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IDEAL User's Manual

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ABSTRACT

IDEAL is a programming language to be used for describing pictures.

The main use of IDEAL is as a preprocessor to TROFF, so that pictures and text may reside in the same file and be typeset together. This manual contains many examples of this use of IDEAL.

IDEAL proper produces device-independent descriptions of pictures, so pictures may also be displayed through the UNIX® plot filters.

This document describes how to use the existing implementation of IDEAL.

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1. Introduction

IDEAL is a language for describing pictures. It is intended primarily to operate as a preprocessor to TROFF[3], much like EQN TBL[2], REFER[0], and PIC

I have explained the principles that motivate the form of IDEAL elsewhere This document describes how to use the existing implementation of IDEAL and treats several examples in depth.

Paragraphs like this that appear in smaller type may be skipped on first reading: they present sidelights that may be ignored safely by beginners.

2. Overview of IDEAL

To take advantage of IDEAL's capabilities, you must believe that

complex numbers are good.

- Complex numbers have a natural correspondence to points in the Cartesian $(x-y)$ coordinate system.
- Using complex numbers obviates the need for distinguishing between "points" and "dimensions."
- Complex numbers capture readily such common operations as translation, rotation, and reflection in the plane.

IDEAL programs define pictures by means of a system of simultaneous equations in the significant points of the picture and a set of drawing instructions to be carried out with respect to those points. IDEAL solves the system of equations, then draws the picture using the points so determined.

All variables in IDEAL programs are complex numbers, with the usual operations:

- component-wise addition and subtraction: $(a,b) \pm (c,d) = (a \pm c, b \pm d)$
- vector multiplication: $(a,b)*(c,d) = (ac-bd, ad+bc)$
- vector division: $(a,b)/(c,d) = (ac+bd, -ad+bc)/(c^2+d^2)$
- component manipulation: $\mathrm{re}((a,b)) = a$, $\mathrm{im}((a,b)) = b$, and $\mathrm{conj}((a,b)) = (a,-b)$
- vector magnitude calculation: $\mathrm{abs}((a,b)) = \sqrt{a^2+b^2}$
- unit vector function: $\mathrm{cis}(\theta) = \cos\theta + i\sin\theta$

A non-standard notation that has proved useful is $\alpha[x,y]$, for complex x and y, defined by $x+\alpha(y-x)$, and meaning "α of the way from x to y."

Scalars are treated as vectors with null imaginary component. For example, "1" is treated as "(1,0)."

The scale of the coordinate system in which IDEAL programs are written is entirely a matter of convenience. The IDEAL processor proper produces output in the same coordinate system as the input. Postprocessors ("filters") scale this coordinate system to make sense for the device on which the picture is displayed.

Some of the pictures below include captions keyed to the associated programs. Some of the labels are not produced by the program: I added them to help explain the picture. Such labels are parenthesized. For pictures and programs that have not been labeled, you may find that labeling them yourself helps you understand the program.

3. Elements of the IDEAL Language

This section presents statements that make up the fundamental units of IDEAL programs, so the displayed program text represents fragments of complete programs. Text that appears between /* and */ is a comment.

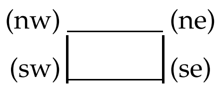
3.1. Boxes

The building blocks of IDEAL programs are called *boxes*, which readers familiar with programming may think of as procedures or subroutines. In fact, the picture drawn by an IDEAL program must itself be a box, called *main*; we suppress this extra level of box-nesting for all of Section 3.

3.1.1. Defining Boxes

Here is a simple box and one instance of it:

```
rect {
        var ne, nw, se, sw,
                wd, ht;
        nw = sw + (0,1)*ht;
        ne = nw + wd;
        se = sw + wd;
        conn ne to nw to sw to se to ne;
}
```

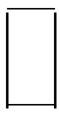


It is called *rect*, has six local complex variables: *ne*, *nw*, *se*, *sw*, *wd*, and *ht*, three equations among these variables, and an instruction to draw four lines.

3.1.2. Placing Boxes

To ask for an instance of *rect*, we use a *put* statement with a *parameter section* containing enough additional equations that the local variables of this instance of *rect* are determined uniquely. For example, we might give the dimensions (*ht* and *wd*) and one of the corners (say *sw*):

```
put rect {
        ht = 2;
        wd = 1;
        sw = 0;
};
```



Any of the following put statements would draw the same rectangle: (C programmers will recognize the /* and */ comment brackets.)

```
/* giving one corner, one dimension
   and a relation on the dimensions */
put rect {
        ht = 2;
        wd = 0.5*ht;
        nw = (0,2);
};
```

```
/* giving two adjacent corners
   and the perpendicular dimension */
put rect {
        nw = (0,2);
        sw = 0;
        wd = 1;
};

/* giving two diagonal corners
   and a relation on the dimensions */
put rect {
        ne = (1,2);
        sw = 0;
        wd = 0.5*ht;
};

/* giving three corners */
put rect {
        ne = (1,2);
        nw = (0,2);
        se = 1;
};

/* giving the center of a side,
   a corner, and another dimension */
put rect {
        (nw+sw)/2 = (0,1);
        nw = (0,2);
        wd = 1;
};
```

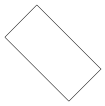
The put statement is to IDEAL what a procedure call is to a conventional programming language. The difference is that none of the variables of a box must be specified to be a parameter whose value is expected in any call: any of the box's variables may be set by the put statement, and IDEAL will determine the rest by means of the equations in the definition of the box. This means we can give whatever information we know about this instance of the box, as long as it is enough to determine everything uniquely. This mechanism is useful because we often want to set down a rectangle by giving one of its corners, but not necessarily the same corner each time; in a conventional programming language, we would need to provide a different procedure for each corner, and the code to solve for the other corners from it. (Almost certainly, not all of the put statements above are equally useful; but it is good to be able to use any of them when the need arises.)

