec=sample(100, 10, replace=TRUE), G=g)
complete<-t1$complete}
decodeAndFixDT(t1$tree, G=g, kvec=sample(100, 10, replace=TRUE))

```

---

decodeCDT

*Converts a complete derivation tree into a program.*


---

**Description**

decodeCDT() returns a program (a text string with the terminal symbol string). If the derivation tree still has non-terminal leaves, the non-terminal leaves are omitted. The program produces a syntax error. The program can not be repaired.

**Usage**

```
decodeCDT(tree, ST)
```

**Arguments**

tree	Derivation tree.
ST	Symbol table.

**Value**

A program.

**See Also**

Other Decoder: [decodeAndFixDT\(\)](#), [decodeDT\(\)](#), [decodeDTsym\(\)](#), [decodeTree\(\)](#), [leavesIncompleteDT\(\)](#)

**Examples**

```

g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
decodeCDT(a, g$ST)

```

---

decodeDT	<i>Decodes a derivation tree into a program.</i>
----------	--

---

**Description**

The program may contain non-terminal symbols and its evaluation may fail.

**Usage**

```
decodeDT(tree, ST)
```

**Arguments**

tree	Derivation tree.
ST	Symbol table.

**Value**

A program

**See Also**

Other Decoder: [decodeAndFixDT\(\)](#), [decodeCDT\(\)](#), [decodeDTsym\(\)](#), [decodeTree\(\)](#), [leavesIncompleteDT\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
t1<-generateDerivationTree(sym=g$Start,sample(100, 10, replace=TRUE), G=g)
decodeDT(t1$tree, g$ST)
```

---

decodeDTsym	<i>Decodes a derivation tree into a list of the leaf symbols of the derivation tree.</i>
-------------	--

---

**Description**

Decodes a derivation tree into a list of the leaf symbols of the derivation tree.

**Usage**

```
decodeDTsym(tree, ST)
```

**Arguments**

tree	Derivation tree.
ST	Symbol table.

**Value**

List of the leaf symbols of the derivation tree.

**See Also**

Other Decoder: [decodeAndFixDT\(\)](#), [decodeCDT\(\)](#), [decodeDT\(\)](#), [decodeTree\(\)](#), [leavesIncompleteDT\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
t1<-generateDerivationTree(sym=g$Start,sample(100, 10, replace=TRUE), G=g)
decodeDTsym(t1$tree, g$ST)
```

---

decodeSymVec

*Decodes a vector of symbols.*

---

**Description**

Decodes a vector of symbols.

**Usage**

```
decodeSymVec(v, ST)
```

**Arguments**

v	Vector of symbols.
ST	Symbol table.

**Value**

A program.

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
r<-treeRoot(a)
decodeSymVec(r, g$ST)
c<-unlist(lapply(treeChildren(a), FUN=treeRoot))
decodeSymVec(c, g$ST)
```

---

decodeTree	<i>Returns a list of all symbols of a derivation tree in depth-first left-to-right order.</i>
------------	---

---

**Description**

decodeTree() returns a list of all symbols of a derivation tree in depth-first left-to-right order (coded as R Factor with the symbol identifiers as levels).

**Usage**

```
decodeTree(tree, ST)
```

**Arguments**

tree	Derivation tree.
ST	Symbol table.

**Value**

List of all symbols in depth-first left-to-right order.

**See Also**

Other Decoder: [decodeAndFixDT\(\)](#), [decodeCDT\(\)](#), [decodeDT\(\)](#), [decodeDTsym\(\)](#), [leavesIncompleteDT\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
decodeTree(a, g$ST)
```

---

filterANL	<i>Filter an Attributed Node List (ANL) of a derivation tree by depth.</i>
-----------	--

---

**Description**

filterANL() deletes all nodes whose depth node\$Depth is less than minb and larger than maxb from the ANL. However, if the resulting list is empty, the original ANL is returned.

**Usage**

