LPFG user's manual

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1 Introduction

lpfg is a plant modeling program. Models are expressed using a formalism based on L-systems; the L+C modeling language adds L-system-specific constructs to the C++ programming language.

1.1 Hardware requirements

lpfg does not have any specific hardware requirements. It uses OpenGL to generate images; therefore, a graphics card capable of accelerated 3D graphics, with a display resolution of at least 1024x768, with a color depth of at least 24 bits, is strongly recommended. A mouse or equivalent pointing device is also required.

1.2 Software requirements

lpfg runs under Microsoft Windows operating systems (95, 98, Me, NT4, 2000, XP). It requires a C++ compiler capable of generating Windows Dynamic Link Libraries (DLLs). *lpfg* was originally developed and tested with Microsoft Visual C++ v6.

A version of *lpfg* is also available for Linux.

1.3 Installation

lpfg is distributed with L-studio; refer to the L-studio documentation for installation instructions.

1.4 Running lpfg

lpfg is designed to be used as a single element of a modeling environment, such as L-studio or Vlab. Usually, it will be invoked by the environment, rather than directly by the user.

1.4.1 Command line options

The following command-line options are supported by *lpfg*:

`lpfg [-a] [-d] [-b] [-cn] [-wnb] [-wnm] [-wr w h] [-wpr x y][-wp x y] [-w w h] [-out filename] [-lp path] [-c] [-dll filename.dll] [colormap_file.map] [material_file.mat] [animation_file.a]` [*functionset_file*.fset] [*drawparameters_file*.dr] [*viewparameters_file*.v] [*contourset_file*.cset] [*environmentfile*.e] *Lsystemfile*.l

-wnb – no borders. The lpfg window is created without borders or title bar. Also the output console window is not shown. Used for demonstration purposes.

-wnm – no message window. The output console window is not shown.

-w – *w* and *h* specify the window's size in pixels.

-wr – specify relative window size. *w* and *h* parameters are numbers between 0 and 1 and specify the relative size of the lpfg window with respect to the screen.

-wp – *x* and *y* specify window's top left corner position in pixels relative to the top-left corner of the screen

-wpr – specify relative window position. *x* and *y* parameters specify the position of the top left corner relative to the top left corner of the screen.

-out – specifies the output string filename

-lp – *path* is the path to be used instead of the LPFGPATH environment variable

-c – compile the L-system to the file `lsys.dll` only, do not run the simulation

-dll – causes lpfg not to generate `lsys.dll`, but instead use DLL *filename.dll.* There is no translation of L+C to C++, and the C++ compiler is not invoked. -c and -dll are useful when a simulation is run many times (for instance, from a batch file) and the L-system doesn't change (but some other input file does).

-cn – check for numerical errors in the arguments of turtle movement modules. When this option is included, lpfg checks that the arguments to modules like F and Right are valid numbers. It is useful to track down division-by-zero errors and similar numerical mistakes in your models.

-a – starts *lpfg* in *animate mode*: *first frame* (as specified in the animation file) steps are performed, as opposed to `derivation length`.

`-d` – starts *lpfg* in *debug mode*: some information about the execution of the program is sent to the standard output. This mode is intended to be used by the developers of *lpfg*.

`-b` – starts *lpfg* in *batch mode*: no window is created. The simulation is performed and the final contents of the string is stored in the file specified by the `-out` option. Only module names are stored in the file. This mode cannot be combined with the `-a` switch.

`-s` – starts *lpfg* in *silent mode*: currently no effect

`-v` – starts *lpfg* in *verbose mode*: displays additional information/warning messages.

`-q` – starts *lpfg* in *quiet mode*: All messages, including warnings and errors, are suppressed.

The only mandatory item is the L-system file. Command line parameters can appear in any order.

All the input file types are recognized based on their extension.

If no colormap file or material file is specified then default colormap is used.

1.5 User interface

1.5.1 Multiple views

More than one output window, or *view*, can be opened within the main lpfg window. The views can be opened by the user using a command from the popup menu, or by calling functions from the L-system.

The user is free to open and close views at will; however, when the last view is closed (by the user or from the L-system) lpfg will exit.

1.5.2 View manipulation

- Rotation – *lpfg* uses XY rotation interface based on the *continuous XY rotation*. The model is rotated around the Y axis when the mouse is moved horizontally, and around the X axis when the mouse is moved vertically. To start rotating, hold the left mouse button.
- Roll – to roll the model around the Z axis, hold Shift + middle mouse button. Moving the mouse to the right rotates the model clockwise, moving the mouse to the left rotates the model counter-clockwise.

- Zoom – to zoom, hold Ctrl + left mouse button or the middle mouse button. Moving the mouse up zooms in, moving down zooms out.
- Pan – to pan, hold Shift + left mouse button.
- Change frustum angle – hold Ctrl + middle mouse button. Moving the mouse up increases the angle, moving down decreases the angle. This operation has effect only in perspective projection mode.

1.5.3 Menu commands

To display the menu click the right mouse button inside the *lpfg* window.

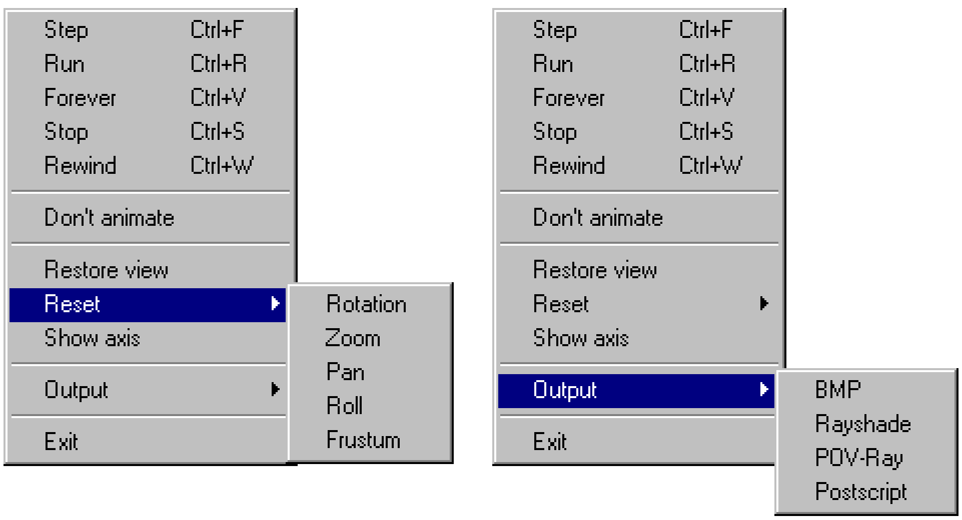


Figure 1 *Lpfg* menu

Step	Advances simulation to the next step. This may correspond to more than one derivation step if parameter *step* in the animate file is present and specifies a value greater than 1.
Run	Starts or resumes the animation.
Forever	Starts or resumes the animation. After the last frame is reached the animation returns to the *first frame* and continues.
Stop	Stops the animation.
Rewind	Resets the animation to the *first frame*.
Don't animate	Stops the animation and generates the image in the still mode (performs the number of derivation steps as specified in the

	`derivation length` statement).
Restore view	Resets rotation, zoom, pan, frustum and roll to the default values.
Reset → Rotation	Resets rotation.
Reset → Zoom	Resets zoom.
Reset → Pan	Resets pan.
Reset → Roll	Resets roll.
Reset → Frustum	Resets frustum (not implemented yet).
Show axes	Turns on or off display of coordinate system axes in the lower left corner.
Output → BMP	Creates image file ***`filename`***`.bmp` containing the current state of the window, where *filename* is the name of the L-system file.
Output → Rayshade	Creates a rayshade file.
Output → POV-Ray	Creates a POV-ray file.
Output → Postscript	Creates a postscript file ***`filename`***`.ps`, where *filename* is the name of the L-system file. All modules `F` are drawn as lines, even if `line style` is set to `cylinder`. If `line style` is `polygon` then modules F are drawn as lines of properly scaled width. The only other modules supported are `Circle` and `Circle0`. No other modules are visualized.
Output → Obj	Creates output file in the Alias/Wavefront .obj format.
Output → View	Creates a file called `viewid.`*`vw`*, where *`vw`* is the numeric id of the current view window. The file contains a single `view:` command (as used in the view file, see section 3.2), describing the current view parameters.
View → *view name*	Opens the specified view window.
View → **Save arrangement**	Creates a file called `winparams.cfg`. This file contains a series of `window:` commands (as used in the view file, see section 3.2), one for every active view, with their current arrangement.