> Here is how IDEAL solves the system of equations implicit in a program: First, all equations are placed on a queue. Every time a box is called, the solutions to these equations may—and probably will—be different, so all the equations of a box are enqueued separately for each time that box is put. (Of course, different copies of the equation refer to different copies of the variable, but IDEAL keeps that straight.) During processing, IDEAL maintains two classes of variables: dependent and independent. Each dependent variable is represented as a linear combination of independent variables plus a constant term. (Variables whose values are known are a trivial case of dependent variables.) All variables start out independent. As long as there are equations on the queue, IDEAL examines the head equation: if, after substituting for all dependent variables, the equation is linear, IDEAL determines new information from it if possible—that is, IDEAL tries to make one variable dependent on the others, thus reducing the number of independent variables—or decides whether it is redundant or inconsistent; if the equation remains non-linear after substitution, IDEAL adds it to the end of the queue and proceeds. If IDEAL ever goes through the whole queue without discovering any new information, the system cannot be solved (by IDEAL, anyway) and IDEAL complains bitterly. If there are any independent variables left after this processing, IDEAL will complain too, because there is no way they can become

known.

The variables *wd* and *ht* above are complex numbers just like the corners, so we can rotate the rectangle by giving them complex non-real values:

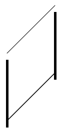
```
put rect {
        sw = 0;
        wd = (1,1)/abs((1,1));
        ht = 2*wd;
};
```



(The double parentheses are needed in ‘‘*abs*((1,1))’’ because ‘‘*abs*(1,1)’’ is parsed as a function with two arguments.) One point about this example often confuses new users: the vectors *wd* and *ht* point in the *same* direction. It is in the definition of *rect* that the *ht* vector is rotated ninety degrees and added to the southern points to arrive at the northern points. Thus, if we give a *ht* that is perpendicular to *wd*, we get a very flat rectangle.

On the other hand, the definition of *rect* does not assure that *ht* and *wd* will point in the same direction. This put statement draws a parallelogram:

```
put rect {
        ht = 1;
        wd = (1,1)/abs((1,1));
        sw = 0;
};
```

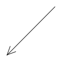


Some people who feel that a box called *rect* should draw only rectangles are disturbed by this example. One remedy is to add another equation to the definition of *rect*, asserting that two adjacent sides are perpendicular; IDEAL will complain if this equation is not satisfied (although it won't stop drawing). One such equation is

```
wd/abs(wd) = ht/abs(ht);
```

Here is a definition for box *arrow* that keeps the head of the arrow symmetrical about its shaft:

```
arrow {
        var hd, tl, head, wing;
        head = 0.1;
        wing = head*(tl-hd)/abs(tl-hd);
        conn hd to tl;
        conn hd + cis(25)*wing to hd to hd + cis(-25)*wing;
}
```



Note the definition of *wing* in the example above: the second part of the expression is a unit vector that points from *tl* to *hd*; this is multiplied by *head*, the length of the ‘‘wings’’ on the arrowhead.

When a put statement is interpreted, the equations in its parameter section are processed before the equations in its definition. Thus, if there are inconsistent equations between the put statement and the box definition, the equations in the put statement take precedence. This can be useful to provide default values for variables of a box. For instance, if the definition of *rect* gave such default values to *ht* and *wd*, they would take effect unless overridden by equations in the parameter section of the put statement.

IDEAL ignores inconsistent equations, but it does generate error messages about them. To avoid this error message about a particular equation, use a tilde (‘‘~’’) instead of an equals sign in the equation. The tilde does *not* give the equation any lower ‘‘priority’’ than an equation with an equals sign: all it does is shut off the error message. So, the two ordered systems ‘‘$x = 1$, x ~ 2’’ and ‘‘x ~ 2, $x = 1$’’ are *different:* in the former, x receives the value 1, and no error message appears when the second equation is processed; in the latter, x receives the value 2, and an error is generated when the second equation is encountered.

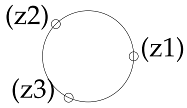
3.2. Special Boxes—Circles and Arcs

Boxes to draw circles and circular arcs are defined in special library files.

3.2.1. Circles

The box named *circle* has five local variables: *center*, *radius*, *z1*, *z2*, and *z3*. The last three may be any points on the circle. As above, we must give enough information to determine a circle; giving two points on it is insufficient, and giving three collinear points is inconsistent. Here are three ways to draw a circle of radius one centered at the origin.

```
/* giving center and radius */
put circle {
        center = 0;
        radius = 1;
};
```



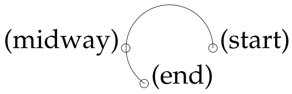

```
/* giving center and a point on the circle */
put circle {
        center = 0;
        z1 = 1; /* could also have given z2 or z3 */
};

/* giving three points on the circle */
put circle {
        z1 = (1,0);
        z2 = cis(135);
        z3 = cis(235);
};
```

Once the circle has been determined, all five of its internal variables are known. So, if we ask for a circle giving three points, the radius and center will be known afterward. On the other hand, if we ask for a circle by giving the center and the radius, the three points $z1$, $z2$, and $z3$, will be known, and will be on the circle, but there is no guarantee where they will be.

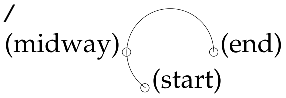
3.2.2. Arcs

Box *arc* has eight local variables: *center*, *radius*, *start*, *midway*, *end*, *startang*, *midang*, and *endang*. It is an arc centered at point *center* with radius *radius*, starting at point *start* at an angle *startang*, passing through point *midway* at an angle *midang*, and ending at point *end* at an angle *endang*. (All angles are measured with respect to *center*, in degrees, with the positive x-axis taken to be zero degrees, and the counterclockwise direction to be positive.) Note that *midway* is *not* necessarily the midpoint of the arc! If neither *midway* nor *midang* is given, the arc is drawn counterclockwise from *start* to *end*. Once again, a variety of put statements draw the same arc:

```
/* giving center, radius, and
   starting and ending angles */
put arc {
        center = 0;
        radius = 1;
        startang = 0;
        endang = 235;
};
```



```
/* giving center, starting point,
   and ending angle */
put arc {
        center = 0;
        start = 1;
        endang = 235;
};

/* giving three points on the arc */
put arc {
        start = cis(235);
        midway = -1;
        end = 0;
};
```



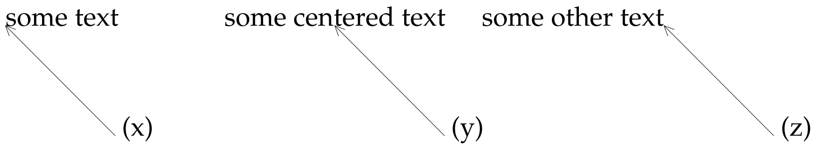
3.3. Other Elements of IDEAL Pictures

IDEAL pictures also may contain text and splines.