```
filterANL(ANL, minb = 1, maxb = 3)
```

**Arguments**

ANL	Attributed node list.
minb	Integer.
maxb	Integer.

**Details**

An attributed node has the following elements:

- \$ID: Id in the symbol table ST.
- \$NonTerminal: Is the symbol a non-terminal?
- \$Pos: Position in the trail.
- \$Depth: Depth of node.
- \$Rdepth: Residual depth for expansion.
- \$subtreedepth: Depth of subtree starting here.
- \$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

**Value**

An attributed node list with nodes whose depths are in minb:maxb. Each node is represented as a list of the following attributes:

- Node\$ID: Id in the symbol table ST.
- Node\$NonTerminal: Is the symbol a non-terminal?
- Node\$Pos: Position in the trail.
- Node\$Depth: Depth of node.
- Node\$Rdepth: Residual depth for expansion.
- Node\$subtreedepth: Depth of subtree starting here.
- Node\$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

**See Also**

Other Access Tree Parts: [filterANLid\(\)](#), [treeANL\(\)](#), [treeChildren\(\)](#), [treeRoot\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
set.seed(111)
a<-randomDerivationTree(g$Start, g, maxdepth=10)
b<-treeANL(a, g$ST)
c<-filterANL(b, minb=1, maxb=3)
d<-filterANL(b, minb=3, maxb=5)
e<-filterANL(b, minb=14, maxb=15)
f<-filterANL(b, minb=13, maxb=15)
```

---

filterANLid	<i>Filter an Attributed Node List (ANL) of a derivation tree by a symbol identifier.</i>
-------------	--

---

### Description

filterANLid() deletes all nodes whose node\$ID does not match node\$ID. If the resulting list is empty, a list of length 0 is returned.

### Usage

```
filterANLid(ANL, nodeID = 1)
```

### Arguments

ANL	Attributed node list.
nodeID	Integer. The identifier of a symbol.

### Details

An attributed node has the following elements:

- \$ID: Id in the symbol table ST.
- \$NonTerminal: Is the symbol a non-terminal?
- \$Pos: Position in the trail.
- \$Depth: Depth of node.
- \$Rdepth: Residual depth for expansion.
- \$subtreedepth: Depth of subtree starting here.
- \$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

For the implementation of crossover and mutation, we expect a non-terminal symbol identifier.

### Value

An attributed node list with nodes whose depths are in minb:maxb. Each node is represented as a list of the following attributes:

- Node\$ID: Id in the symbol table ST.
- Node\$NonTerminal: Is the symbol a non-terminal?
- Node\$Pos: Position in the trail.
- Node\$Depth: Depth of node.
- Node\$Rdepth: Residual depth for expansion.
- Node\$subtreedepth: Depth of subtree starting here.
- Node\$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

**See Also**

Other Access Tree Parts: [filterANL\(\)](#), [treeANL\(\)](#), [treeChildren\(\)](#), [treeRoot\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
set.seed(111)
a<-randomDerivationTree(g$Start, g, maxdepth=10)
b<-treeANL(a, g$ST)
c<-filterANLid(b, nodeID=5)
d<-filterANLid(b, nodeID=6)
e<-filterANLid(b, nodeID=7)
f<-filterANLid(b, nodeID=8)
```

---

generateCDT

*Generates a complete derivation tree from an integer vector.*

---

**Description**

generateCDT() generates a derivation tree from an integer vector. The derivation tree may be incomplete. (For grammatical evolution).

**Usage**

```
generateCDT(sym, kvec, complete = TRUE, G, maxdepth = 5)
```

**Arguments**

sym	Non-terminal symbol.
kvec	Integer vector.
complete	Boolean. FALSE for incomplete derivation trees.
G	Grammar.
maxdepth	Integer. Maximal depth of the derivation tree.

**Details**

generateDerivationTree() recursively expands non-terminals and builds a derivation tree.

**Value**

A named list l\$tree, l\$kvec, l\$complete.

**See Also**

Other Generate Derivation Tree: [generateDerivationTree\(\)](#), [randomDerivationTree\(\)](#), [rndsub\(\)](#), [rndsubk\(\)](#), [substituteSymbol\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-sample(100, 100, replace=TRUE)
b<-generateCDT(sym=g$Start, kvec=a, G=g, maxdepth=10)
decodeDT(b$tree, g$ST)
```

---

```
generateDerivationTree
```

*Generates a derivation tree from an integer vector.*

---

**Description**

generateDerivationTree() generates a derivation tree from an integer vector. The derivation tree may be incomplete. (For grammatical evolution).