2 The L+C modeling language

L-system input files to *lpfg* use a new L-system-based modeling language, L+C. It is a declarative language which combines L-system constructs (notably, modules and productions) with the general-purpose programming language C++. L-system constructs have syntax which is similar to the traditional notation of L-systems (used, for instance, in *cpfg*); however, this syntax is also not too different from that of C++. The principle advantage of this hybrid approach is that the expressive power of C++ can be used in L+C programs; experience has shown that developing complex models is substantially easier in L+C than in traditional L-system notation.

2.1 L-system file

A typical L-system program file has the following format:

```
#include <lpfgall.h>
derivation length: d;
// declarations of data structures
// declarations of functions
// module declarations
derivation length: n;
axiom: module_list;
// productions
```

All elements of a program can appear in any order except for the following restrictions:

1) all elements referred to in a statement must be declared beforehand. Types used as parameters of a module must be declared before the module is declared. Modules that appear in an `ignore` or `consider` statement must be declared beforehand.
2) Productions are matched in the order in which they are declared.

2.1.1 Mandatory elements

Every L-system must include the statements `derivation length` and `axiom`.

2.1.2 Include files

The first line in the L-system is the `#include` statement. The `lpfgall.h` include file includes the following header files:

- `memory.h` and `stdlib.h` are standard C header files. They are required by the code generated by the L2C translator.

- `lparams.h` – This file contains the declarations and definitions of parameters used by *lpfg*, the L2C translator, and the C++ code generated by the translator, such as the maximum number of parameters per module, the maximum number of modules in a production predecessor, and so on.
- `lintrfc.h` – This file contains declarations and definitions that are used by *lpfg* and the C++ code generated by the L2C translator, such as types used for communication between the L-system and *lpfg*, predefined vector types, and internal types relating to productions and context.
- `lsys.h` – This file contains declarations and definitions required by the C++ code generated by the L2C translator. These include definitions of some predefined functions: `Forward()`, `Backward()`, etc.
- `stdmods.h` contains the declarations of predefined modules.

lpfg standard header files should be treated the same way as the standard C header files: they should never be changed or edited in any way. If they are altered, models might not compile, stop working, or *lpfg* may hang or crash.

2.2 L+C language constructs

A typical L+C program consists of standard C++ declarations (such as data structures, global variables, or function definitions) and L-system constructs. For an introduction to C++ syntax, see a standard C++ textbook; the L-system-specific constructs are described here.

2.2.1 Derivation length

The derivation length must be defined in all L+C files. It specifies the number of derivation steps for the L-system:

```
derivation length: expression;
```

The expression must evaluate to an integer, though other than that there are no restrictions on it. However, some care should be taken that the value is constant; the expression may be evaluated more than once, and *lpfg*'s behaviour is undefined if the value changes.

2.2.2 Module declarations

L+C requires that all modules which are to be used in an L-system be declared. Many standard modules are predefined (see section 2.3); the syntax for declaring new modules is

```
module name(parameters);
```

Here *name* is the module's name, and *parameters* is a list of the types of the module's parameters. For instance:

```
module A(int,int);
module B();
module C(float,data);
```

The module `A` has two parameters, both with type `int`; `B` has no parameters; and `C` has two parameters, the first with type `float`, the second with some previously defined type `data`. If a module has no parameters, it can also be declared omitting the parentheses:

```
module B;
```

All types (such as `data` above) must be defined before being used in the module declaration. In addition, each type must be a single identifier; compound types such as `char*` or `unsigned int` are not allowed. If you want to use these types, use a `typedef` statement to give them single names:

```
typedef char* string;
typedef unsigned int uint;
```

Note also that, unlike function arguments, module parameters have no names; thus, the declaration

```
module A(int id, int age);
```

is illegal. However, it is often useful to note the parameter names:

```
module A(int /* id */, int /* age */);
```

Unlike *cpfg*, a module name cannot be used twice, even with different types or numbers of parameters.

2.2.3 Axiom

The `axiom` statement defines the L-system's axiom. Its syntax is:

```
axiom: module-string;
```

where the *module-string* is a sequence of modules. Some valid axioms are:

```
axiom: A(1,2) B() A(0,0);
axiom: A( idx*2, (int)(sin(x*M_PI)) );
```

If a module has no parameters, you may omit the parentheses:

```
axiom: A(1,2) B A(0,0);
```

2.2.4 `ignore` and `consider`

These statements have the following syntax:

```
ignore: module_names;
```

or

```
consider: module_names;
```

where *module_names* is a sequence of module names. Valid `ignore` or `consider` statements include:

```
ignore: F P RollR;
consider: G A Circle;
```

Only one of `ignore` or `consider` may be used in an L+C program. They affect which modules are considered in context matching when applying productions. By default, all modules are considered when matching contexts. (More or less: see the Appendix *How productions are matched*.) When an `ignore` statement is used, all modules listed in it are ignored for the purposes of matching context. If a `consider` statment is used, only those modules listed are considered in context matching.

`SB` and `EB` modules are always considered. Listing them in an `ignore` or `consider` statement has no effect.

2.2.5 Control statements

There are four control statements which are called by *lpfg* while performing L-system derivation. The statement `Start` is called before the string is initialized to the axiom; the statement `StartEach` is called before each derivation step; the statement `EndEach` is called after each derivation step; and the statement `End` is called after the final derivation step. Any of these four control statements can be defined in the L+C program as procedures, and they may contain any valid C++ statements. For instance, to maintain a global variable `steps` equal to the current derivation step, you could define the control statements:

```
int steps;

Start:
{
  steps = 0;
}

EndEach:
{
  steps++;
}
```

Note: the statement `End` is called after the final derivation step. This means that if you are in Animate mode and stop or rewind the animation before it reaches the final derivation step, the `End` statement is never called. If the `End` statement runs a vital command (for instance, to close an output file), you should make sure that you let the animation reach the final frame.

2.2.6 Productions

Productions define the way the structure defined by the L-system string develops over time by specifying the fate of each module. A production definition has two parts: the predecessor, declaring which module is being changed (the *strict predecessor*), and what context it must be found in; and the production body, declaring how it changes in the next derivation step:

```
predecessor:
{
 production body
}
```

2.2.6.1 The predecessor

The predecessor of a production contains, at a minimum, the strict predecessor. This is the module or sequence of modules which, if the production is applied, will be replaced by new modules at the next derivation step. Valid productions containing only a strict predecessor include:

```
F(x):
{...}

A(age,length) B():
{...}
```

Any parameters must be listed and given unique names, even if they are not used in the production body. Also, unlike the `axiom` and `produce` statements, a module with no parameters must be followed by parentheses `()`.

In addition to the strict predecessor, a production may also list a context to its left or right (or both). These contexts must also be matched within the string for the production to be applied, although only the strict predecessor will be replaced. The left context is set to the left of the strict predecessor, and separated by a <; the right predecessor is to the right, separated by a >. Some examples include:

```
A(ageL,lengthL) < A(age,length) > A(ageR,lengthR):
{...}

B() B() > B() B():
{...}
```

Note that, again, all parameters must be given unique names.

Finally, a production may list either a right or left new context. The new context is an L-system construct new to lpfg. It lets you take advantage of the fact that the actual computation of L-system derivations happens sequentially from one end of the string to the other to transfer information from end to end in a single derivation step. Normally the direction of derivation is from left to right ("forward"); the statements Forward() and Backward() let you control this derivation direction. If the derivation direction is from left to right, the new left context can be used; if the derivation direction is from right to left, the new right context can be used.

These new contexts are set off from the strict predecessor by a << (for left context) or >> (for right context). For example, the production

```
B() << D():
{...}
```

will match if the module `B()` exists in the new left context of the module `D()`.

The new and old contexts can be combined, as in

```
A(age,length) < B() >> B():
{...}
```

which matches an `A(x,y)` in the old left context and a `B()` in the new right context.

Finally, note that a new-context production will never match if the derivation is going in the wrong direction; a new right context will not match if the direction is left-to-right ("forward"), and a new left context will not match if the direction is right-to-left ("backward").

2.2.6.2 Production body

If a production predecessor is matched successfully, *lpfg* executes the production body. This is a block which may contain any valid C++ statement. In the production body, the names given to the module parameters in the predecessor act akin to function parameters in a C++ function.

Normally, the production body will end with a `produce` statement. The `produce` statement ends execution of the production body (like a `return` statement in a C++ function) and tells *lpfg* what the successor is. Its syntax is:

```
produce module_string;
```

where the *module_string* is a sequence of modules. For instance:

```
produce A(newAge,newLength);
produce B() A(x,length*12) B();
```

As with the axiom, if a module has no parameters, the parentheses may be omitted:

```
produce B A(x,length * 12) B;
```

In general, it is possible for a production to end in one of two ways. First, a `produce` statement may be reached. In this case, the production is applied with the given successor. Second, the production body may end execution in some other way: by reaching the end of the block, or by a `return` statement. In this case, the production is considered *not applied*, and *lpfg* will continue to look for a production that does apply to the predecessor. For instance:

```
A(age,length):
```

```
{
 if (age < 10)
        produce A(age+1,length+dl);
}
A(age,length):
{
 if(age >= 10)
        produce B(length);
}
```

The first production will only be applied if the first parameter of the module `A` is less than 10; otherwise, it will not be applied, and the second production will be tried, following the usual application order for L-system productions. The second production will only be applied if the first parameter is greater or equal to 10.