3.3.1. Text Captions

There are three commands to place text with respect to a point. The *left* command left-justifies the text with respect to the specified location: the text will start there. The *right* command right-justifies the text so that it ends at the specified location. The default is to center the text at the point. (The arrows in this picture point to the locations of the named points.)

```
left "some text" at x;

"some centered text" at y;

right "some other text" at z;
```

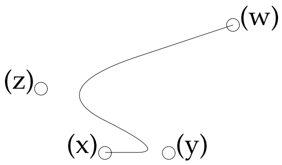


To include a double quote mark in a string, escape it with a back-slash. If you have a line running through a point at which you place some text, you may want to add a space to one end of the text so that the line doesn't chop through the text. The string may include TROFF special characters (like \(bu) and commands to other preprocessors (notably EQN), but IDEAL should be run before any other preprocessors.

3.3.2. Splines

IDEAL provides quadratic splines that are drawn with a B-spline basis: the user supplies a sequence of guiding points, and IDEAL draws a smooth curve that is tangent to the polygonal path they define at the midpoint of each segment; the spline also starts at the first point and ends at the last.

```
spline x to y to z to w;
```



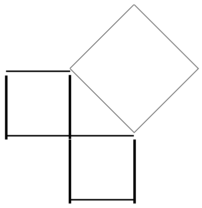
4. Putting Boxes Together

In this section we present several complete IDEAL programs to show how to build up pictures from boxes.

4.1. Naming Instances of Boxes

Most pictures involve more than placements of simple boxes. And when pictures involve several boxes, certain geometrical relationships should exist among them. We can refer to the local variables of a box that has been put—all we need to do is name the put statement. Here is a simple example showing a diagram that could be used to illustrate Pythagoras's Theorem for isoceles triangles:

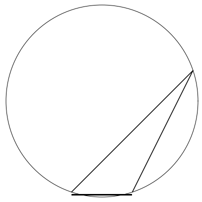
```
main {
        put first: rect {
                sw = 0;
                ht = wd = 1;
        };
        put next: rect {
                nw = first.se;
                ht = wd = first.ht;
        };
        put last: rect {
                sw = first.ne;
                se = next.ne;
                ht = wd;
        };
}
```



First we place an instance of *rect* called *first*. Then we place another *rect* with its upper left corner (*ne*) at the lower right of *first*. Finally, we draw a third square, two of whose adjacent points are identified with points on the first two squares placed. We could have used any two adjacent points on *last*: if we had placed *last.ne* at *first.ne* and *last.nw* at *next.ne*, IDEAL would have figured all the relationships out right, although the program might be quite inscrutable to humans.

How can we circumscribe a triangle? If we name the put statement that produces the instance, we can just give its three vertices as values for $z1$, $z2$, and $z3$ in an instance of *circle*.

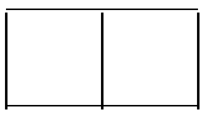
```
triangle {
        var z1, z2, z3;
        conn z1 to z2 to z3 to z1;
}

main {
        put T: triangle {
                z1 = 0;
                z2 = 1;
                z3 = (2,2);
        };
        put circle {
                z1 = T.z1;
                z2 = T.z2;
                z3 = T.z3;
        };
}
```



4.2. Parameter Section Commands

Any IDEAL statement may appear in the parameter section of a put statement. This section illustrates some uses of this feature.

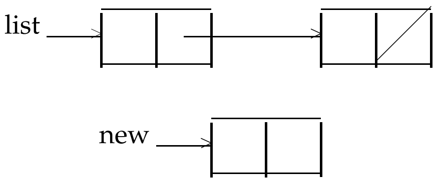
Suppose we will need to draw pictures of a linked list before and after insertion of a new node. We might start with this definition of a *listnode*:



```
listnode {
        put info: rect {
                var hook;
                hook = (nw + sw)/2;
                ht = lht;
                wd = lwd/2;
        };
        put next: rect {
                var c;
                c = (nw + se)/2;
                sw = info.se;
                ht = lht;
                wd = lwd/2;
        };
}
```

This version of *listnode* depends on *rect*. Notice that it references two variables (*lwd* and *lht*) that are not local to itself: these variables must be defined in any environment in which *listnode* is put. (They are global to it.) We have added statements that define new variables (*hook* in *first* and *c* in *next*) that are local to the particular instance of *rect*.

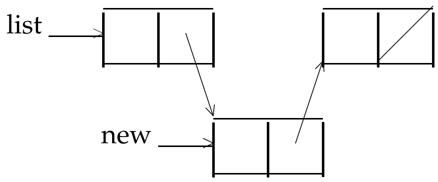
Now we draw the list as it is before insertion:




```
main {
        var lht, lwd;
        lht = 1;
        lwd = 2*lht;
        put first: listnode {
                info.sw = 0;
        };
        put last: listnode {
                info.sw = 2[first.info.sw,first.next.se];
                conn next.sw to next.ne;
        };
        put new: listnode {
                info.nw = 2[first.next.ne,first.next.se];
        };
        put arrow {
                hd = last.info.hook;
                tl = first.next.c;
        };
        put arrow {
                hd = new.info.hook;
                tl = hd - 1;
                right "new " at tl;
        };
        put arrow {
                hd = first.info.hook;
                tl = hd - 1;
                right "list " at tl;
        };
}
```

Here we have added statements directly to the parameter section of two of the calls to *arrow* to avoid either naming each instance of *arrow* or naming the tails of these arrows so that text could be placed there. We have also added a statement to draw the null pointer in box *last*.