**Usage**

```
generateDerivationTree(sym, kvec, complete = TRUE, G, maxdepth = 5)
```

**Arguments**

sym	Non-terminal symbol.
kvec	Integer vector.
complete	Boolean. FALSE for incomplete derivation trees.
G	Grammar.
maxdepth	Integer. Maximal depth of the derivation tree.

**Details**

generateDerivationTree() recursively expands non-terminals and builds a derivation tree.

**Value**

A named list l\$tree, l\$kvec, l\$complete.

**See Also**

Other Generate Derivation Tree: [generateCDT\(\)](#), [randomDerivationTree\(\)](#), [rndsub\(\)](#), [rndsubk\(\)](#), [substituteSymbol\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-sample(100, 100, replace=TRUE)
b<-generateDerivationTree(sym=g$Start, kvec=a, G=g, maxdepth=10)
decodeDT(b$tree, g$ST)
```

---

leavesIncompleteDT      *Returns the list of symbol identifiers of the leaves of a derivation tree.*

---

### Description

For incomplete derivation trees, non-terminal symbols are leaves.

### Usage

```
leavesIncompleteDT(tree, ST, leavesList = list())
```

### Arguments

tree	Derivation tree.
ST	Symbol table.
leavesList	List of symbol identifiers.

### Details

Must perform a depth-first left-to-right tree traversal to collect all leaf symbols (terminal and non-terminal symbols).

### Value

List of symbol identifiers.

### See Also

Other Decoder: [decodeAndFixDT\(\)](#), [decodeCDT\(\)](#), [decodeDT\(\)](#), [decodeDTsym\(\)](#), [decodeTree\(\)](#)

### Examples

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
leavesIncompleteDT(a, g$ST)
```

---

newE	<i>Returns empty data frame for edges.</i>
------	--

---

**Description**

Data frame with columns from root (numerical identifier) and to kid (numerical identifier).

**Usage**

```
newE()
```

**Value**

Data frame.

**See Also**

Other Data frames for igraph: [addE\(\)](#), [addV\(\)](#), [newV\(\)](#)

**Examples**

```
df<-newE()  
print(df)
```

---

newV	<i>Returns empty data frame for vertices.</i>
------	---

---

**Description**

Data frame with columns id (numerical identifier) and name (symbol of the grammar).

**Usage**

```
newV()
```

**Value**

Data frame.

**See Also**

Other Data frames for igraph: [addE\(\)](#), [addV\(\)](#), [newE\(\)](#)

**Examples**

```
df<-newV()  
print(df)
```

---

printDerivations      *Print derivations.*

---

### Description

A depth-first left-to-right tree traversal without recursion.

### Usage

```
printDerivations(tree, G, verbose = FALSE)
```

### Arguments

tree	Derivation tree.
G	The context-free grammar.
verbose	If TRUE, the list of derivations is printed. Default: FALSE.

### Details

Works with complete and incomplete derivation trees.

### Value

A list of derivations.

### Examples

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
l<-printDerivations(a, g, verbose=TRUE)
```

---

randomDerivationTree      *Generates a random derivation tree.*

---

### Description

randomDerivationTree() generates a random derivation tree.

### Usage

```
randomDerivationTree(sym, G, maxdepth = 5, CompletedT = TRUE)
```

**Arguments**

sym	Non-terminal symbol.
G	Grammar.
maxdepth	Integer. Maximal depth of the derivation tree.
CompleteDT	Boolean. Generate a complete derivation tree? Default: TRUE.

**Details**

RandomDerivationTree() recursively expands non-terminals and builds a depth-bounded derivation tree.

**Value**

Derivation tree (a nested list).

**See Also**

Other Generate Derivation Tree: [generateCDT\(\)](#), [generateDerivationTree\(\)](#), [rndsub\(\)](#), [rndsubk\(\)](#), [substituteSymbol\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
b<-randomDerivationTree(g$Start, g, maxdepth=10)
c<-randomDerivationTree(g$Start, g, 2, FALSE)
```