2.2.6.2.1 Alternative successors

It is important to note that a `produce` statement may be found anywhere in the production body where a C++ statement is valid, and causes the production to be applied with the given successor. Just as it is possible in C++ to have alternative return values, it is possible in L+C to choose between alternative successors:

```
A(age,length):
{
 if ( age < 10 )
        produce A(age+1,length+dl);
 else
        produce B(length);
}
```

In this single production, both productions shown in the last section have been combined into one. If the first parameter is less than 10, the first successor will be produced; otherwise, the second successor will be produced.

2.2.6.2.2 Empty successor

A `produce` statement may be issued without a sequence of modules:

```
produce;
```

If this statement is reached in executing the production body, the production will be applied with an empty successor; the strict predecessor will be removed from the string, and will not be replaced. Note the difference between ending with a `return` statement, in which case the production will not be applied, and an empty `produce` statement, in which case the production is applied but produces nothing.

2.2.6.2.3 The `nproduce` statement

It is sometimes useful to build a production's successor incrementally. The `nproduce` statement specifies part of a successor, but, critically, does not end the production. It syntax is like that of the `produce` statement:

```
nproduce module_list;
```

The `nproduce` statement adds the listed modules to the currently defined successor, but does not end execution of the production. A subsequence `produce` statement will add its own argument to the successor, then produce that successor. If the production body ends without a `produce` statement, the production is not applied, and the partial successor is ignored. For instance:

```
A(age,length):
{
  for(int i = 0; i < age; i++)
         nproduce B;
  produce A(age+1,length);
}
```

An empty `produce` statement adds no more modules to the successor, but will still produce the successor specified by `nproduce` statements.

2.2.6.3 Decomposition rules

While productions specify how a structure evolves over time, decomposition rules specify how a structure is composed of substructures. After the axiom and every derivation step, a *decomposition step* is performed. Decomposition is performed as long as the string does not contain any modules that can be further decomposed, or the *maximum decomposition depth* is reached. Syntactically, decomposition rules are very similar to regular productions except for the following differences:

- only one module is allowed in the strict predecessor, and
- decomposition rules are always context-free.

When the statement `decomposition:` is present in the L-system it specifies that all the following rules are decomposition rules, until the end of the source file or until a `production:` or `interpretation:` statement is encountered. The statement `maximum depth:` specifies the maximum decomposition depth. It must be placed in the global scope after the `decomposition:` statement. The syntax of the maximum depth statement is:

```
maximum depth: expression;
```

The default maximum decomposition depth is 1. An L-system may contain many `decomposition` sections, but only one instance of the `maximum depth` statement is allowed: it is applied to all decomposition rules in the program.

Decomposition rules can be *recursive*: the module in the strict predecessor can appear in the successor. For example:

```
decomposition:
maximum depth: 6;
A(age,length):
{
  if (length > 0)
    produce F(1) A(age,length - 1);
}
```

Note: decomposition is internally implemented by a recursive call to a function. If the maximum depth is a very large number the thread stack might overflow, causing *lpfg* to crash.

2.2.7 Interpretation rules

Interpretation rules are syntactically very similar to decomposition rules. To specify interpretation rules the `interpretation:` statement must be given. Like decomposition rules, interpretation rules must have exactly one module in the strict predecessor and must be context-free. A `maximum depth` definition may be given after the `interpretation` statement. As with decomposition rules, there may be only one `maximum depth` definition, which applies to all of the interpretation rules in the program. The default `maximum depth` is 1.

Interpretation rules are equivalent to "homomorphisms" in *cpfg*. They are executed only during the interpretation of the string. Modules produced by interpretation rules are not inserted into the string used in the next derivation step; they are used as commands for the turtle when interpreting the string.

The interpretation step is performed in the following cases:

1. When redrawing the model in the window
2. When generating output file (rayshade, POVray, postscript)
3. When calculating the *view volume*.
4. After axiom and each derivation step, if any of the productions' predecessors contain query or communication modules

Interpretation rules can be helpful in properly expressing visual models. They are especially useful in separating the functional aspect of a model from its graphical display.

2.2.7.1 Visual groups

lpfg allows multiple view windows to be open simultaneously. Each view window has its own interpretation section, called a *visual group*. To specify a visual group use the following syntax:

```
vgroup nn:
```

where *nn* is a numerical identifier. Visual groups are somewhat similar to groups of productions (section 2.2.9.2). By default (no `vgroup` command) interpretation rules belong to vgroup 0. Visual groups can be mixed with groups. For example:

```
interpretation:
group 0:
vgroup 0:
/* Interpretation rules here belong to group 0, vgroup 0 */
vgroup 1:
/* Interpretation rules here belong to group 0, vgroup 1 */
group 1:
/* Interpretation rules here belong to group 1, vgroup 1 */
vgroup 0:
/* Interpretation rules here belong to group 1, vgroup 0 */
```

2.2.8 Production blocks

It is possible to specify regular productions after decomposition and interpretation rules. To specify regular productions use the `production:` statement. This possibility leads to another way to organize models. Instead of dividing the model into `production`, `decomposition`, and `interpretation` sections, all rules that apply to one type of module can be grouped together. For example:

```
production:
A() : { … }
decomposition:
A() : { … }
interpretation:
A() : { … }

production:
B() > A() : { … }
decomposition:
B() : { … }
```

2.2.9 L-systems extensions

2.2.9.1 Ring L-systems

A *ring L-system* provides an alternate topology for the L-system string. The derivation is performed as if the last module in the string and the first module in the string are adjacent, so that the string forms a ring. Productions which are applied to the beginning of the string have their left contexts matched against the end of the string, and productions which are applied to the end of the string have their right contexts matched against the beginning of the string. For example:

```
Axiom: A;
A() < A() > A() : { produce B; }
```

will yield the string `B`, and

```
Axiom: B C A;
C() < A() > B() : { produce D; }
```

will yield the string `BCD`.

To specify a ring L-system, include the statement

```
ring L-system: value;
```

where *`value`* is some nonzero value, or an expression returning a nonzero value.

2.2.9.2 Groups of productions

It is possible to specify alternate groups of productions and switch between them when generating the model. By default, all productions, decompositions, and interpretation rules belong to the default group, numbered 0. To specify productions for another group, use the `group` statement:

```
group number:
```

where *number* is an integer constant. You can switch between groups any number of times. The statement `endgroup` is equivalent to `group 0:` it ends the definition of the current group, and returns to defining the default group.

When *lpfg* is started, the default group of productions is used. The function

```
void UseGroup(int grpid);
```

changes which group of productions is currently in use; it can be called at any time, but will only take effect on the next derivation step.

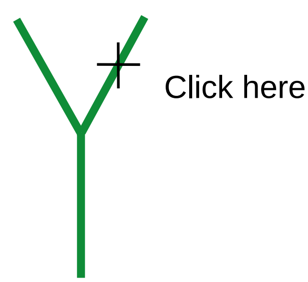
The default group has a special property: if no production in the current group can be applied to a symbol, the productions in the default group will be tried, even if it is not the current group.

2.2.9.3 Interaction with the model

Lpfg makes it possible to interact with a running L-system model. The user can point to an element of the model on the screen and click to insert a predefined module (`MouseIns` or `MouseInsPos`) in the string immediately before the module pointed to by the user. For example, if the current string is

```
F(1) SB Left(30) F(1) EB SB Right(30) F(1) EB
```

then the lpfg window will show a "Y" shape:



If the user clicks on the line as shown, the string will be modified:

```
F(1) SB Left(30) F(1) EB SB Right(30) MouseIns F(1) EB
```

Now, if the L-system contains the production

```
MouseIns() : { produce F(0.2) Cut; }
```

then it will be applied in the next derivation step and the string will become:

```
F(1) SB Left(30) F(1) EB SB Right(30) F(0.2) EB
```

This interaction thus simulates pruning.

To insert the module `MouseIns` press Ctrl and Shift and click with the left mouse button. There is also `MouseInsPos` module that can be inserted by holding Alt and Ctrl while left-clicking. `MouseInsPos` has two parameters:

```
module MouseInsPos(float, float);
```

The values of these parameters are the relative horizontal and vertical position of the mouse on the screen when clicking. The first parameter has a value of 0 if the mouse is at the left edge of the screen, increasing to 1 at the right. The second parameter has a value of 0 at the top of the screen, increasing to 1 at the bottom.