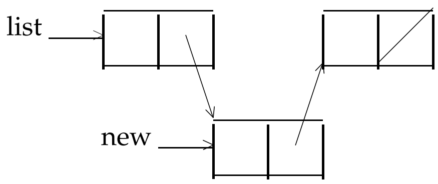
The program to draw the list after insertion of the new node remains largely unchanged: the nodes haven't moved; only the arrows hooking them together have moved.




```
main {
        var lht, lwd;
        lht = 1;
        lwd = 2*lht;
        put first: listnode {
                info.sw = 0;
        };
        put last: listnode {
                info.sw = 2[first.info.sw,first.next.se];
                conn next.sw to next.ne;
        };
        put new: listnode {
                info.nw = 2[first.next.ne,first.next.se];
        };
        /* These two arrows are different: */
        put arrow {
                hd = new.info.nw;
                tl = first.next.c;
        };
        put arrow {
                hd = last.info.sw;
                tl = new.next.c;
        }
        /* These are the same as before: */
        put arrow {
                hd = new.info.hook;
                tl = hd - 1;
                right "new " at tl;
        };
        put arrow {
                hd = first.info.hook;
                tl = hd - 1;
                right "list " at tl;
        };
}
```

4.3. A Shorter Version

The previous example is somewhat long-winded because it demonstrates many features of IDEAL that really aren't needed. For instance, it would probably have made better sense to define *listnode* as a basic element rather than building it out of *rect*s. This would reduce the need for delving deep into the internals of boxes from outside (e.g. *first.info.hook*). Here is the same example reworked:



```
listnode {
        var n, s, e, w, ne, nw, se, sw, next;
        n = s + (0,1)*lht;
        ne = n + 0.5*lwd = nw + lwd;
        se = s + 0.5*lwd = sw + lwd;
        e = (ne + se)/2;
        w = (nw + sw)/2;
        next = (ne + s)/2;
        conn nw to ne to se to sw to nw;
        conn n to s;
}

main {
        var lht, lwd;
        lht = 1;
        lwd = 2;
        put first: listnode {
                sw = 0;
        };
        put last: listnode {
                sw = 2[first.sw,first.se];
                conn s to ne;
        };
        put new: listnode {
                nw = 2[first.ne,first.se];
        };
        put arrow {
                hd = new.nw;
                tl = first.next;
        };
        put arrow {
                hd = last.sw;
                tl = new.next;
        };
        put arrow {
                hd = new.w;
                tl = hd - 1;
                right "new " at tl;
        };
        put arrow {
                hd = first.w;
                tl = hd - 1;
                right "list " at tl;
        };
}
```

Notice that equations need not be just a left side and a right side: they may include several expressions that should be equal.

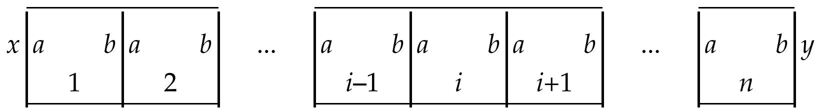
5. Iteration of IDEAL Constructs

5.1. Pens

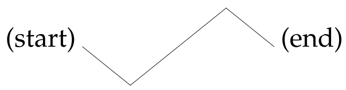
In Donald Knuth's METAFONT system, pens are different shapes—circles, ellipses, and polygons—that draw along curves. IDEAL includes pens as a generalization of this idea: *any* box may be used to draw along a line. For instance, users may define "dashed" or "dotted" pens. A pen statement looks like this:

```
conn x to y
        using n pen {
                ...
        } <a,b>;
```

(The only keywords in this statement are *conn, to,* and *using*.) *Pen* may be any box. IDEAL will place *n* copies of *pen* in the space from *x* to *y*. *a* and *b* are expressions known to *pen*. The first instance of *pen* will have *a* at *x*, and the last instance of *pen* will have *b* at *y*; every instance in between will have its *a* at the preceding one's *b*, and its *b* at the succeeding one's *a*, as shown in this picture:

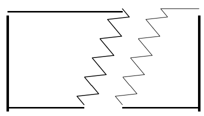


Here is an example box that contains an angular wavy path:



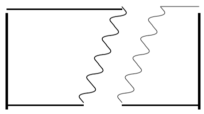

```
wavy {
        var start, end, perp, pt1, pt2, ht;
        perp = (0,1)*(start - end)/abs(start - end);
        pt1 = 0.25[start,end] + perp*ht;
        pt2 = 0.75[start,end] - perp*ht;
        conn start to pt1 to pt2 to end;
}
```

Here we use *wavy* as a pen to indicate that part of a rectangle is missing.



```
main {
        var ne, nw, se, sw;
        var n1, s1, n2, s2;
        ne = nw + 2;
        se = sw + 2;
        ne = se + (0,1);
        n2 - 0.4 = n1 = 0.6[nw,ne];
        s2 - 0.4 = s1 = 0.4[sw,se];
        conn n1 to nw to sw to s1;
        conn n1 to s1
                using int(5*abs(n1-s1)) wavy {
                        ht = -0.1;
                } <start,end>;
        conn n2 to ne to se to s2;
        conn n2 to s2
                using int(5*abs(n2-s2)) wavy {
                        ht = -0.1;
                } <start,end>;
}
```

We can change *wavy* to contain a smooth wave by changing the word *conn* in the fifth line of its definition to *spline*, and use the same instructions above to draw the picture with the new pen.



5.2. Pens as For-Statements

The pen statement

```
conn x to y
        using n pen {
                ...
        } <a,b>;
```

has the same effect as

```
for i = 1 to n {
        put pen {
                a = ((i-1)/n)[x,y];
                b = (i/n)[x,y];
                ...
        };
}
```

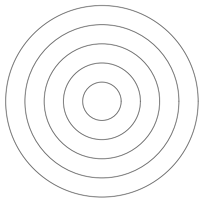
imagining for a moment that IDEAL had for-statements.

