PIC — A Graphics Language for Typesetting
User Manual

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Revised, May, 1991
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Brian W. Kernighan
AT&T Bell Laboratories
Murray Hill, New Jersey 07974

ABSTRACT

Pic is a language for drawing simple figures on a typesetter. The basic objects in pic are boxes, circles, ellipses, lines, arrows, arcs, spline curves, and text. These may be placed anywhere, at positions specified absolutely or in terms of previous objects. The example below illustrates the style and basic capabilities of the language.

This picture was created with the input

```
.PS
ellipse "document"
arrow
box "PIC"
arrow
box "TBL/EQN" "(optional)" dashed
arrow
box "TROFF"
arrow
ellipse "typesetter"
.PE
```

Pic is a troff preprocessor; it passes most of its input through untouched, but translates commands between .PS and .PE into troff commands that draw the pictures.

Revised, May, 1991

† This is a revised version of [5].
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1. Introduction

Pic is a language for drawing pictures. It operates as yet another troff [8] preprocessor (in the same style as eqn [7] and tbl [4]), with pictures delimited by .PS and .PE.

Pic was inspired partly by Chris Van Wyk’s early work on ideal [9]; it has somewhat the same capabilities, but quite a different flavor. In particular, pic is much more procedural—a picture is drawn by specifying (sometimes in painful detail) the motions that one goes through to draw it. Other direct influences include the PICTURE language [2], the V viewgraph language [1], and, more recently, new features from the grap language [3] for typesetting graphs.

This paper is primarily a user’s manual for pic; a discussion of design issues and user experience may be found in [6]. The next section shows how to use pic in the most simple way. Subsequent sections describe how to change the sizes of objects when the defaults are wrong, and how to change their positions when the standard positioning rules are wrong. An appendix describes the language succinctly and summarizes changes since the last manual.

2. Basics

Pic provides boxes, lines, arrows, circles, ellipses, arcs, and splines (smooth curves), plus facilities for positioning and labeling them. The picture below shows all of the fundamental objects (except for splines) in their default sizes:

```
  box   line   arrow   circle   ellipse   arc
```

Each picture begins with .PS and ends with .PE; between them are commands to describe the picture. Each command is typed on a line by itself. For example

```
.PS
box "this is" "a box"
.PE
```

creates a standard box (¼ inch wide, ½ inch high) and centers the two pieces of text in it:

```
  this is
  a box
```

Each line of text is a separate quoted string. Quotes are mandatory, even if the text contains no blanks. (Of course there needn’t be any text at all.) Each line will be printed in the current size and font, centered horizontally, and separated vertically by the current troff line spacing. Pic does not center the complete drawing itself, but the default definitions of .PS and .PE in the -ms macro package do.

† This is a revised version of [5].
You can use circle or ellipse in place of box:

![Box and Circle Examples](image)

Text is centered on lines and arrows; if there is more than one line of text, the lines are centered above and below:

```
line "this is" "a line"
```

```
arrow "this is" "an arrow"
```

Boxes and lines may be dashed or dotted; just add the word dashed or dotted after box or line:

```
line dashed "dashed" "line"
```

A spline might well do this job better; we will return to that shortly.

As you might guess,

```
arc; arc; arc; arc
draws a circle, though not very efficiently. Notice that several commands can be put on a single line if they are separated by semicolons.

Objects are normally drawn one after another, left to right, and connected at the obvious places:

```
arrow; box "input"; arrow; box "process"; arrow; box "output"; arrow
```

One way to leave a space is with move:

```
box; move; box; move; box
```

Although objects are normally connected left to right, this can be changed. If you specify a direction (as a separate object), subsequent objects will be joined in that direction:

```
down; box; arrow; ellipse; arrow; circle
```
Each new picture begins going to the right.

Normally, figures are drawn at a fixed scale, with objects of a standard size. It is possible, however, to arrange that a figure be expanded or shrunk to fit a particular width. If the .PS line contains a number, the drawing is forced to be that many inches wide, with the height scaled proportionately. Thus

\[ .PS \ 3.5 \]

causes the picture to be 3.5 inches wide. If two dimensions are specified, the second is the height.

*Pic* is pretty dumb about the size of text in relation to the size of boxes, circles, and so on. There is no way to say “make a box that just fits around this text” or “make this text fit inside this circle” or “draw a line as long as this text.” Tight fitting of text can generally only be done by trial and error.

Speaking of errors, if you make a grammatical error in the way you describe a picture, *pic* will complain and try to indicate where. For example, the invalid input