2.2.9.4 Gillespie groups

Gillespie groups are as yet undocumented.

2.3 Predefined functions

There are many functions and structures predefined by *lpfg* for controlling the derivation of the L-system, accessing the system, and for general convenience.

2.3.1 Vector structures

lpfg provides four structures that represent vectors. The structures are:

```
struct V2f
{ float x, y; };
struct V3f
{ float x, y, z; };
struct V2d
{ double x, y; };
struct V3d
{ double x, y, z; };
```

These structures are used as parameters for some predefined modules. They can also be used in the user's code in the L-system. Additionally, if the preprocessor symbol `NOAUTOOVERLOAD` is not defined before `#include <lpfgall.h>`, these structures receive additional functionality: operators for addition, subtraction of two structures of the same type, unary negation, multiplication and division of a vector by a scalar, dot product, and assignment operators `+=`, `-=`, `*=`, and `/=`. In addition, cross product is defined on `V3f` and `V3d`,with operator `%`.

```
V2f a(1.5, 2.0), b(0, 0.5);
V2f c = a + 2.5*b;
float x = a * b;

V3f d(1.2,2.3,0) , e(0,0.5,0.1);
V3f f = d % e;
```

Two further methods are defined:

`f Length();` returns the vector's length (as float or double, depending on the structure).

`void Normalize();` normalizes the vector. (This function's behaviour is undefined if the vector's `Length()` is zero.)

`void Set(x, y);` sets the `x` and `y` components of a `V2f` or `V2d`; `V3f` and `V3d` have a corresponding method `Set(x, y, z).`

Refer to the file `lintrfc.h` in the `lpfg/include` directory to see full definition of these structures.

2.3.2 Controlling L-system derivation

`void Forward()`

This function specifies that the derivation of the string should be performed forward – from left to right. This is the default.

`void Backward()`

This function specified that the derivation of the string should be performed backward – from right to left.

`Forward` and `Backward` can be used anywhere in the code where it is legal to call a function. They take effect on the next derivation step. In particular, if called in the `StartEach` statement, they affect the immediately succeeding derivation step.

`bool IsForward()`

Returns the last derivation direction, as set by `Forward` or `Backward`. **Note:** this function returns a variable set by `Forward` and `Backward`. Consequently, it may not reflect the current derivation direction if it is changed *during* a derivation step.

`void Environment(); void NoEnvironment().`

These functions specify whether or not the "interpretation for environment step" should be performed after the current derivation step. `NoEnvironment` turns the environment off unconditionally.

`void UseGroup(int);`

Specifies current group of productions that should be used. See *Table L-systems*.

`int CurrentGroup();`

Returns the number of the current group. See *Table L-systems*.

`void DisplayFrame();`

Displays a frame of the animation at the current derivation step, when `display on request` is `on` in the animation file. If `display on request` is `off`, this function has no effect.

`void Stop();`

Stops the simulation. The `End` statement is executed after the current derivation step.

2.3.3 Manipulating views

To manipulate multiple views use the following functions:

`void UseView(int vid);`

opens or activates view identified by *vid*.

`void CloseView(int vid);`

closes the view identified by *vid*. If the view is not open, a warning message will be printed.

The L-system can also access some of the current view parameters.

```
float vvXmin(int id);
float vvYmin(int id);
float vvZmin(int id);
float vvXmax(int id);
float vvYmax(int id);
float vvZmax(int id);
```

return the coordinates of bounding box of view number `id`.

`float vvScale(int id);`

returns the current projection scaling factor of view number `id`.

2.3.4 External access

```
void Printf(const char*, …).
```

This function is similar to the standard C function `printf`. Its use is recommended over the `printf` for the following reasons:

- Output generated by `printf` is not stored in the `lpfg.log` file.
- In the future releases *lpfg* might not be connected to any console, but instead provide its own output window (like *cpfg*'s message log). In that case, output of `printf` would not be visible anywhere.

```
void Run(const char* cmnd);
```

This function works like standard C `system` function, except that it does not wait for the called process to terminate. It is equivalent to adding a '&' at the end of the command in a Unix shell.

```
void OutputString(std::string filename);
void LoadString(std::string filename);
```

These functions write the current string to a file and overwrite the current string with a saved string, respectively. At the moment, it is not checked if `LoadString` is called during a production or a control block. If it is called during a production, then lpfg will probably crash. Calling during a control block is safe. Note also that it is only the string that is saved and loaded, not any global variables that you may have created.

2.3.5 Curves and functions

```
float func(int id, float x)
```

This function returns the value of function `id` in the function-set file (if one is specified on the command line). The parameter `id` must be in the range [1, *num of functions*]. The second parameter is the *x* value whose *y* value is requested. *x* must be in the range [0, 1].

If the parameter `id` is incorrect (outside the range), the value 0 is returned and a warning message is printed. If the parameter `x` has invalid value then:

- if `x < 0` then `func(id, 0)` is returned, or
- if `x > 1` then `func(id, 1)` is returned

In the case of invalid value of `x`, a warning message is printed in Verbose mode only.

When calling the pre-processor *lpfg* `#define`s macros with the names of the functions in the .fset file. The values correspond to the numerical identifiers of the functions. For example: if the first function in the .fset file is named `Func1` then the following macro is defined: `#define Func1 1`.

Consequently it is possible to call `func` using the identifier `Func1` instead of the integer literal 1: `float y = func(Func1, 0.5);`

```
float curveX(int id, float t);
float curveY(int id, float t);
float curveZ(int id, float t);
V2f curveXY(int id, float t);
V3f curveXYZ(int id, float t);
```

These functions return the coordinates of the curve defined in a contour-set file. `id` is the number of the curve, and `t` is the arc-length parameter. When calling the pre-processor, *lpfg* will `#define` numerical values for the names of the curves, just as for functions (see above).

```
void curveScale(int id, float x, float y, float z);
```

Scales the curve identified by `id` by the factors `x`, `y`, and `z`.

```
void curveSetPoint(int id, int p, float x, float y, float z);
```

Assigns the `p`th control point of curve `id` the position `(x,y,z)`. After this function is used the curve must be recalculated by a call to

```
void curveRecalculate(int id);
```

in order for the curveX|Y|Z functions to return the proper values.

```
void curveReset(int id);
```

Resets the curve to the state defined in the .cset file. The file is not re-read.

2.3.6 Dynamic surfaces

LPFG makes it possible to create and use dynamic surfaces. Dynamic surfaces are single-patch Bezier surfaces that can be manipulated from within the L-system. They are useful, for example, when creating an animation with the use of "keyframe" surfaces, or when building a family of similar surfaces that are modifications of a predefined set of base surfaces.

The manipulations that can be performed on dynamic surfaces include:

- Non-uniform scaling
- Linear interpolation between surfaces
- Manipulation of individual control points defining the surface

The central point in the manipulation of the dynamic surfaces is the class `SurfaceObj` defined in `lintrfc.h`.

Creating dynamic surfaces

There are two basic ways of initializing a dynamic surface object for further manipulation:

- Using a predefined surface (surface loaded into the object using the surface: command in the view file)
- Creating a surface from scratch by initializing coordinates of individual control points

To use a predefined surface use the GetSurface function:

```
SurfaceObj GetSurface(int id);
```

This function takes the numerical identifier of the surface and returns a SurfaceObj object that contains the control points of the predefined surface. If the predefined surface contains more than one patch only the first patch is returned. For the numeric identifier you can use the same symbolic identifiers that are available for the `Surface` and `Surface3` modules.

To create a surface by initializing its control points individually, use the `SurfaceObj::Set` method (described below).

Manipulating dynamic surfaces

To get the coordinates of a control point use the Get method:

```
V3f SurfaceObj::Get(int id) const;
```

To set explicitly coordinates of a control point, use one of the Set methods:

```
void SurfaceObj::Set(int id, const float* arr);
void SurfaceObj::Set(int id, const V3f& v);
```

The scalar multiplication operator allows the scaling of the surface object by a real number:

```
const SurfaceObj& SurfaceObj::operator*(float r);
```

To scale the surface non-uniformly (by different factor in every direction) make the scaling factors coordinates of a V3f vector and use the method:

```
void SurfaceObj::Scale(V3f scale);
```

The addition operator combines two surfaces by pointwise adding their control points.

```
friend SurfaceObj operator+(const SurfaceObj& l, const SurfaceObj& r);
```

The addition operator, along with the scalar multiplication operator, defines a vector space over Bezier patches. This can be used to interpolate between surfaces. For example:

```
SurfaceObj s1, s2;
float weight;
…
SurfaceObj interpolated = s1*weight + s1*(1-weight);
```

Drawing dynamic surfaces

To draw a dynamic surface, use the DSurface module.

```
module DSurface(SurfaceObj);
```

Example

Let us consider a developmental model of a plant. In the model individual leaves are represented by module L(float). The parameter specifies the age of the leaf. The values of age are in range [0, 1].