This means a pen statement can be used to synthesize a for-statement in an IDEAL program. Here is a pen statement to draw a dashed arc:

```
conn 0 to 180
        using 10 arc {
                center = 0;
                radius = 1;
        }<startang, 9+endang>;
```

To draw a set of concentric circles we can say:

```
main {
        conn 1 to 6
                using 5 circle {
                        center = 0;
                        } <radius,radius+1>;
}
```



In the first example, the second expression in angle brackets is important: it means that each ''dash'' covers nine degrees. In the second example, this expression is redundant: its only purpose is to prevent IDEAL from generating a stream of error messages about inconsistent equations. This contorted way of simulating for-statements is necessary only because pens are meant to do the right thing at each end of and all along a path that is being drawn with some box, and not as general iteration constructs.

Why doesn't IDEAL have for-statements? Notice that every variable in an IDEAL program is assigned a value exactly once. Obviously the index of a for-statement must be an exception to that rule. Generating the index internally prevents the need to have two kinds of variables—changing and fixed. The local variables of boxes placed by pen statements cannot be referenced outside the pen statement, because the boxes are not named when they are placed. A general for-statement could lead to the need to generate automatically names for different instances of boxes, a hard problem that I don't understand well enough yet.

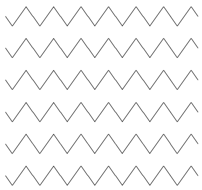
5.3. Filling Regions

Because any box can be used as a pen, we can shade regions. (We can have not only dashed and dotted ink, but checkered paint!) Take box *wavy*, for instance. First we construct a box *brush*, which consists of seven copies of *wavy* going horizontally:

```
brush {
        var top, bot;
        var bwd, bht;
        var leftpt, rightpt;
        leftpt = 0.5*(top+bot) - bwd/2;
        rightpt = 0.5*(top+bot) + bwd/2;
        conn leftpt to rightpt
                using 7 wavy {
                        ht = bht;
                }<start,end>;
}
```

Then we use ''brush'' to draw vertically over the region of interest.

```
conn (0,1) to (0,-1)
        using 6 brush {
                bwd = 2;
                bht = 0.1;
                }<top,bot>;
```



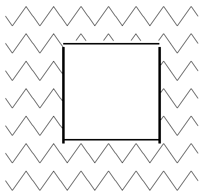
6. Opaque Boxes

IDEAL includes statements to blot out pieces of a picture. In this section we will sometimes place opaque boxes without explicitly drawing any background. In such cases, assume that we have painted over the area with pens as above.

6.1. Opaque Polygons

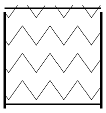
IDEAL needs to know the vertices of a polygon in order to opaque the area it covers. The vertices are specified as a list in a *bdlist* statement. For instance, to opaque a rectangular region using the *rect* box defined in Section 3, we could use the following statement:

```
put rect {
        opaque;
        bdlist = sw, se, ne, nw;
        sw = (-0.4,-0.4);
        wd = ht = 1;
};
```



The sides of the rectangle are drawn by *rect*: they are not supplied automatically by the opaqueing routine. If we wanted to save only the interior of the rectangle, we could use almost the same statement:

```
put rect {
        opaque exterior;
        bdlist = sw, se, ne, nw;
        sw = (-0.4,-0.4);
        wd = ht = 1;
};
```



If we plan to opaque a lot of rectangles, we should include a *bdlist* in the definition of *rect*. Such a default *bdlist* would be referenced only if the parameter section of the put statement included an opaque statement *and* did not include its own *bdlist*.

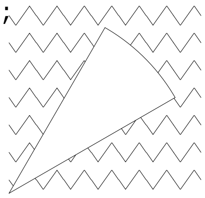
6.2. Opaque Circular Arc Polygons

The edges of opaque regions can also be circular arcs.

This generalization of the simple boundary statement is the most recent addition to IDEAL. It avoids treating circles and their sectors and segments as special cases, and makes opaqueing circular arc polygons much easier.

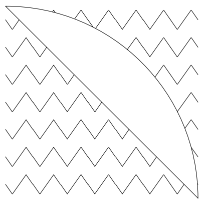
To specify a circular arc edge, one gives its endpoints and a point through which it passes; this ‘‘pass-through’’ point is marked in the boundary list by the symbol ‘‘ˆ’’. For example, the boundary list for the sector shown below is

```
boundary = center, cis(30), ^ cis(45), cis(60);
```



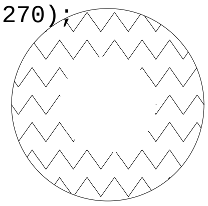
Another common opaque arc is the segment:

```
boundary = cis(0), ^ cis(45), cis(90);
```



One can construct an opaque circle out of two semicircular edges:

```
boundary = cis(0), ^ cis(90), cis(180), ^ cis(270);
```



Here, the outer circle has an opaque exterior, while the inner circle has an opaque interior.

6.3. Order is Important

Without the ability to opaque, the order in which boxes are put does not matter. But when some boxes are opaque, order obviously *does* matter. Put statements are executed in the order in which they appear in the box definition. When an opaque box is drawn, the opaquing is done *first*, then the lines of the box are drawn; so, for instance, an opaque *listnode* does include the line down its middle separating its *info* field from its *next* field.

6.4. Some Hard Facts

Neither text nor splines can be used to opaque objects, nor will they be clipped properly if they are in a picture and an opaque box is placed over them.

> The problem with text is that IDEAL operates as a TROFF preprocessor, so it cannot determine anything about the size of the text, and it needs to know that if it is to do anything involving opaquing and text.
>
> The problem with splines is more subtle. When a line or circular arc is chopped, it is easy to specify the lines or circular arcs that remain. But when a spline is chopped, the guiding points of the resulting curve pieces are hard to determine.

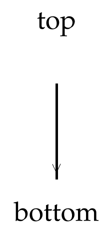
7. Paper Commands

IDEAL includes two commands that are analogous to the way people draw on paper.