---

rndPartition                      *Randomly partitions n in k parts.*

---

**Description**

Sampling a partition is a two-step process:

1. The k parts of the partition are sampled in the loop. This implies that the first partition p is a random number between 1 and 1+n-k. The next partition is sampled from 1 to 1+n-k-p.
2. We permute the partitions.

**Usage**

```
rndPartition(n, k)
```

**Arguments**

n	The integer to divide.
k	Number of parts.

**Value**

The integer partition of n in k parts.

**Examples**

```
rndPartition(10, 4)
```

---

rndsub	<i>Transforms a non-terminal symbol into a random 1-level derivation tree.</i>
--------	--

---

**Description**

`rndsub()` expands a non-terminal by a random derivation and returns a 1-level derivation tree.

**Usage**

```
rndsub(sym, PT)
```

**Arguments**

sym	Non-terminal symbol.
PT	Production table.

**Value**

Derivation tree with 1-level.

**See Also**

Other Generate Derivation Tree: [generateCDT\(\)](#), [generateDerivationTree\(\)](#), [randomDerivationTree\(\)](#), [rndsubk\(\)](#), [substituteSymbol\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())  
rndsub(g$Start, g$PT)
```

---

rndsubk	<i>Transforms a non-terminal symbol into a 1-level derivation tree for a given k.</i>
---------	---

---

**Description**

rndsubk() expands a non-terminal by a derivation specified by k and returns a 1-level derivation tree.

**Usage**

```
rndsubk(sym, k, PT)
```

**Arguments**

sym	Non-terminal symbol.
k	Codon (An integer).
PT	Production table.

**Value**

1-level derivation tree.

**See Also**

Other Generate Derivation Tree: [generateCDT\(\)](#), [generateDerivationTree\(\)](#), [randomDerivationTree\(\)](#), [rndsub\(\)](#), [substituteSymbol\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
rndsubk(g$Start, 207, g$PT)
```

---

substituteSymbol	<i>Codes the substitution of a non-terminal symbol by the symbols derived by a production rule as a nested list.</i>
------------------	--

---

**Description**

substituteSymbol() generates a nested list with the non-terminal symbol as the root (first list element) and the derived symbols as the second list element.

**Usage**

```
substituteSymbol(rindex, PT)
```

**Arguments**

r index	Rule index.
PT	Production table.

**Value**

2-element list.

**See Also**

Other Generate Derivation Tree: [generateCDT\(\)](#), [generateDerivationTree\(\)](#), [randomDerivationTree\(\)](#), [rndsub\(\)](#), [rndsubk\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
substituteSymbol(3, g$PT)
```

---

```
testGenerateDerivationTree
```

*Generate, decode, and show times derivation trees from random integer vectors for grammar BNF on the console.*

---

**Description**

Generate, decode, and show times derivation trees from random integer vectors for grammar BNF on the console.

**Usage**

```
testGenerateDerivationTree(
  times,
  G,
  generateDT = generateDerivationTree,
  verbose = TRUE
)
```

**Arguments**

times	Number of derivation trees which should be generated.
G	A grammar object G.
generateDT	Function for generating a derivation tree.
verbose	Boolean. If TRUE (default) , print decoded derivation tree on console.

**Value**

Number of complete derivation trees generated.

**Examples**

```
g<-compileBNF(booleanGrammar())
testGenerateDerivationTree(5, g)
```

---

treeANL	<i>Builds an Attributed Node List (ANL) of a derivation tree.</i>
---------	---

---

**Description**

treeANL() recursively traverses a derivation tree and collects information about the derivation tree in an attributed node list (ANL).

**Usage**