Let us also assume that the lpfg model contains two one-patch surfaces (commands surface: in the view file) named L_YOUNG and L_MATURE. The following interpretation rule could be used to render the leaf by interpolating between the two predefined surfaces.

```
interpretation:
Leaf(age) :
{
  SurfaceObj young = GetSurface(L_YOUNG);
  SurfaceObj mature = GetSurface(L_MATURE);
  SurfaceObj leaf_surface = young*(1-age) + mature*age;
  produce DSurface(leaf_surface);
}
```

2.3.7 Other predefined functions

`float ran(float range)`

Generates a pseudorandom number uniformly distributed in the range [0, range).

`void sran(long seed)`

Seeds the pseudorandom number generator used by `ran`. You can use `sran` in the `Start` control block, for instance, to ensure that every run is identical, even after rewinding.

`void SeedGillespie(long seed)`

Seeds the pseudorandom number generator used by the Gillespie engine. You can use `SeedGillespie` in the `Start` control block, for instance, to ensure that every run is identical, even after rewinding.

2.4 Predefined modules

The following table lists all of the predefined modules.

Module	Description	Equivalent in *cpfg*

Modeling branching structures

`SB()`	Starts a new branch by pushing the current state of the turtle onto the turtle stack.	`[`
`EB()`	Ends a branch by popping the state of the turtle from the turtle stack.	`]`
`Cut()`	Cuts the remainder of the current branch. If the derivation direction is from left to right (“forward”), then when this module is detected in the string during a derivation, it and all following modules up to the closest unmatched `EB` module are ignored for derivation purposes. If no unmatched `EB` module can be found, symbols are ignored until the end of the string. This symbol has no effect if the derivation direction is from right to left (“backward”).	`%`

Changing position and drawing

Turtle commands

`F(float /*d*/)`	Moves forward a step of length `d` and draws a line segment from the original position to the new position of the turtle. If the polygon flag is on (see modules SP, PP and EP), the final position is recorded as a vertex of the current polygon.	`F(d)`
`f(float /*d*/)`	Moves forward a step of length `d`. No line is drawn. If the polygon flag is on, the final position is recorded as a vertex of the current polygon.	`F(d)`
`G(float /*d*/)`	Same as F, except that it does not create polygon vertices	`G(d)`
`g(float /*d*/)`	Same as f, except that it does not create polygon vertices	`g(d)`
`MoveTo (float /*x*/, float /*y*/, float /*z*)`	Sets the turtle’s position to (`x`, `y`, `z`).	`@M(x,y,z)`
`MoveTo3f (V3f /*p*/)`	Moves the turtle to point p.	`@M`
`MoveTo3d (V3d /*p*/)`	Same as `MoveTo3f`.	`@M`
`MoveTo2f (V2f /*p*/)`	Moves the turtle to point `p`. The *z* coordinate is assumed to be 0.	`@M`
`MoveTo2d (V2d /*p*/)`	Same as `MoveTo2f`.	`@M`
`MoveRel3f (V3f /*p*/)`	Move the turtle to the point `p2` = (*turtle position*) + `p`. The heading, left and up vectors are not changed.	
`MoveRel3d (V3d /*p*/)`	Same as `MoveRel3f`.	
`MoveRel2f (V2f /*p*/)`	Same as `MoveRel3f`, except that *z* coordinate is assumed to be 0.	
`MoveRel2d (V2d /*p*/)`	Same as `MoveRel2f`.	

Affine geometry support

`Line3f (V3f /*p1*/,`	Draws a line from the point `p1` to the point `p2`. After the interpretation of the module, the turtle position is equal to	

V3f /*p2*/)	p2. Heading, left and up vectors are not changed. If the distance between p1 and p2 is less than ε (a constant set to 10^{-5}), the module is ignored.	
Line3d (V3d /*p1*/, V3d /*p2*/)	Same as Line3f.	
Line2f (V2f /*p1*/, V2f /*p2*/)	Same as Line3f, except that the *z* coordinate is assumed to be 0.	
Line2d (V2d /*p1*/, V2d /*p2*/)	Same as Line2f.	
LineTo (float /*x*/, float /*y*/, float /*z*)	Draws a line from the turtle's current position to the point (x, y, z).	
LineTo3f (V3f /*p*/)	Draws a line from the current turtle position to the point p. After the interpretation of the module the turtle position is equal to p. Heading, left and up vectors are not changed. If the distance from the current position to p is less than ε, the module is ignored.	
LineTo3d (V3d /*p*/)	Same as LineTo3f.	
LineTo2f (V2f /*p*/)	Same as LineTo3f, except that *z* coordinate is assumed to be 0.	
LineTo2d (V2d /*p*/)	Same as LineTo2f.	
LineRel3f (V3f /*p*/)	Draws a line from the current turtle position to the point p2 = (*turtle position*) + p. After the interpretation of the module the turtle position is equal to p2. Heading, left and up vectors are not changed. If the length of vector p is less than ε, the module is ignored.	
LineRel3d (V3d /*p*/)	Same as LineRel3f.	
LineRel2f (V2f /*p*/)	Same as LineRel3f, except that *z* coordinate is assumed to be 0.	
LineRel2d (V2d /*p*/)	Same as LineRel2f.	

Turtle rotations

Left (float /*a*/)	Turns left by angle a around the **U** axis.	+(a)
Right (float /*a*/)	Turns right by angle a around the **U** axis.	-(a)
Up(float /*a*/)	Pitches up by angle a around the **L** axis.	^(a)
Down (float /*a*/)	Pitches down by angle a around the **L** axis.	&(a)
RollL (float /*a*/)	Rolls left by angle a around the **H** axis.	\(a)
RollR (float /*a*/)	Rolls right by angle a around the **H** axis.	/(a)
TurnAround()	Turns around 180 degrees around the **U** axis. This is	|

	equivalent to `Left(180)` or `Right(180)`. It does not roll or pitch the turtle.	
`SetHead (float /*hx*/, float /*hy*/, float /*hz*, float /*ux*/, float /*uy*/, float /*uz*)`	Sets the heading vector of the turtle to `hx`, `hy`, `hz` and the up vector to `ux`, `uy`, `uz`. The left vector is set to the cross product of the new **H** and **U**. The values do not need to specify normalized vectors. The module is ignored if any of the following is true: a) `(hx,hy,hz)` specify a vector of length less than ε b) `(ux,uy,uz)` specify a vector of length less than ε c) Length of the cross product of new **H** and **U** is less than ε.	`@R (hx,hy,hz, ux,uy,uz)`
`RollToVert()`	Rolls the turtle around the **H** axis so that **H** and **U** line in a common vertical plane, with **U** closer to up than down.	`@v`

Changing turtle parameters

`IncColor()`	Increases the current colour index or material index by one.	`;`
`DecColor()`	Decreases the current colour index or material index by one.	`,`
`SetColor (int /*n*/)`	Sets the current colour index or material index to `n`. If `n` is less than 1 or greater than 255, the module is ignored.	`;(n)` `,(n)`
`SetWidth (float /*v*/)`	Sets the current line width to `v`. If `v`≤0, the module is ignored.	`#(n)` `!(n)`

Drawing circles and spheres

`Circle (float /*r*/)`	Draws a circle in the HL plane, centered at the current turtle position and with radius r. The number of sides in the approximation is controlled by the `contour sides:` parameter in the view file and the `ContourSides` module, as for generalized cylinders.	`@o(d)`
`Sphere (float /*r*/)`	Draws a sphere of radius `r` at the current turtle position.	`@O(d)`
`Circle0()`	Draws a circle of diameter equal to the current line width in the HL plane.	`@o`
`Sphere0()`	Draws a sphere of diameter equal to the current line width.	`@O`
`CircleFront (float /*r*/)`	Draws a circle of radius `r` in the screen plane.	
`CircleFront0()`	Draws a circle of diameter equal to the current line width in the screen plane.	

(Note that in *cpfg*, the parameters of the modules `@o` and `@O` specify the diameter, not the radius.)

Drawing other shapes

`Rhombus(float /*length*/, float /*width*/)`	Draws a rhombus in the HL plane.	
`Triangle(float /*width*/, float /*height*/)`	Draws an isosceles triangle.	