7.1. Construct

The *construct* statement looks just like a put statement, with the keyword *put* replaced by *construct*. It is best to think of it as laying a sheet of tracing paper over the current drawing. Anything constructed will be drawn on this sheet. When you return to the layer underneath, you may refer to any of the local variables as with a put statement, but the lines and curves in the constructed picture don't show.

```
main {
        construct A: rect {
                sw = 0;
                wd = ht = 1;
        };
        construct B: rect {
                n = A.s - (0,1);
                wd = ht = 1;
        };
        'top' at A.c;
        'bottom' at B.c;
        put arrow {
                hd = B.n;
                tl = A.s;
        };
}
```

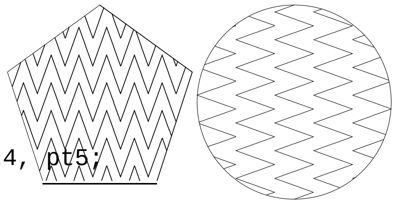


Here we have used "invisible boxes" to place the arrow around the text without drawing the boxes.

7.2. Draw

The construct command may also be used to localize the effects of opaque boxes. We saw above how to draw a filled polygon: paint over the area, then opaque the exterior of the polygon. But how can we draw *two* filled polygons in the same picture?

One solution is to construct them both, then use the *draw* command to add them to the main picture. The draw command transfers the contents of the named sheet of tracing paper to the sheet below.



```
null {
}

pentagon {
        var center, radius,
                pt1, pt2, pt3, pt4, pt5;
        pt1 = center + radius;
        pt2 = center + cis(72)*radius;
        pt3 = center + cis(144)*radius;
        pt4 = center + cis(-144)*radius;
        pt5 = center + cis(-72)*radius;
        conn pt1 to pt2 to pt3 to pt4 to pt5 to pt1;
        bdlist = pt1, pt2, pt3, pt4, pt5;
}

main {
        construct A: null {
                conn (0,1) to 0
                        using 7 brush {
                                bwd = 1;
                                bht = 0.1;
                                }<top,bot>;
                put pentagon {
                        center = (0,0.5);
                        radius = (0,0.5);
                        opaque exterior;
                };
        };
        construct B: null {
                conn (0.5,0.5) to (1.5,0.5)
                        using 5 brush {
                                bwd = (0,1);
                                bht = 0.1;
                                }<top,bot>;
                put circle {
                        center = (1,0.5);
                        radius = 0.5;
                        opaque exterior;
                };
        };
        draw A;
        draw B;
}
```

Even put statements can be added to the parameter sections of construct (and put) statements! Believe it or not, box *null* defined above is one of the most useful: it gives us a way to name a set of commands and variables so that we may reference them later, yet it doesn't require us to define a box that will be used only once.

Given construct and draw, why do we need a special box *hole* to opaque a circular area without drawing anything? Why not just construct an opaque circle, then draw it on the main picture? The problem is that the effect of opaquing is localized just as much as the drawing, so an opaque constructed circle won't opaque anything that lies underneath.

8. Library Files

Library files are available to draw common figures and for special figures like circles and arcs. To include a library file as part of an IDEAL program, include the line

```
...libfile name
```

in your IDEAL program (between the .IS and .IE lines that mark its start and end.) This section describes available library files that have been alluded to up to now.

8.1. Rectangle

File *rect* contains the definition of box *rect*, which looks like the definition in Section 3, with five more variables: *n, s, e, w,* and *c,* which are the four compass points and the center, respectively.

```
rect {
        var ne, nw, sw, se,
        n, e, w, s, c,
        ht, wd;
        ne = se + (0,1)*ht;
        nw = sw + (0,1)*ht;
        ne = nw + wd;
        n = (ne+nw)/2;
        s = (se+sw)/2;
        e = (ne+se)/2;
        w = (nw+sw)/2;
        c = (ne+sw)/2;
        ht ˜ 1;
        wd ˜ 1.5;
        bdlist = ne, nw, sw, se;
        conn ne to nw to sw to se to ne;
}
```

8.2. Arrow

File *arrow* contains the definition of box *arrow* as given in Section 3.

```
arrow {
        var tl, hd, head, perp, headang;
        conn tl to hd;
        perp = head*(tl-hd)/abs(tl-hd);
        conn hd + cis(headang)*perp to hd to hd + cis(-headang)*perp;
        head ˜ 0.1;
        headang ˜ 25;
}
```

8.3. Wavy

Library file *wavy* contains the definition for the familiar *wavy*.

```
wavy {
        var start, end, perp, pt1, pt2, ht;
        perp = (0,1)*(start - end)/abs(start - end);
        pt1 = 0.25[start,end] + perp*ht;
        pt2 = 0.75[start,end] - perp*ht;
        conn start to pt1 to pt2 to end;
}
```

8.4. Dash

Library file *dash* contains the definition of box *dash*, which may be useful for drawing dashed lines:

```
dash {
        var start, end;
        conn start to 0.25[start,end];
        conn 0.75[start,end] to end;
}
```

8.5. Circles

Box *circle* resides in a library file of the same name, and has the local variables described in Section 3: *center*, *radius*, $z1$, $z2$, and $z3$.

Box *circle* actually consists of variable declarations and a put of box *CIRCLE*. So, if you will have many circles of a particular radius, it might be easier for you to define your own, say, *circle*3:

```
circle {
        var center, radius, z1, z2, z3;
        put CIRCLE {
                radius = 3;
        }
}
```

8.6. Arcs

Box *arc* is contained in a library file of the same name, with local variables as described in Section 3: *center*, *radius*, *start*, *midway*, *end*, *startang*, *midang*, and *endang*.

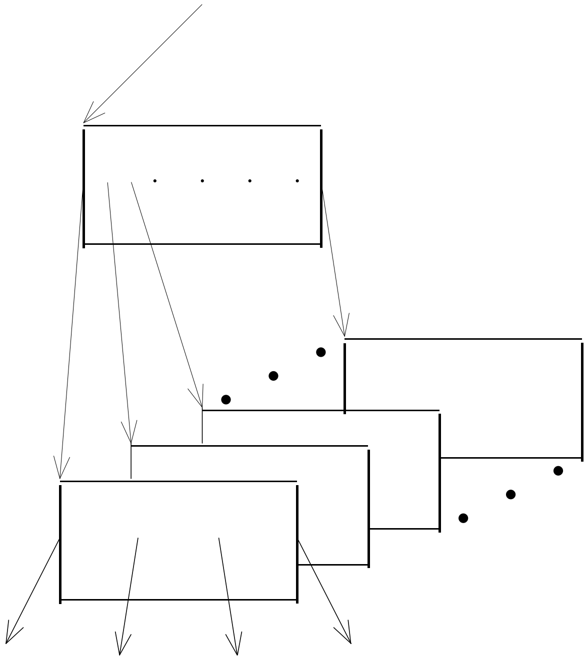
As above, *arc* calls on a box called *ARC*.