```
treeANL(
  tree,
  ST,
  maxdepth = 5,
  ANL = list(),
  IL = list(),
  count = 1,
  depth = 1
)
```

**Arguments**

tree	A derivation tree.
ST	A symbol table.
maxdepth	Limit on the depth of a derivation tree.
ANL	Attributed node list (empty on invocation).
IL	Index function list (empty on invocation).
count	Trail count (1 on invocation).
depth	Derivation tree depth (1 on invocation).

**Details**

An attributed node has the following elements:

- \$ID: Id in the symbol table ST.
- \$NonTerminal: Is the symbol a non-terminal?
- \$Pos: Position in the trail.

- \$Depth: Depth of node.
- \$Rdepth: Residual depth for expansion.
- \$subtreedepth: Depth of subtree starting here.
- \$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

These elements can be used e.g.

- for inserting and extracting subtrees (Pos or node\$Index),
- for checking the feasibility of subtree substitution (ID),
- for checking depth bounds (Depth, RDepth, and subtreedepth), ...

### Value

A list with three elements:

1. \$count: The trail length (not needed).
2. \$subtreedepth: The derivation tree depth (not needed).
3. \$ANL: The attributed node list is a list of nodes. Each node is represented as a list of the following attributes:
  - Node\$ID: Id in the symbol table ST.
  - Node\$NonTerminal: Is the symbol a non-terminal?
  - Node\$Pos: Position in the trail.
  - Node\$Depth: Depth of node.
  - Node\$Rdepth: Residual depth for expansion.
  - Node\$subtreedepth: Depth of subtree starting here.
  - Node\$Index: R index of the node in the derivation tree. Allows fast tree extraction and insertion.

### See Also

Other Access Tree Parts: [filterANL\(\)](#), [filterANLid\(\)](#), [treeChildren\(\)](#), [treeRoot\(\)](#)

### Examples

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
b<-treeANL(a, g$ST)
c<-treeANL(a, g$ST, 10)
d<-treeANL(a, g$ST, maxdepth=10)
```

---

treeChildren	Returns the children of a derivation tree.
--------------	--

---

**Description**

treeChildren() returns the children of a derivation tree represented as a list of derivation trees.

**Usage**

```
treeChildren(tree)
```

**Arguments**

tree	Derivation tree.
------	------------------

**Value**

The children of a derivation tree (a list of derivation trees).

**See Also**

Other Access Tree Parts: [filterANL\(\)](#), [filterANLid\(\)](#), [treeANL\(\)](#), [treeRoot\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeChildren(a)
```

---

treeExtract	Extracts the subtree at position pos in a derivation tree.
-------------	--

---

**Description**

treeExtract() returns the subtree at position pos in a derivation tree.

**Usage**

```
treeExtract(tree, node)
```

**Arguments**

tree	Derivation tree.
node	Attributed node.

**Details**

An attributed node is a list whose element `node$Index` contains an access function to the node. The access function is represented as a string with an executable R index expression. All what remains to be done, is

- to complete the access statement and
- to return the result of parsing and evaluating the string.

**Value**

Derivation tree.

**See Also**

Other Tree Operations: [compatibleSubtrees\(\)](#), [treeInsert\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
t1<-randomDerivationTree(g$Start, g)
t1anl<-treeANL(t1, g$ST)
n1<-chooseNode(t1anl$ANL)
st1<-treeExtract(t1, n1)
decodeCDT(st1, g$ST)
st2<-treeExtract(t1, chooseNode(t1anl$ANLa))
decodeCDT(st2, g$ST)
```

---

treeInsert

*Inserts a subtree into a derivation tree at a node.*

---

**Description**

`treeInsert()` inserts a subtree into a tree at a node.

**Usage**

```
treeInsert(tree, subtree, node)
```

**Arguments**

tree	Derivation tree.
subtree	Subtree.
node	Attributed node.

## Details

An attributed node is a list whose element `node$Index` contains an access function to the node. The access function is represented as a string which contains an executable R index expression. All what remains to be done, is

- to complete the assignment statement and
- to parse and evaluate the string.

## Value

A derivation tree.