`SP()`	Starts a polygon.	`{`
`EP()`	Ends a polygon.	`}`
`PP()`	Sets a polygon vertex. There may be at most 16 vertices in a polygon.	`.`
`Orient()`	Draws three lines of unit length at the turtle's current position. The red line represents the heading vector, the green line represents the left vector, and the blue line represents the up vector. This module is useful for model debugging.	

Drawing bicubic parametric surfaces

`Surface (int /*id*/, float /*scale*/)`	Draws the predefined Bezier surface identified by the identifier `id` at the current location and orientation. The surface is uniformly scaled by the factor `scale`. Surfaces are specified in the view file. The first surface specified in the view file has `id`=0. Like functions and contours, surface names are `#defined` by *lpfg*.	`~`
`Surface3 (int /*id*/, float /*xscale*/, float /*yscale*/, float /*zscale*/)`	Draws the predefined Bezier surface identified by the identifier `id` at the current location and orientation. The surface is scaled independently along the X, Y, and Z axes by `xscale`, `yscale`, and `zscale`, respectively.	`~`
`BSurface (int /*id*/, float /*scale*/)`	Draws the predefined B-spline surface identified by the identifier `id` at the current location and orientation. The surface is uniformly scaled by the factor `scale`. B-spline surfaces are specified in the view file with the command `bsurface` (see below).	
`SetUPrecision (float /*precsn*/)`	Sets the drawing precision of bicubic surfaces in the U direction. If set to an invalid value (such as zero), the U precision resets to the surface default, defined in the view file.	
`SetVPrecision (float /*precsn*/)`	Sets the drawing precision of bicubic surfaces in the V direction. If set to an invalid value, the V precision resets to the surface default.	
`InitSurface (int /*id*/)`	Initializes the L-system-defined surface with id `id`. Currently, there is only one surface allowed, so the parameter is ignored.	`@PS`
`SurfacePoint (int /*id*/, int /*p*/, int /*q*/)`	Sets the (`p`,`q`) control point (with 0 ≤ `p`, `q` < 4) of the L-system-defined surface with id `id` to the current turtle position. The first parameter is ignored.	`@PC`
`DrawSurface (int /*id*/)`	Draws the L-system defined surface with id `id`. The parameter is currently ignored.	`@PD`
`DSurface (SurfaceObj /*s*/)`	Draws the given `SurfaceObj`. See the section on "Dynamic Surfaces" above.	

Drawing generalized cylinders

`CurrentContour (int /*id*/)`	Sets the contour specified by `id` as the current contour for generalized cylinders. If `id` equal to 0 is specified then the default contour (circle) is used.	`@#(id)`
`StartGC()`	Starts a generalized cylinder at the current turtle position.	`@Gs`

`PointGC()`	Specifies a control point on the central line of the generalized cylinder.	`@Gc(n)` (but not exactly)
`EndGC()`	Ends a generalized cylinder.	`@Ge`
`CurrentContours (int /*id1*/, int /*id2*/, float /*blend*/)`	Sets the current contour to be an interpolated contour between `id1` and `id2` with blending coefficient blend. At `blend`==0, the contour is `id1`; at `blend`==1, the contour is `id2`.	
`ScaleContour (float /*p*/, float /*q*/)`	Scales the contour independently by `p` (left) and `q` (up)	
`ContourSides (int /*sides*/)`	Specifies how many sides generalized cylinders will be drawn with. If this module is interpreted outside a generalized cylinder (that is, before StartGC and after EndGC, if any), then it affects all subsequent generalized cylinders. If it is interpreted within a generalized cylinder, it is ignored.	
`CurrentTexture (int /*txtid*/)`	Specifies which texture should be used to texture map generalized cylinders. Calling this function with `txtid` = 0 will turn off texture mapping of generalized cylinders.	
`TextureVCoeff (float /*v*/)`	Sets the texture's v coordinate scaling factor. If `v = 1`, then when the turtle moves forward by one unit, the generalized cylinder will be textured by the entire texture. If, for instance, you want to texture a cylinder 10 units long, then setting the v scaling factor to 0.1 will map the texture exactly onto the cylinder. If the texture's v coordinate exceeds one, then the texture wraps (sets v to 0).	

Tropism

`SetElasticity (int /*id*/, float /*v*/)`	Sets the elasticity parameter of tropism `id` to `v`.	`@Ts`
`IncElasticity (int /*id*/)`	Increments the elasticity parameter of tropism `id` by the elasticity step parameter of the tropism.	`@Ti`
`DecElasticity (int /*id*/)`	Decrements the elasticity parameter of tropism `id` by the elasticity step parameter of the tropism	`@Td`

Simple tropism

`Elasticity (float /*v*/)`	Sets the elasticity to `v`.	`_` `(underscore)`

Query and communication modules

`GetPos (float /*x*/, float /*y*/, float /*z*/)`	Queries the current turtle position. If any *query module* is present in the predecessor of any production in the L-system, a special interpretation step is performed after each generate step, when productions are applied. The string is interpreted even if no drawing occurs. During the interpretation the three parameters of the module are set to the `x`, `y` and `z` coordinates of the current turtle position.	`?P(x,y,z)`

`GetHead (float /*x*/, float /*y*/, float /*z*)`	Queries the current turtle heading vector.	`?H(x,y,z)`
`GetLeft (float /*x*/, float /*y*/, float /*z*)`	Queries the current turtle left vector.	`?L(x,y,z)`
`GetUp (float /*x*/, float /*y*/, float /*z*)`	Queries the current turtle up vector.	`?U(x,y,z)`
`E`*n*`(float …)`	Communication modules used to send and receive environmental information. There are different modules for different numbers of parameters: E1(float), E2(float,float), E3(float,float,float), and so on.	`?E(v)`
`MouseIns()`	When the user holds Ctrl and Shift and left clicks on a module in the simulator window, the `MouseIns` module is inserted immediately before the clicked-on module in the string.	
`MouseInsPos (float /*xr*/, float /*yr*/)`	When the user holds Ctrl and Alt and left clicks on a module in the simulator window, the `MouseInsPos` module is inserted immediately before the clicked-on module in the string. The parameters give the relative position of the mouse on the screen while clicking: `xr` is 0 at the left edge of the screen, increasing to 1 and the right edge; `yr` is 0 at the top of the screen, increasing to 1 at the bottom.	

Miscellaneous

`Label(Text str)`	Prints the string `str` in the drawing window at the current turtle location. `Text` is a datatype defined in `lintrfc.h` as `const char*`.	`@L(str)`

3 Other input files

3.1 Animation parameters file

Command	Comments
`first frame:` *n*	Derivation step to be interpreted as the first frame. Default is 0. **Note:** in *cpfg*, the first frame defaults to 1. This is why Rewind in *cpfg* rewinds to the first derivation step, while in *lpfg* Rewind rewinds to axiom.
`last frame:` *n*	Derivation step to be interpreted as the last frame. Default is the number of derivation steps.
`swap interval:` *t*	Minimum time interval between frames.
`step:` *n*	Number of derivation steps between drawing of frames. Default is 1

`double buffer: on|off`	Specifies if the double buffer mode should be used. Default is `on`.
`clear between frames: on|off`	Specifies whether to clear the screen between frames. Default is `on`.
`hcenter between frames: on|off`	Specifies whether model should be horizontally centered between frames. Default is off.
`scale between frames: on|off`	Specifies whether the model should be scaled to fit in the *lpfg* window between frames. Default is off.
`New view between frames: on|off`	Currently has no effect.
`display on request: on|off`	If "on", then when running an animation, only the first and last frame are displayed automatically. To display a frame, the L-system must call the function DisplayFrame(). This makes it possible to skip drawing frames which do not advance time, but perform other calculations. If "off" (the default), then frames are displayed according to the "step" parameter.
`frame numbers: consecutive|stepno`	Specifies the way the frames are numbered when the "Recording" menu command is checked. If "consecutive" (the default), each file's number reflects the frame number, not the derivation step. If this parameter is set to "stepno", the number in the filename is the derivation step number.

3.2 Draw/view parameters file

Drawing and viewing parameters are stored in the view file. This file can have extension `.v` or `.dr`. The view file is preprocessed by the C++ preprocessor; therefore, the use of comments (both C style `/* … */` and C++ style `//`), as well as `#define`s, `#if`s, and all other standard preprocessor directives are allowed. The commands are interpreted in the order in which they appear in the file. If there are two or more commands that specify the same parameter, the last one takes precedence. This does not apply to commands that specify new set of parameters every time they appear (e.g. *lights*, *tropisms*). Every command must be contained on a single line.