9. Examples

9.1. B-Trees

This example depicts a B-tree whose nodes have many children.*

*P. J. Weinberger, Unix B-trees, Bell Laboratories, 1981.

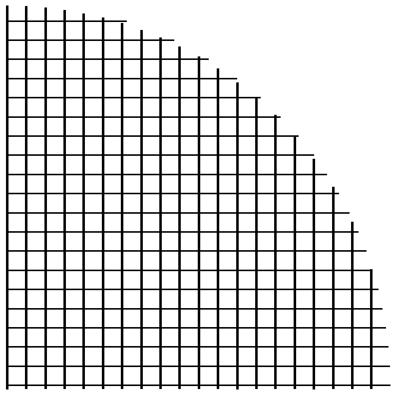


```
...libfile rect
arrow {
	var tl, hd, headvec, head;
	headvec = hd + head*(tl - hd)/abs(tl - hd);
	conn tl to hd;
	conn hd + cis(20)*(headvec - hd)
		to hd
		to hd + cis(-20)*(headvec - hd);
}

dot {
	var s, e;
	'\(bu' at 0.5[s, e] - (0,0.1);
}

per {
	var s, e;
	'.' at 0.5[s, e];
}

main {
	var rw, rh;
	rw = 2;
	rh = 1;
	var hmv, vmv;
	hmv = 0.6;
	vmv = 0.3;
	var ah;
	ah = 0.2;
	put root: rect {
		sw = (0,1);
		wd = rw;
		ht = 1;
	};
	put next: rect {
		sw = youngest.sw + 2*(hmv, vmv);
		wd = rw;
		ht = rh;
	};
	put youngest: rect {
		sw = bro.sw + (hmv, vmv);
		wd = rw;
		ht = rh;
		opaque;
	};
	put bro: rect {
		sw = eldest.sw + (hmv, vmv);
		wd = rw;
		ht = rh;
		opaque;
	};
	put eldest: rect {
		im(nw) = im(3[root.nw,root.sw]);
		re(0.5[nw, next.nw]) = re(0.5[root.nw, root.ne]);
		wd = rw;
		ht = rh;
		opaque;
		put arrow {
			head = ah;
```

```
                tl = 0.0[sw, se] + 0.5 * (nw - sw);
                hd = tl - (0, 1) * cis(-27);
        };
        put arrow {
                head = ah;
                tl = 0.33[sw, se] + 0.5 * (nw -sw);
                hd = tl - (0,1) * cis(-9);
        };
        put arrow {
                head = ah;
                tl = 0.67[sw, se] + 0.5 * (nw - sw);
                hd = tl - (0,1) * cis(9);
        };
        put arrow {
                head = ah;
                tl = 1.0[sw, se] + 0.5 * (nw -sw);
                hd = tl - (0,1) * cis(27);
        };
};
put arrow {
        head = ah;
        tl=root.sw + 0.5 * (root.nw - root.sw);
        hd=eldest.nw;
};
put arrow {
        head = ah;
        tl=0.1[root.sw,root.se] + 0.5 * (root.nw - root.sw);
        hd=bro.nw;
};
put a: arrow {
        head = ah;
        tl=0.2[root.sw,root.se] + 0.5 * (root.nw - root.sw);
        hd=youngest.nw;
};
put b: arrow {
        head = ah;
        tl = 0.5[root.ne, root.se];
        hd = next.nw;
};
put arrow {
        head = ah;
        hd = root.nw;
        tl = 0.5[root.nw, root.ne] + (0, 1.0);
};
conn next.nw to youngest.nw using 3 dot{}<s, e>;
conn next.se to youngest.se using 3 dot{}<s, e>;
conn b.tl to a.tl using 4 per{}<s, e>;
        }
```

9.2. A Sector Grid

Norm Schryer used this figure to show how numerical integration is used to find the area of planar regions.