## See Also

Other Tree Operations: [compatibleSubtrees\(\)](#), [treeExtract\(\)](#)

## Examples

```
g<-compileBNF(booleanGrammar())
t1<-randomDerivationTree(g$Start, g)
t2<-randomDerivationTree(g$Start, g)
t1anl<-treeANL(t1, g$ST)
n1<-chooseNode(t1anl$ANL)
t2<-randomDerivationTree(n1$ID, g)
tI1<-treeInsert(t1, t2, n1)
decodeCDT(tI1, g$ST)
```

---

treeLeaves

*Measures the number of leaves of a complete derivation tree.*

---

## Description

`treeLeaves()` returns the number of terminal symbols in a complete derivation tree.

## Usage

```
treeLeaves(tree, ST)
```

## Arguments

tree	Derivation tree.
ST	Symbol table.

## Value

Integer. Number of terminal symbols in a complete derivation tree.

**See Also**

Other Measures of Tree Attributes: [treeListDepth\(\)](#), [treeNodes\(\)](#), [treeProbability\(\)](#), [treeSize\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeLeaves(a, g$ST)
((treeLeaves(a, g$ST)+treeNodes(a, g$ST)) == treeSize(a))
```

---

treeListDepth

*Measures the depth of a (nested) list.*

---

**Description**

treeListDepth() returns the depth of a nested list. For a derivation tree, this is approximately twice the derivation depth.

**Usage**

```
treeListDepth(t, tDepth = 0)
```

**Arguments**

t	List.
tDepth	Integer. List depth. Default: 0.

**Value**

Depth of a nested list.

**See Also**

Other Measures of Tree Attributes: [treeLeaves\(\)](#), [treeNodes\(\)](#), [treeProbability\(\)](#), [treeSize\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeListDepth(a)
```

---

treeNodes	<i>Measures the number of inner nodes in a derivation tree.</i>
-----------	---

---

**Description**

treeNodes() returns the number of non-terminal symbols in a derivation tree.

**Usage**

```
treeNodes(tree, ST)
```

**Arguments**

tree	Derivation tree.
ST	Symbol table.

**Value**

Integer. Number of non-terminal symbols in a derivation tree.

**See Also**

Other Measures of Tree Attributes: [treeLeaves\(\)](#), [treeListDepth\(\)](#), [treeProbability\(\)](#), [treeSize\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeNodes(a, g$ST)
```

---

treeProbability	<i>The (path) probability of generating tree by grammar G.</i>
-----------------	--

---

**Description**

treeProbability() returns the path probability of generating the derivation tree tree by the context-free grammar G. The probability is exact, if the grammar is not ambiguous and if the grammar does not contain redundant rules.

**Usage**

```
treeProbability(tree, G)
```

**Arguments**

tree            Derivation tree.  
G                A context-free grammar.

**Value**

Real. The probability of generating tree by grammar G.

**See Also**

Other Measures of Tree Attributes: [treeLeaves\(\)](#), [treeListDepth\(\)](#), [treeNodes\(\)](#), [treeSize\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
decodeTree(a, g$ST)
treeProbability(tree=a, G=g)
```

---

treeRoot	<i>Returns the root of a derivation tree.</i>
----------	---

---

**Description**

treeRoot() returns the root of a derivation tree.

**Usage**

```
treeRoot(tree)
```

**Arguments**

tree            Derivation tree.

**Value**

Root of a derivation tree.

**See Also**

Other Access Tree Parts: [filterANL\(\)](#), [filterANLid\(\)](#), [treeANL\(\)](#), [treeChildren\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeRoot(a)
```

---

treeSize	<i>Measures the number of symbols in a derivation tree.</i>
----------	---

---

**Description**

treeSize() returns the number of symbols in a derivation tree.

**Usage**

```
treeSize(tree)
```

**Arguments**

tree            Derivation tree.

**Value**

Integer. Number of symbols in a derivation tree.

**See Also**

Other Measures of Tree Attributes: [treeLeaves\(\)](#), [treeListDepth\(\)](#), [treeNodes\(\)](#), [treeProbability\(\)](#)

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
treeSize(a)
```

---

treeToDataFrames	<i>Convert a tree to two dataframes.</i>
------------------	--

---

**Description**

Converts a derivation tree into a list of two data frames. With the R-package `igraph` the data frames can be plotted as a derivation tree.