Command	**Comments**
Setting the view	
`projection: parallel | perspective`	Default is `parallel`.
`scale factor: `*`s`* `scale: `*`s`*	*s* specifies the size of the final image on the screen. 1.0 corresponds to full size. Default is 0.9. Either scale or scale factor may be used; they are equivalent.
`min zoom: `*`v`*	*v* specifies the minimum value of zooming factor (see Interactive view manipulation). Default is 0.05.
`max zoom: `*`v`*	*v* specifies the maximum value of zooming factor (see Interactive view manipulation). Default is 50.
`line style: `*`style`*	*style* must be one of the following: `pixel`, `polygon` or `cylinder`. Default is `pixel`.
`front distance: `*`x`*	*x* specifies the distance to the front clipping plane

`back distance:` *`x`*	*x* specifies the distance to the back clipping plane
`regenerate view:` `on | off | triggered`	Defaults to *off*. If *on,* the L-system string is regenerated (the simulator rewinds to the axiom and performs derivations again) every time the view changes (through rotation, zoom, or pan). If *triggered*, the string is regenerated after the user completes each view change (after the user releases the mouse button). (*triggered* is currently the same as *on*.)
`view:` *`id rotx roty roll scale panx pany panz`*	Defines the view transform to be used for the view window with id *`id.`*

`window:` *`name left top width height`*	Declares that the window with the given name should be placed with its top left corner at relative position (*left*,*top*) within the main lpfg window, with relative width and height *width* and *height*. The views will be numbered in the order in which they appear in the view file, and the name *name* will be `#defined` as the view number, so that the L-system can contain commands like:
	`UseView(Plant);`
	`vgroup Graph:`

Rendering parameters

`z buffer: on|off`	Default is `off`.
`render mode:` *`mode`*	*Mode* must be one of the following: `filled`, `wireframe` or `shaded`. Default is `filled`.
`light:` *`command`*$_1$ *`command`*$_2$ …	Each *command* must be one of the following: `O: x y z` origin of point light source `V: x y z` vector of directional source `A: r g b` ambient `D: r g b` ambient `S: r g b` specular `P: x y z e c` spotlight with the direction (`x`,`y`,`z`), exponent `e`, cutoff angle `c` `T: c l q` attenuation factors. Up to 8 lights can be specified. (8 is the minimum number of lights that must be supported according to the OpenGL specifications.)
`contour sides:` *`sides`*	Specifies the number of sides that will be drawn on generalized cylinders. This command affects all generalized cylinders in the model; however, it is overridden by either the `ContourSides` module or the contour-specific “samples” parameter.

Other commands

`surface:` *`filename [scale [s-div t-div [txid]]]`*	Declares a predefined Bezier surface. The `surface` command can be used with 1, 2, 4, or 5 parameters. The required parameter *filename* is the filename of a surface (`.s`) file. *scale*, which defaults to 1, is a file-specific scaling parameter which is multiplied by the scaling parameter specified in the `Surface` module to produce the total scaling factor. *s-div* and *t-div* specify the number of subdivisions to draw along the s and t axes. *txid*, if present, specifies the identifier of the texture associated with the surface. See the description of the module `Surface` in Predefined modules. **Note:** this command may be dropped in a future version when the surface gallery is introduced.
`bsurface:`*`filename [scale`*	Declares a predefined B-spline surface. The `bsurface` command

[s-div t-div [txid]]]	can be used with 1, 2, 4, or 5 parameters. The required parameter *filename* is the filename of a surface (`.s`) file. *scale*, which defaults to 1, is a file-specific scaling parameter which is multiplied by the scaling parameter specified in the `Surface` module to produce the total scaling factor. *s-div* and *t-div* specify the number of subdivisions to draw along the s and t axes. *txid*, if present, specifies the identifier of the texture associated with the surface. See the description of the module `BSurface` in Predefined modules.
`texture:` *filename*	*filename* specifies the image file that contains the texture. Both width and height of the image must be powers of 2. Textures are indexed starting at 0. Currently only SGI RGB files are supported.
`tropism:` *command*$_1$ …	Each *command* must be one of the following: `T: x y z` tropism vector (required) `A: a` angle. Default is 0. `I: x` intensity. Default is 1 `E: e` elasticity. Default is 0 `S: de` elasticity step. Default is 0. Any number of tropisms can be specified in the view file.
`torque:` *command*$_1$ …	Each *command* must be one of the commands valid for tropism except for `A`.
`winfont:` *font size* `[bi]`	Specifies the font to be used for the module Label. `Font` is the name of the font. If the name consists of more than one word (e.g. Times New Roman) it should be enclosed in the quotation marks ("Times New Roman"). `Size` specifies the font size in pixels. Optional `b` and `i` flags specify bold and italic respectively.
`stropism:` *x y z, e*	Specifies the direction and elasticity of the tropism. This is the "old-style tropism" or "simple tropism" as introduced in cpfg by Jim Hanan.

3.3 Environment parameters file

The environment parameters file has extension `.e`. It is read in by both *lpfg* and the environmental program, and defines how they should communicate.

Command	**Remarks**
`executable:` *command*	Specifies the environmental process's executable, together with its optional command line parameters
`communication type:` `pipes|sockets|memory|files`	Ignored. The only communication supported in the current version is files.
`following module: on|off`	Defines whether the module following the communication module is sent to the environmental process. Default is `off`. If the following module has parameters, they must all be `float`s.
`turtle position:` *format* `turtle heading:` *format* `turtle left:` *format* `turtle up:` *format* `turtle line width:` *format* `turtle scale factor:` *format*	printf-like format string used when sending turtle parameters. All are optional, but most environmental programs will require at least the turtle position. For example: `Turtle position: P: %f %f %f`
`verbose: on|off`	Verbose mode generates additional information about the details of the communication

3.4 Miscellaneous input files

All of these file formats are described in the CPFG User's Manual.

3.4.1 Colourmap file

Specifies 256 colours. Colourmap mode is used to create schematic images. See also material file.

3.4.2 Material file

Specifies 256 materials. Materials are specified by the following components: ambient colof, diffuse color, specular color, emission color, specular exponent, and transparency. See the OpenGL documentation for further explanation. Material mode is used to create realistic images.

3.4.3 Surface file

Specifies surfaces composed of one or more Bézier patches.

3.4.4 Function-set file

Specifies functions of one variable. The functions are defined as B-spline curves constrained in such a way that they assign exactly one *y* to every *x* in the normalized function domain [0, 1].

3.4.5 Contour-set file

Specifies contours defined as planar B-spline curves. The curves are considered as cross-sections of generalized cylinders.

3.4.6 Textures

Currently the only supported format of textures is SGI RGB. Textures in the RGB format may contain Alpha (transparency) channel.

4 Appendix: How productions are matched

When rewriting the string it is necessary to determine which production must be applied to each module in the string. The process of determining the applicable production is called *production matching*. For every module in the string, productions are checked for matching. The productions are checked in the order in which they are specified in the L-system.

For a production to match, all three components of the predecessor (left context, strict predecessor and right context) must match. The rules for matching each of these components are different. This is because the L-system string is a means of representing branching structures and symmetric operations on the string do not (in general) correspond to symmetric operations on the branching structure.

This section contains a detailed explanation of rules that control the process of production matching. The notation used here utilizes symbols [and] to denote beginning of branch and end of branch (modules `SB` and `EB` in lpfg).

When the strict predecessor is compared with the contents of the string in the current position in order for it to match the modules in the strict predecessor have to match exactly the modules in the string.

When matching the right context and a module in the context is not the same as module in the string the following rules apply:

- If a module in the string is [and the module expected is not [then the branch is skipped. This rule reflects the fact that modules may be topologically adjacent, even though in the string representation of the structure the two modules may be separated by modules representing the lateral branch `B` (see Figure 2).
- When a branch in the right context ends (with a right bracket) then the rest of the branch in the string is ignored by skipping to the first unmatched]. This rule also reflects the topology of the branching structure, not its string representation. For example in Figure 3, module `C` is closer to `A` than `D`.
- If multiple lateral branches start at a given branching point, then the predecessor in Figure 3 would check the first branch (see Figure 4). To skip a branch it is necessary to specify explicitly which branch at the branching point should be

tested (see Figure 5). This notation is a simple consequence of the rule presented in Figure 3. In the current L-system notation there is no shortcut to specify the second, third etc. lateral branch in a branching point without explicitly including pairs [ ] in the production predecessor. There is also no way to specify “any of the lateral branches”.