```
box arrow box
```

will draw the message

```
pic: syntax error near line 5, file -
context is
    box >>> arrow <<< box
```

The brackets point to the place where the error was first noted; it sometimes follows the word in error, although in this example it’s right on target. The filename ‘-’ is the standard input.

3. Controlling Sizes

This section deals with how to control the sizes of objects when the default sizes are not what is wanted. The next section deals with positioning them when the default positions are not right.

Each object that *pic* knows about (boxes, circles, etc.) has associated dimensions, like height, width, radius, and so on. By default, *pic* tries to choose sensible default values for these dimensions, so that simple pictures can be drawn with a minimum of fuss and bother. All of the figures and motions shown so far have been in their default sizes:
box \hspace{1cm} \frac{3}{4}" \text{ wide } \times \frac{1}{2}" \text{ high}
circle \hspace{1cm} \frac{1}{2}" \text{ diameter}
elipse \hspace{1cm} \frac{3}{4}" \text{ wide } \times \frac{1}{2}" \text{ high}
arc \hspace{1cm} \frac{1}{2}" \text{ radius}
line or arrow \hspace{1cm} \frac{1}{2}" \text{ long}
move \hspace{1cm} \frac{1}{2}" \text{ in the current direction}

When necessary, you can make any object any size you want:

\begin{verbatim}
box width 3 height 0.1; circle radius 0.1
\end{verbatim}

All positions and dimensions are in inches, so the box is 3 inches wide and 1/10 inch high and the circle has radius 1/10 inch.

An attribute like width changes only the one instance of the object. You can also change the default size for all objects of a particular type by assigning values to \textit{pic} variables; this will be discussed in Section 6.

The attributes of height (which you can abbreviate to \textit{ht}) and width (or \textit{wid}) apply to boxes, circles, ellipses, and to the head on an arrow. The attributes of radius (or \textit{rad}) and diameter (or \textit{diam}) can be used for circles and arcs if they seem more natural.

Lines and arrows are most easily drawn by specifying the amount of motion from where you are right now, in terms of directions. Accordingly the words up, down, left and right and an optional distance can be attached to line, arrow, and move:

\begin{verbatim}
line up 1 right 2
arrow left 2
move left 0.1
line <-> down 1 "height " rjust
\end{verbatim}

The notation <-> indicates a two-headed arrow; use -> for a head on the end and < for one on the start. Lines and arrows are really the same thing; in fact, \textit{arrow} is a synonym for \textit{line ->}.

If you don’t specify any distance after up, down, etc., \textit{pic} uses the standard distance:

\begin{verbatim}
line up right; line down; line down left; line up
\end{verbatim}

If you omit the direction associated with a distance, the current direction is used.

Boxes and lines may be dotted or dashed:

\begin{verbatim}
box dotted; line dotted; move; line dashed; box dashed
\end{verbatim}
If there is a number after dot, the dots will be approximately that far apart. You can also control the size of the dashes (at least somewhat): if there is a length after the word dashed, the dashes will be that long, and the intervening spaces will be as close as possible to that size:

\[
\begin{align*}
\text{line right} & \text{ 5 dashed; move left 5 down .25; right} \\
\text{line right} & \text{ 5 dashed 0.25; move left 5 down .25; right} \\
\text{line right} & \text{ 5 dashed 0.5; move left 5 down .25; right} \\
\text{line right} & \text{ 5 dashed 1}
\end{align*}
\]

\[
\begin{array}{cccccccccc}
\hline
\text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} \\
\text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} \\
\text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} & \text{-----} \\
\hline
\end{array}
\]

Dotted or dashed attributes apply only to lines and boxes.

You can make any object invisible by adding the word invis after it. This is particularly useful for positioning things correctly near text:

\[
\text{box invis "input"]; arrow; box invis "output"}
\]

input \[\rightarrow\] output

Text may be positioned on lines and arrows:

\[
\begin{align*}
\text{arrow "on top of"; move} \\
\text{arrow "above" "below"; move} \\
\text{arrow "above" above; move} \\
\text{arrow "below" below; move} \\
\text{arrow "above" "on top of" "below"}
\end{align*}
\]

The ‘‘width’’ of an arrowhead is the distance across its tail; the ‘‘height’’ is the distance along the shaft. The arrowheads in this picture are default size and shape.

As we said earlier, arcs go 90 degrees counterclockwise from where you are right now, and arc cw changes this to clockwise. The default radius is the same as for circles, but you can change it with the rad attribute. It is also easy to draw arcs between specific places; this will be described in the next section.

To put an arrowhead on an arc, use one of <-, -> or <->, as with lines.

In all cases, unless an explicit dimension for some object is specified, you will get the default size. If you want an object to have the same size as the previous one of that kind, add the word same. Thus in the set of boxes given by

\[
\begin{align*}
down; \text{box} \text{ ht 0.2 wid 1.5; move down 0.15; box same; move same; box same}
\end{align*}
\]
the dimensions set by the first box are used several times; similarly, the amount of motion for the second move is the same as for the first one.

You can change the default sizes of objects by assigning values to the variables that define their values. Here is the list, with their default values:

\[
\begin{align*}
\text{boxwid} &= 0.75; \quad \text{boxht} = 0.5 \\
\text{linewid} &= 0.75; \quad \text{lineht} = 0.5 \\
\text{circlerad} &= 0.25; \quad \text{arcrad} = 0.25 \\
\text{ellipsewid} &= 0.75; \quad \text{ellipseht} = 0.5 \\
\text{movewid} &= 0.75; \quad \text{moveht} = 0.5 \\
\text{textwid} &= 0; \quad \text{textht} = 0 \\
\text{arrowwid} &= 0.05; \quad \text{arrowht} = 0.1 \quad \text{(These refer to the arrowhead.)} \\
\text{dashwid} &= 0.05; \quad \text{arrowhead} = 2 \quad \text{(Arrowhead fill style)} \\
\text{maxpsht} &= 8.5; \quad \text{maxpswid} = 11 \quad \text{(Maximum picture dimensions)} \\
\text{fillval} &= 0.3; \quad \text{scale} = 1
\end{align*}
\]

So if you want all your boxes to be long and skinny, and relatively close together,

\[
\begin{align*}
\text{boxwid} &= 0.1; \quad \text{boxht} = 1 \\
\text{movewid} &= 0.2 \\
\text{box; move; box; move; box}
\end{align*}
\]

Setting the variable \text{arrowhead} to a value like 7 causes arrowheads to be filled by overstriking; the default is 2:

\[
\begin{align*}
\text{arrowhead} &= 7; \quad \text{arrow; move; arrowhead} = 2; \quad \text{arrow}
\end{align*}
\]

\text{Pic} works internally in inches. Setting the variable \text{scale} to some value causes all dimensions to be scaled down by that value. Thus, for example, \text{scale=2.54} causes dimensions to be interpreted as centimeters.

The numbers given in the .PS line override the dimensions given in the picture; these can be used to force a picture to a particular width and height. Experience indicates that a good way to get a picture of the right size is to enter its dimensions in inches, then if necessary add a width and perhaps height to the .PS line.

Once set, variables like \text{boxht} retain their values from one picture to the next. You can reset variables to their default values by listing them in a \text{reset} statement:

\[
\begin{align*}
\text{reset boxht, boxwid}
\end{align*}
\]

A bare \text{reset} resets all variables.

There is a minimal facility for filling or shading objects, intended for Postscript output devices. The attribute \text{fill expr} sets the gray scale value to \text{expr}; the default, determined by the variable \text{fillval}, is 0.3. Following Postscript, smaller values are darker. Thus:
4. Controlling Positions

You can place things anywhere you want; *pic* provides a variety of ways to talk about positions. *Pic* uses a standard Cartesian coordinate system with $x$ increasing rightwards and $y$ increasing upwards, so any point or object has an $x$ and $y$ position, measured in inches. The first object is placed with its start at position 0,0 by default. The $x,y$ position of a box, circle or ellipse is its geometric center; the position of a line or spline or motion is its beginning; the position of an arc is the center of the corresponding circle.

Position modifiers like `from`, `to`, `by` and `at` are followed by an $x,y$ pair, and can be attached to boxes, circles, lines, motions, and so on, to specify or modify a position.

You can also use `up`, `down`, `right`, and `left` with `line` and `move`:

```
box ht 0.2 wid 0.2 at 0,0 "1"
move right 0.5 # or "move to 0.5,0"
box ht 0.2 wid 0.2 "2"
move right 0.5 # or "move 0.5" or "move same"
box ht 0.2 wid 0.2 "3"
```

Comments can be used in pictures; they begin with a `#` and end at the end of the line.

Attributes like `ht` and `wid` and positions like `at` can be written out in any order. So

```
box ht 0.2 wid 0.2 at 0,0
box at 0,0 wid 0.2 ht 0.2
box ht 0.2 at 0,0 wid 0.2
```

are all equivalent, though the last is harder to read and thus less desirable.

The `from` and `to` attributes are particularly useful with arcs, to specify the endpoints. By default, arcs are drawn counterclockwise:

```
"+" at 0,0
arc -> from 0.5,0 to 0,0.5
arc -> cw from 0,0 to 1,0.5
```

The radius can be made large to provide flat arcs:

```
arc -> cw from 0,0 to 2,0 rad 15
```

If the circle is under-specified, *pic* guesses a radius and/or center; you will have to provide them explicitly if the guess is wrong.
We said earlier that objects are normally connected left to right. This is an over-simplification. The truth is that objects are connected together in the direction specified by the most recent up, down, left or right (either alone or as part of some object). Thus, in

```
arrows left; box; arrows; circle; arrows
```

the left implies connection towards the left:

![Diagram showing connection left of circle to box]

This could also be written as

```
left; arrows; box; arrows; circle; arrows
```

Objects are joined in the direction determined by the last up, down, etc., with the entry point of the second object attached to the exit point of the first (which is fixed at the time of entry). Entry and exit points for boxes, circles and ellipses are on opposite sides. This automatic connection and direction selection works well if the direction doesn’t change but it will occasionally surprise you:

```
arrows; circle; down; arrows
```

The arrow comes out of the right side of the circle, not the bottom, as might be expected.

If a set of commands is enclosed in braces `{...}`, the current position and direction of motion when the group is finished will be exactly where it was when entered. Nothing else is restored. There is also a more general way to group objects, using `[ ]`, which is discussed in Section 9.

5. Labels and Corners

Objects can be labelled or named so that you can talk about them later. For example,

```
Box1: box
    # ... other stuff ...
    move to Box1
```

Place names must begin with an upper case letter (to distinguish them from variable names, which begin with lower case letters). The name refers to the “center” of the object, which is the geometric center for most things.

Other combinations also work:

```
line from Box1 to Box2
move to Box1 up 0.1 right 0.2
move to Box1 + 0.2,0.1  # same as previous
line to Box1 - 0.5,0
```

The reserved name Here may be used to refer to the current position.

Labels can be reset several times in a single picture, so a statement like

```
Box1: Box1 + 1,1
```

is perfectly legal.

You can also refer to previously drawn objects of each type, using the word last. For example, given the input
then 'last box' refers to box C, 'last circle' refers to circle B, and '2nd last box' refers to box A. Numbering of objects can also be done from the beginning, so boxes A and C are '1st box' and '2nd box' respectively.

To cut down the need for explicit coordinates, objects have “corners” named by compass points:

B: box "B.c" ht 1 wid 1.5
  "B.e" at B.e ljust
  "B.ne" at B.ne ljust
  "B.se" at B.se ljust
  "B.s" at B.s below
  "B.n" at B.n above
  "B.sw " at B.sw rjust
  "B.w " at B.w rjust
  "B.nw " at B.nw rjust

Note the use of ljust, rjust, above, and below to alter the default positioning of text, and of a blank within some strings to help space them away from a vertical line.

Lines and arrows have a start, an end and a center in addition to corners. Circles and ellipses have corners too; an arc has the same corners as the circle of which it is a part. The words left, right, top, and bottom are synonyms for west, east, north and south.

It is often easiest to position objects by positioning some part of one at some part of another, for example the southwest corner of one at the southeast corner of another. The with attribute permits this kind of positioning:

box ht 0.75 wid 0.75
box ht 0.5 wid 0.5 with .sw at last box.se

Notice that the corner after with is written .sw.

As another example, consider

e llipse
  ellipse ht .2 wid .3 with .se at 1st ellipse.nw
  ellipse ht .2 wid .3 with .sw at 1st ellipse.ne

Sometimes it is desirable to have a line intersect a circle at a point which is not one of the eight compass points that pic knows about. In such cases, the proper visual effect can be obtained by using the attribute chop to
chop off part of the line:

```plaintext
circlerad = 0.15; arrowhead = 7
circle "a"
circle "b" at 1st circle - (0.4, 0.6)
circle "c" at 1st circle + (0.4, -0.6)
arrow from 1st circle to 2nd circle chop
arrow from 1st circle to 3rd circle chop
```

By default the line is chopped by `circlerad` at each end. This may be changed:

```plaintext
line ... chop r
```

chops both ends by `r`, and

```plaintext
line ... chop r1 chop r2
```

chops the beginning by `r1` and the end by `r2`. More complicated intersections can be computed with the built-in trigonometric functions listed in the next section.

There is one other form of positioning that is sometimes useful, to refer to a point some fraction of the way between two other points. This can be expressed in `pic` as

```
fraction of the way between position1 and position2
```

where `fraction` is any expression, and `position1` and `position2` are any positions. You can abbreviate this rather windy phrase; ‘of the way’ is optional, and the whole thing can be written instead as

```
fraction < position1 , position2 >
```

As a pair of examples:

```plaintext
box
  arrow right from 1/3 of the way between last box.ne and last box.se
  arrow right from 2/3 <last box.ne, last box.se>
```

```plaintext
A: ellipse
  ellipse ht .2 wid .3 with .se at 1st ellipse.nw
  ellipse ht .2 wid .3 with .sw at 1st ellipse.ne
  circle rad .05 at 0.5 <A.nw,A.c>
  circle rad .05 at 0.5 <A.ne,A.c>
  arc from 0.25 <A.w,A.e> to 0.75 <A.w,A.e>
```

Naturally, the distance given by `fraction` can be greater than 1 or less than 0.

Advice: experience suggests that the easiest way to position objects is by placing them relative to previous
objects and places, using with, at, etc. This is better than using move; you should generally avoid move.

6. Variables, Expressions and Built-in Functions

It’s generally a bad idea to write everything in absolute coordinates if you are likely to change things. Pic variables let you parameterize your picture:

```latex
a = 0.5;  b = 1
box wid a ht b
ellipse wid a/2 ht 1.5*b
Box2: Box1 - (a/2, b/2)
```

Expressions may use the standard operators $+$, $-$, $\times$, $/$, $\%$, $^\wedge$ (exponentiation), and parentheses for grouping.

The most important variables are the predefined ones for controlling the default sizes of objects, listed in Section 3. These may be set at any time in any picture, and retain their values from picture to picture until reset.

You can use the height, width, radius, and $x$ and $y$ coordinates of any object or corner in an expression:

```latex
Box1.x # the $x$ coordinate of the center of Box1
Box1.ne.y # the $y$ coordinate of the northeast corner of Box1
Box1.wid # the width of Box1
Box1.ht # and its height
2nd last circle.rad # the radius of the 2nd last circle
```

Any pair of expressions enclosed in parentheses defines a position; furthermore such positions can be added or subtracted to yield new positions:

```latex
(x, y)
(x_1, y_1) + (x_2, y_2)
```

If $p_1$ and $p_2$ are positions, then $(p_1, p_2)$ refers to the point $(p_1.x, p_2.y)$.

Pic provides a small collection of standard functions:

```latex
\sin(expr), \cos(expr), \atan2(y,x) \quad \text{(angle in radians)}
\log(expr), \exp(expr) \quad \text{(Beware: both base 10)}
\sqrt{expr}, \max(e_1,e_2), \min(e_1,e_2)
\int(expr) \quad \text{(integer part of expr)}
\text{rand}() \quad \text{(random number between 0 and 1)}
```

7. More on Text

Normally, text is centered at the geometric center of the object it is associated with. The attribute ljust causes the left end to be at the specified point (which means that the text lies to the right of the specified place!), and rjust puts the right end at the place. above and below center the text one half line space in the given direction.

Text attributes can be compounded:

```latex
\text{arrow 1 "ljust above" ljust above}
```

Text is most often an attribute of some other object, but you can also have self-standing text:

```latex
"origin" "(0,0)" at 0,0
"this is" "(1,1)" at 1,1
box ht 1 wid 1 dotted with .sw at 0,0
```
In effect, *n* text strings are contained in an invisible box of width \textwidth and height \( n \times \text{textht} \). The variables \textwidth and \textht may be set to any values; they are normally zero.

A list of numeric expressions can be converted to a formatted string with the \texttt{sprintf} function and used anywhere a quoted string can be:

\begin{verbatim}
B: box wid log(20)
sprintf("width = %g, height = %g ", B.wid, B.ht) rjust at B.w
\end{verbatim}

\begin{verbatim}
width = 1.30103, height = 0.5
\end{verbatim}

8. Lines and Splines

A “line” may actually be a path, that is, it may consist of connected segments:

\begin{verbatim}
line right 1 then down .5 left 1 then right 1
\end{verbatim}

The word \texttt{then} separates components of the path.

A spline is a smooth curve guided by a set of straight lines just like the line above. It begins at the same place, ends at the same place, and in between is tangent to the mid-point of each guiding line. The syntax for a spline is identical to a (path) line except for using \texttt{spline} instead of \texttt{line}:

\begin{verbatim}
line dashed right 1 then down .5 left 1 then right 1
spline from start of last line \ 
right 1 then down .5 left 1 then right 1
\end{verbatim}

(Long input lines can be split by ending each piece with a backslash.)

The elements of a path, whether line or spline, are specified as a series of points, either in absolute terms or by up, down, etc.

\begin{verbatim}
spline right then up then left then down ->
\end{verbatim}
spline right then up left then down ->

Notice that arrowheads may be put on the ends of a line or spline.

9. Blocks

Any sequence of \textit{pic} statements may be enclosed in brackets \([\) and \(]\) to form a block, which can then be treated as a single object, and manipulated rather like an ordinary box:

```
box "1"
[ box "2"; arrow "3" above; box "4" ] with .n at last box.s - (0,0.1)
"Thing 2: " rjust at last []).w
```

Notice that “last”-type constructs treat blocks as a unit and don’t look inside for objects; “last box.s” refers to box 1, not box 2 or 4. You can use \texttt{last []}, etc., just like \texttt{last box}.

Blocks have the same compass corners as boxes (determined by the bounding box). It is also possible to position a block by placing either an absolute coordinate (like \((0,0)\)) or an internal label (like \(A\)) at some external point, as in

```
[ ...; A: ...; ... ] with .A at ...
```

By default, blocks join with other things as boxes do, at the center of the appropriate side.

Names of variables and places within a block are local to that block, and thus do not affect variables and places of the same name outside. (In particular, that includes the built-in variables like \texttt{boxwid}, etc.; if they are set within a block, they revert to their original values when the block is left.) You can get at the internal place names with constructs like

```
last [].A
```
or

```
B.A
```

where \(B\) is a name attached to a block:

```
B: [ ... ; A: ...; ]
```

When combined with \texttt{define} statements (next section), blocks provide a reasonable simulation of a procedure mechanism.

Although blocks nest, it is currently possible to look only one level deep with constructs like \texttt{B.A}, although \(A\) may be further qualified by a corner name (i.e., \texttt{B.A.sw} or \texttt{top of B.A} are legal).

The following example illustrates most of the points made above about how blocks work:
h = .5; dh = .02; dw = .1

[ Ptr: [ boxht = h; boxwid = dw
    A: box
    B: box
    C: box
    box wid 2*boxwid "...
    D: box
  ]

  Block: [
    boxht = 2*dw; boxwid = 2*dw
    movewid = 2*dh
    A: box; move
    B: box; move
    C: box; move
    box invis "...
    box wid 2*boxwid; move
    D: box
  ] with .t at Ptr.s - (0,h/2)
  arrow from Ptr.A to Block.A.nw + (dh,0)
  arrow from Ptr.B to Block.B.nw + (dh,0)
  arrow from Ptr.C to Block.C.nw + (dh,0)
  arrow from Ptr.D to Block.D.nw + (dh,0)
]

box dashed ht last [].ht+dw wid last [].wid+dw at last []

This produces

![Diagram of boxes and arrows]

10. Macros

*Pic* provides a basic macro facility. In the simplest form,

```latex
define name ( replacement text )
```

defines *name* to be the *replacement text*. Any subsequent occurrence of *name* will be replaced by *replacement text*.

Macros may have arguments. If the replacement text of a macro definition contains occurrences of $\$1$, $\$2$, etc., these will be replaced by the corresponding actual arguments when the macro is invoked. The invocation for a macro with arguments is

```latex
name(arg1, arg2, ...)
```

Non-existent arguments are replaced by null strings. Macro definitions last from picture to picture; a macro definition can be removed by

```latex
undef macro-name
```

As an example, one might define a square by

```latex
define square ( box ht $1 wid $1 $2 )
```

and use it as
Notice how the second argument may be used to pass in arbitrary contents.

Coordinates like $x,y$ may be enclosed in parentheses, as in $(x,y)$, so they can be included in a macro argument.

11. File Copy

The statement

```plaintext
copy "filename"
```

inserts the contents of the named file at that point in the input. Any .PS or .PE lines within the file are ignored, so previously prepared pictures can be used as parts of larger ones without editing.

*Pic* also provides the `copy thru` mechanism found in *grap*:

```plaintext
copy "file" thru macro-name
```

copies *file*, treating each line as an invocation of the named macro (each field being an argument). A literal macro may be used instead of a name:

```plaintext
copy "file" thru { macro replacement text }
```

and if no file name is given, the remainder of the input until the next .PE is used. So to plot a set of circles at points whose coordinates and radii are included in-line:

```plaintext
copy thru { circle rad $3$ at $1,2$ }
0 0 0.05
1 1 .1
...
```

The `sh` command executes an arbitrary commandline:

```plaintext
sh { anything }
```

Macros within *anything* are expanded first.

12. Loops and Conditionals

*Pic* provides an *if* statement and a *for* loop.
\[ \pi = \arctan(0, -1) \]

for \( i = 0 \) to \( 2 \times \pi \) by \( 0.1 \) do {
    "-" at \( i/2, 0 \)
    "s" at \( i/2, \sin(i)/2 \)
    "c" at \( i/2, \cos(i)/2 \)
}

The \textit{by} clause is optional; if the value is preceded by a \*, the steps are multiplicative, not additive. The body of the loop is delimited by braces, which are also used for definitions, \texttt{copy}, \texttt{sh} and \texttt{if} statements.

The \textit{if} statement is

\[
\text{if } \text{expression} \text{ then } \{ \text{anything} \} \text{ else } \{ \text{anything} \}
\]

where the \texttt{else} clause is optional. The \textit{expression} may use the usual relational operators: \(==\), \(!=\), \(>\), \(>=\), \(<\), \(<=\), \&\& and \(||\).

\[ \pi = \arctan(0, -1) \]

for \( i = 0 \) to \( \pi \) by \( 0.1 \) do {
    if \( (s = \sin(i)) > 0.8 \) then \{ \( s = 0.8 \) \}
    "x" at \( i/2, s/2 \)
}

A string comparison using \(==\) or \(!=\) is also permitted, to compare quoted strings:

\[
\text{if } "\text{string1}" == "\text{string2}" \text{ then } ...
\]

13. \textit{Troff Interface}

\texttt{Pic} is usually run as a \texttt{troff} preprocessor:

\[
\text{pic file | troff -ms}
\]

Run it before \texttt{eqn} if it is also present.

If the \texttt{.PS} line looks like

\[
\text{.PS <file}
\]

then the contents of \texttt{file} are inserted in place of the \texttt{.PS} line, whether or not the file contains \texttt{.PS} or \texttt{.PE}. (This feature is deprecated in favor of the \texttt{copy} statement.)

\texttt{Pic} copies the \texttt{.PS} and \texttt{.PE} lines from input to output intact, except that it adds two things on the same line as the \texttt{.PS}:

\[
\text{.PS h w}
\]

\(h\) and \(w\) are the picture height and width in units. The \texttt{-ms} macro package has definitions for \texttt{.PS} and \texttt{.PE} that cause pictures to be centered and offset a bit from surrounding text. (See the appendix.)

If \texttt{".PF"} is used instead of \texttt{.PE}, the position after printing is restored to where it was before the picture started, instead of being at the bottom. (\texttt{"F"} is for "flyback."
Any input line that begins with a period is assumed to be a *troff* command that makes sense at that point; it is copied to the output at that point in the document. It is asking for trouble to add vertical space or in any way fiddle with the line spacing here, but point size and font changes are generally harmless:

```
.ps 24
circle radius .4 at 0,0
.ps 12
circle radius .2 at 0,0
.ps 8
circle radius .1 at 0,0
.ps 6
circle radius .05 at 0,0
.ps 10 " don’t forget to restore size
```

*Pic* does preserve the state of *troff’s* fill mode across pictures.

It is also safe to include sizes, fonts and local motions within quoted strings )..."" in *pic*, so long as whatever changes are made are unmade before exiting the string. For example, to print text in Helvetica Bold 2 points larger:

```
ellipse "\s+2\f(HBSmile!\fP\s-2"
```

This is essentially the same rule as applies in *eqn*.

There is a subtle problem with complicated equations inside *pic* pictures — they come out wrong if *eqn* has to leave extra vertical space for the equation. If your equation involves more than subscripts and superscripts, you must add to the beginning of each equation the extra information `space 0`:

```
arrow
box "space 0 (H( omega )) over (1 - H( omega ))"$
arrow
```

14. Some Examples

Here are a handful of larger examples:
define ndblock {
    box wid boxwid/2 ht boxht/2
down; box same with .t at bottom of last box; box same
}

boxht = .2; boxwid = .3; circlerad = .3; dx = 0.05
down; box; box; box; box; box ht 3*boxht .". " .". " .".
L: box; box; box invis wid 2*boxwid "hashtab:" with .e at 1st box .w right
Start: box wid .5 with .sw at 1st box.ne + (.4,.2) "...
N1: box wid .2 "n1"; D1: box wid .3 "d1"
N3: box wid .4 "n3"; D3: box wid .3 "d3"
box wid .4 "...
N2: box wid .5 "n2"; D2: box wid .2 "d2"
arrow right from 2nd box
ndblock
spline -> right .2 from 3rd last box then to N1.sw + (dx,0)
spline -> right .3 from 2nd last box then to D1.sw + (dx,0)
arrows right from last box
ndblock
spline -> right .2 from 3rd last box to N2.sw-(dx,.2) to N2.sw+(dx,0)
spline -> right .3 from 2nd last box to D2.sw-(dx,.2) to D2.sw+(dx,0)
arrows right 2*linewid from L
ndblock
spline -> right .2 from 3rd last box to N3.sw + (dx,0)
spline -> right .3 from 2nd last box to D3.sw + (dx,0)
circlerad = .3
circle invis "ndblock" at last box.e + (1.2,.2)
arrows dashed from last circle.w to last box chop 0 chop .3
box invis wid 2*boxwid "ndtable:" with .e at Start.w
There are eighteen objects (boxes and arrows) in the picture, and one line of pic input for each; this seems like an acceptable level of verbosity.
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More recent versions of pic have benefited greatly from adventurous use by Jon Bentley and Ravi Sethi; their comments on the manual are also much appreciated.

References


Pictures

The top-level object in pic is the "picture":

```
picture:
  .PS optional-width optional-height
  element-list
  .PE
```

If `optional-width` is present, the picture is made that many inches wide, regardless of any dimensions used internally. The height is scaled in the same proportion unless `optional-height` is present. If instead the line is

```
  .PS <file
```

the file `file` is inserted in place of the `.PS` line. If `.PF` is used instead of `.PE`, the position after printing is restored to what it was upon entry.

In no case will the picture be larger than `maxpsht` x `maxpswid`.

Elements

An `element-list` is a list of elements (what else?); the elements are

```
element:
  primitive attribute-list
  placename : element
  placename : position
  var = expr
direction
  { element-list }
  [ element-list ]
  for var = expr to expr by expr do { anything }
  if expr then { anything } else { anything }
  copy file
  copy thru macro
  copy file thru macro
  sh { commandline }
  print expr
  reset optional var-list
  troff-command
```

Elements are separated by newlines or semicolons; a long element may be continued by ending the line with a backslash. Comments are introduced by a `#` and terminated by a newline.

Variable names begin with a lower case letter; place names begin with upper case. Place and variable names retain their values from one picture to the next.
The current position and direction of motion are saved upon entry to a {...} block and restored upon exit.

Elements within a block enclosed in {...} are treated as a unit; the dimensions are determined by the extreme points of the contained objects. Names, variables, and direction of motion within a block are local to that block.

`troff-command` is any line that begins with a period. Such a line is assumed to make sense in the context where it appears; accordingly, if it doesn’t work, don’t call.

**Primitives**

The primitive objects are

```
primitive:
    box
circle
ellipse
arc
text-list
```

`arrow` is a synonym for `line ->`.

**Attributes**

An `attribute-list` is a sequence of zero or more attributes; each attribute consists of a keyword, perhaps followed by a value.