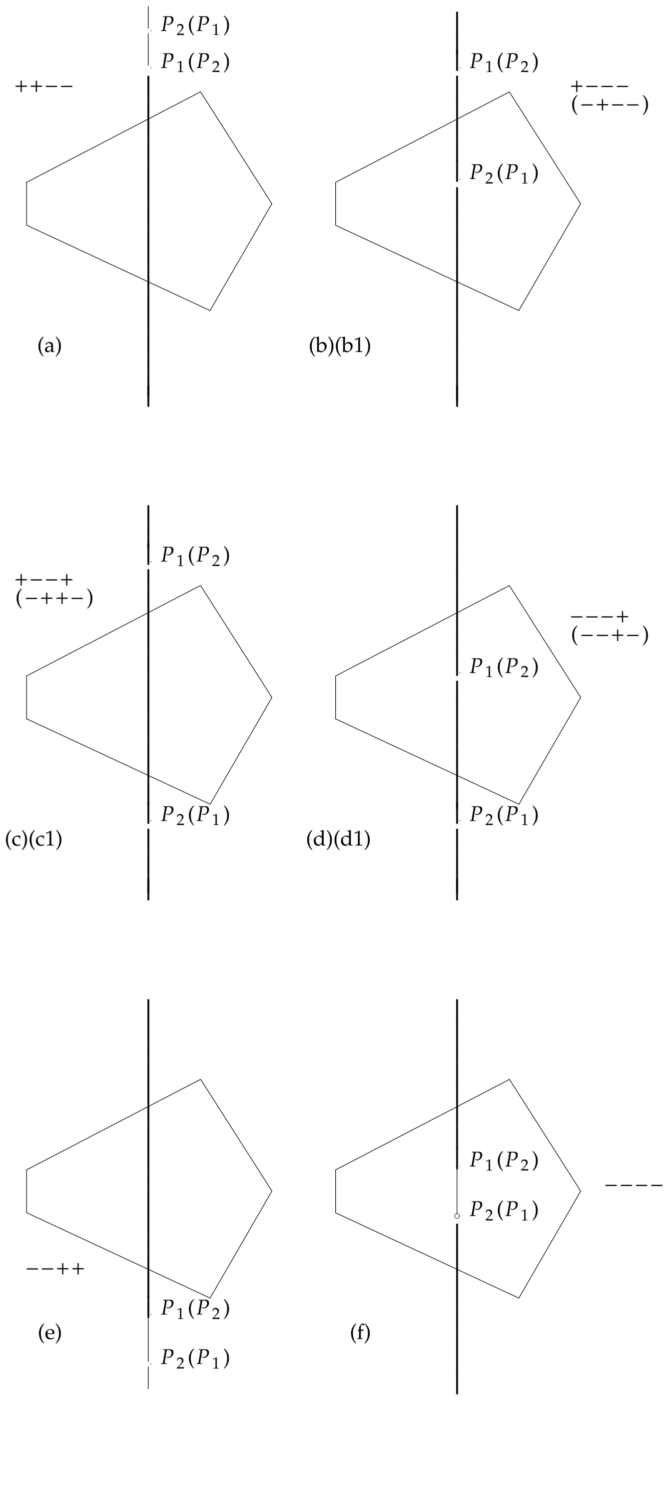


```
...libfile hole
gridline {
        var a,b;
        var neg, pos;
        conn a - neg to a + pos;
}

main {
        var n;
        n = 21;
        conn (0,0) to (0,1+1/(n-1))
                using n gridline {
                        neg = 0;
                        pos = 1;
                } <a,b>;
        conn (0,0) to (1+1/(n-1),0)
                using n gridline {
                        neg = 0;
                        pos = (0,1);
                } <a,b>;
        put hole {
                radius = 1;
                center = (0,0);
                opaque exterior;
        };
}
```

9.3. Polygon Clipping

This example illustrates all possible positions of a line segment with respect to a polygon. It will appear in a book on graphics and image processing.*

*T. Pavlidis, Graphics and Image Processing, to be published.



$P_2(P_1)$
$P_1(P_2)$
$++--$
(a)
$P_1(P_2)$
$+---$
$(-+--)$
$P_2(P_1)$
(b)(b1)
$P_1(P_2)$
$+--+$
$(-++-)$
$P_2(P_1)$
(c)(c1)
$---+$
$(--+-)$
$P_1(P_2)$
$P_2(P_1)$
(d)(d1)
$--++$
$P_1(P_2)$
(e)
$P_2(P_1)$
$P_1(P_2)$
$P_2(P_1)$
$----$
(f)

```
.ps 8
.EQ
gsize 8
define P12 " P sub 1 ( P sub 2 ) "
define P21 " P sub 2 ( P sub 1 )"
.EN
...libfile circle
...minx -1
...maxx 6
...miny -1
...maxy 12
box spot{
        var loc;
        put circle{
                var center, radius;
                center = loc;
                radius = 0.02;
                opaque;
                };
        }
box vert{
        var midd, llength;
        conn midd+llength to midd-llength;
        }
box poly{
        var c1,p1,p2,p3,p4,p5,r1,tp,bp,ta,tb;
        p1 = c1+r1;
        p2 = cis(65)[c1,p1];
        p3 = cis(170)[c1,p1];
        p4 = cis(190)[c1,p1];
        p5 = cis(300)[c1,p1];
        tp = c1+(0,ta)*r1;
        bp = c1+(0,tb)*r1;
        conn p1 to p2;
        conn p2 to p3;
        conn p3 to p4;
        conn p4 to p5;
        conn p5 to p1;
        put vert{ midd=c1; llength=(0,1.6)*r1; };
        put spot{ loc=tp; };
        put spot{ loc=bp; };
        left '$P12$' at tp+0.1;
        left '$P21$' at bp+0.1;
        }
box main {
        put poly{
                c1 =(1,9); r1 = (1,0); ta=1.1; tb=1.4;
                left '$++--$' at p2-1.5;
                right '(a)' at c1-(0.7,1.2);
                };
        put poly{
                c1 =(3.5,9); r1 = (1,0); ta=1.1; tb=0.2;
                left '$+---$' at p2+0.5;
                left '$(-+--)$' at p2+(0.5,-0.15);
                right '(b)(b1)' at c1-(0.7,1.2);
                };
        put poly{
                c1 =(1,5); r1 = (1,0); ta=1.1; tb=-1;
                left '$+--+$' at p2-1.5;
```

```
                left '$(-++-)$' at p2-(1.5,0.15);
                right '(c)(c1)' at c1-(0.7,1.2);
                };
        put poly{
                c1 =(3.5,5); r1 = (1,0); ta=0.2; tb=-1;
                left '$---+$' at p2+(0.5,-0.3);
                left '$(--+-)$' at p2+(0.5,-0.45);
                right '(d)(d1)' at c1-(0.7,1.2);
                };
        put poly{
                c1 =(1,1); r1 = (1,0); ta=-1; tb=-1.4;
                left '$--++$' at p4-(0,0.5);
                right '(e)' at c1-(0.7,1.2);
                };
        put poly{
                c1 =(3.5,1); r1 = (1,0); ta=0.2; tb=-0.2;
                left '$----$' at p1+0.2;
                right '(f)' at c1-(0.7,1.2);
                };
}
```

10. Acknowledgements

My thanks to all who read drafts of this manual and criticized constructively: Al Aho, Lorinda Cherry, Eric Grosse, Steve Johnson, Brian Kernighan, John Mashey, Doug McIlroy, and Theo Pavlidis; and to early users of IDEAL, especially Eric Grosse, Theo Pavlidis, Norm Schryer, and Peter Weinberger.

2. M. E. Lesk, *Tbl—a program to format tables,* Bell Laboratories, Murray Hill, New Jersey (1976).

3. Joseph F. Ossanna, *NROFF/TROFF User's Manual,* Bell Laboratories, Murray Hill, New Jersey (1976).