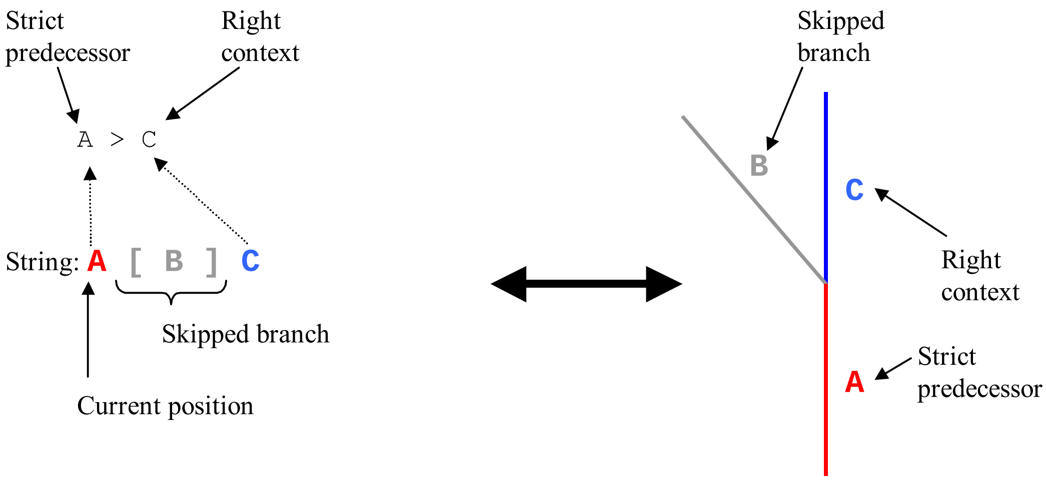


Figure 2 Matching right context, lateral branches are implicitly ignored

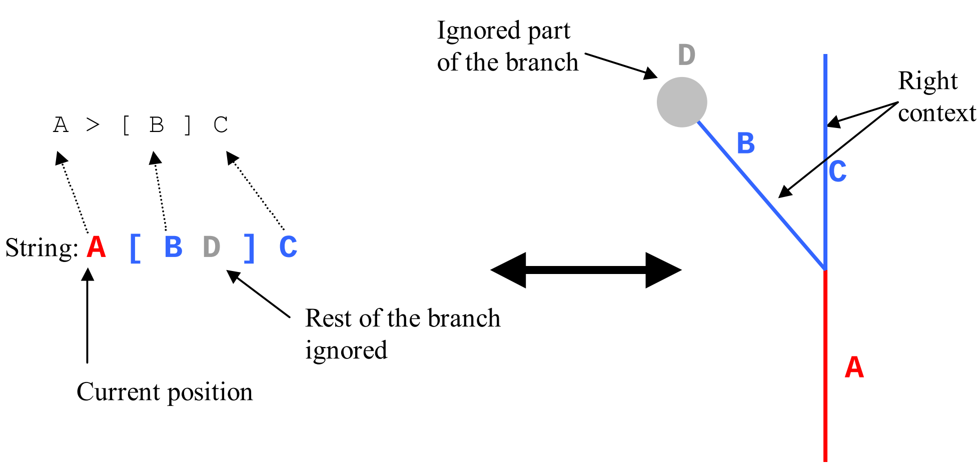


Figure 3 Matching right context, remainder of lateral branch is implicitly ignored

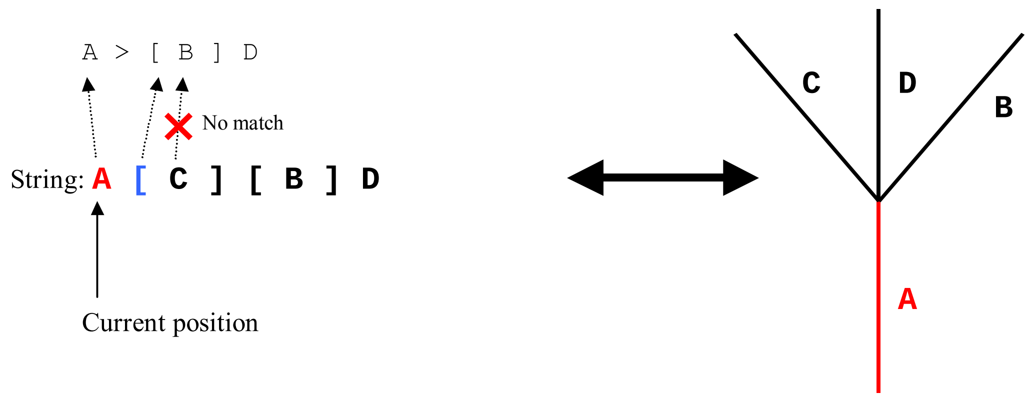


Figure 4 Problem with multiple lateral branches when matching the right context

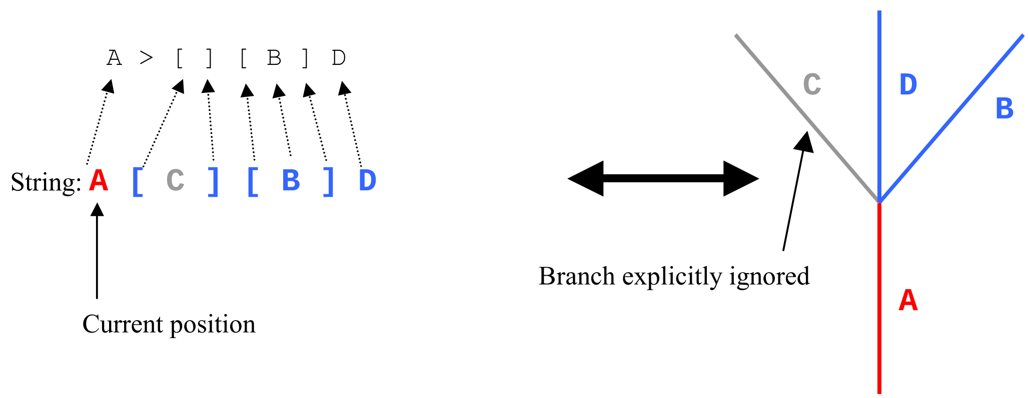


Figure 5 Explicit enumeration of lateral branches in the right context

When matching the left context the following rules apply:

- Module [is always skipped, since the preceding module will be topologically adjacent (see Figure 6).
- If the module in the string indicates the end of a branch then the entire branch is skipped (Figure 7).

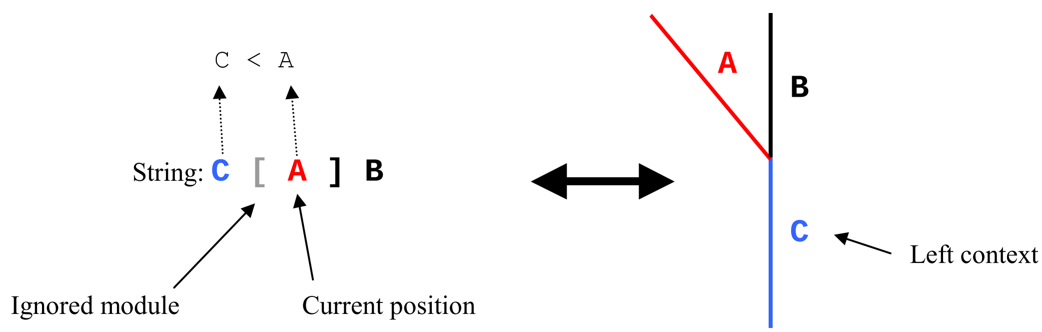


Figure 6 Matching left context, beginning of the branch implicitly ignored

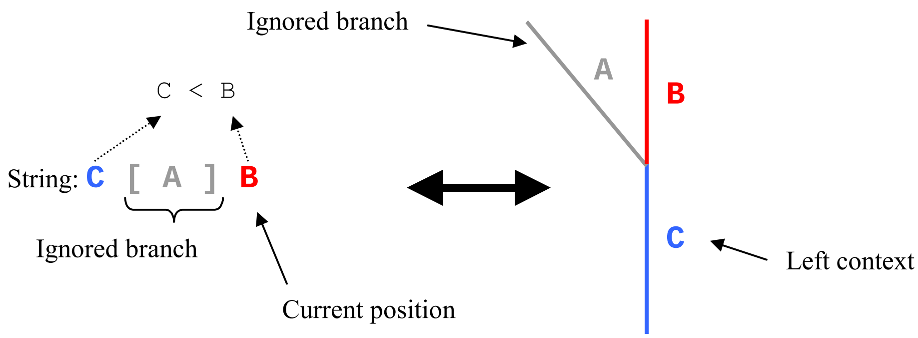


Figure 7 Matching left context, lateral branches implicitly ignored

The rule illustrated in Figure 6 is a pronounced manifestation of asymmetry in the left context – right context relationship: module `C` is left context of both `A` and `B`. But `C`'s right context is `B` (unless [ ] delimiters are used explicitly). The relation of the left context can be thought of as the *parent* module: the module before (below) the branching point. It is then natural to say that `C` is parent module for both `A` and `B`.