**Usage**

```
treeToDataFrames(tree, G, verbose)
```

**Arguments**

tree            Derivation tree.  
G                The context-free grammar.  
verbose         If TRUE, print derivations on console. Default: FALSE.

**Details**

Works with complete and incomplete derivation trees.

**Value**

A named list with two data frames:

1. The data frame  $V$  of vertices with the columns  $V$id$  (numerical identifier) and  $V$name$  (symbol of the grammar  $G$ ).
2. The data frame  $E$  of edges with the columns  $E$from$  and  $E$to$ .

**Examples**

```
g<-compileBNF(booleanGrammar())
a<-randomDerivationTree(g$Start, g)
x<-treeToDataFrames(a, g, verbose=TRUE)
# library(igraph)
# g1<-graph_from_data_frame(x$E, directed=TRUE, vertices=x$V)
# plot(g1, layout=layout_as_tree)
```

---

xegaDerivationTrees    *Package xegaDerivationTrees*

---

**Description**

Derivation Trees

**Details**

The implementation of a data type for derivation trees.

The derivation tree operations for generating complete random subtrees and for subtree extraction and insertion are formally introduced in Geyer-Schulz (1997) and used for implementing mutation and crossover operations.

Efficient selection of random subtrees is implemented by building a list of annotated tree nodes by a left-right depth-first tree traversal. For each node, the R-index to access the subtree is built and stored in the node. The R-index element of a node allows subtree extraction and insertion operations with the cost of the R-index operation. In addition, filtering operations the node list by different criteria (min depth, max depth, and non-terminal symbol type) allow the implementation of flexible and configurable crossover and mutation operations.

## The Architecture of the xegaX-Packages

The xegaX-packages are a family of R-packages which implement eXtended Evolutionary and Genetic Algorithms (xega). The architecture has 3 layers, namely the user interface layer, the population layer, and the gene layer:

- The user interface layer (package `xega`) provides a function call interface and configuration support for several algorithms: genetic algorithms (`sga`), permutation-based genetic algorithms (`sgPerm`), derivation-free algorithms as e.g. differential evolution (`sgde`), grammar-based genetic programming (`sgp`) and grammatical evolution (`sge`).
- The population layer (package `xegaPopulation`) contains population-related functionality as well as support for adaptive mechanisms which depend on population statistics. In addition, support for parallel evaluation of genes is implemented here.
- The gene layer is split in a representation-independent and a representation-dependent part:
  1. The representation-independent part (package `xegaSelectGene`) is responsible for variants of selection operators, evaluation strategies for genes, as well as profiling and timing capabilities.
  2. The representation-dependent part consists of the following packages:
    - `xegaGaGene` for binary-coded genetic algorithms.
    - `xegaPermGene` for permutation-based genetic algorithms.
    - `xegaDfGene` for derivation-free algorithms. For example, differential evolution.
    - `xegaGpGene` for grammar-based genetic algorithms.
    - `xegaGeGene` for grammatical evolution algorithms.

The packages `xegaDerivationTrees` and `xegaBNF` support the last two packages: `xegaBNF` essentially provides a grammar compiler, and `xegaDerivationTrees` an abstract data type for derivation trees.

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## URL

[<https://github.com/ageyerschulz/xegaDerivationTrees>](https://github.com/ageyerschulz/xegaDerivationTrees)

## Installation

From cran with `install.packages("xegaDerivationTrees")`

## Author(s)

Andreas Geyer-Schulz

**References**

Geyer-Schulz, Andreas (1997): *Fuzzy Rule-Based Expert Systems and Genetic Machine Learning*, Physica, Heidelberg. (ISBN:978-3-7908-0830-X)

**See Also**

Useful links:

- <https://github.com/ageyerschulz/xegaDerivationTrees>

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