```
attribute:
    h(eigh)t expr
    wid(th) expr
    rad(ius) expr
    diam(eter) expr
    up opt-exp
    right opt-exp
    from position
    at position
    by expr, expr
    dotted opt-exp
    chop opt-exp
    invis
    fill opt-exp
    text-list
```

Missing attributes and values are filled in from defaults. Not all attributes make sense for all primitives; irrelevant ones are silently ignored. The attribute `at` causes the geometrical center to be put at the specified place; `with` causes the position on the object to be put at the specified place. For lines, splines and arcs, `height` and `width` refer to arrowhead size. A bare `expr` implies motion in the current direction.

**Text**

Text is normally an attribute of some primitive; by default it is placed at the geometrical center of the object. Stand-alone text is also permitted. A `text-list` is a list of text items; a text item is a quoted string optionally followed by positioning requests:

```
text-item:
    "..." positioning ...
sprintf("format", expr, ...) positioning ...
positioning:
    center ljust rjust above below
```

If there are multiple text items for some primitive, they are centered vertically except as qualified. Positioning
requests apply to each item independently.

Text items can contain \texttt{t}roff\ commands for size and font changes, local motions, etc., but make sure that these are balanced so that the entering state is restored before exiting.

\textbf{Positions and places}

A position is ultimately an \(x,y\) coordinate pair, but it may be specified in other ways.

\begin{verbatim}
position:
  expr, expr
place ± expr, expr
place ± ( expr, expr )
( position, position )
expr [of the way] between position and position
expr < position , position >
( position )
\end{verbatim}

\begin{verbatim}
place:
  placename optional-corner
  corner of placename
  nth primitive optional-corner
  corner of nth primitive
\end{verbatim}

An \texttt{optional-corner} is one of the eight compass points or the center or the start or end of a primitive.

\begin{verbatim}
optional-corner:
  .n .e .w .s .ne .se .nw .sw .c .start .end
\end{verbatim}

\begin{verbatim}
corner:
  top bot left right start end
\end{verbatim}

Each object in a picture has an ordinal number; \texttt{nth} refers to this.

\begin{verbatim}
nth:
  nth
  nth last
\end{verbatim}

Since barbarisms like 1th and 3th are barbaric, synonyms like 1st and 3rd are accepted as well.

\textbf{Variables}

The built-in variables and their default values are:

\begin{verbatim}
boxwid 0.75  boxht 0.5
circlerad 0.25  arcrad 0.25
ellipsewid 0.75  ellipsetht 0.5
linewid 0.5  lineht 0.5
movewid 0.5  moveht 0.5
textwid 0  textht 0
arrowwid 0.05  arrowht 0.1
dashwid 0.1  arrowhead 2
maxpsht 8.5  maxpswid 11
scale 1  fillval .3
\end{verbatim}

These may be changed at any time, and the new values remain in force from picture to picture until changed again or reset by a \texttt{reset} statement. Variables changed within \texttt{[} and \texttt{]} revert to their previous value upon exit from the block. Dimensions are divided by \texttt{scale} during output.

\textbf{Expressions}

Expressions in \texttt{pic} are evaluated in floating point. All numbers representing dimensions are taken to be in inches.
expr:
  expr op expr
  - expr
  ! expr
  ( expr )
  variable
  number
  place .x
  place .y
  place .ht
  place .wid
  place .rad
  sin(expr) cos(expr) atan2(expr,expr) log(expr) exp(expr)
  sqrt(expr) max(expr,expr) min(expr,expr) int(expr) rand()

op:
  + - * / % ^
  < <= > >= == != && ||

Definitions

The define and undef statements are not part of the grammar.

define:
  define name { replacement text }

undef:
  undef name

Occurrences of $1$, $2$, etc., in the replacement text will be replaced by the corresponding arguments if name is invoked as

name(arg1, arg2, ...)

Non-existent arguments are replaced by null strings. Replacement text may contain newlines. The undef statement removes the definition of a macro.

The .PS and .PE Macros

This is the default definition of the .PS and .PE macros:

.de PS " start picture; $1 is height, $2 is width, in inches
 .sp .3
 .in (\n(1u-\$2)/2u
 .ne \$1
 ..
.de PE " end of picture
 .in
 .sp .6
 ..

Summary of Features Added Since Original Version

The built-in functions sin, cos, atan2, log, exp, sqrt, max, min, int, and rand are available.

The copy statement includes data from a file or that follows immediately:

  copy "filename"
  copy thru macro
  copy "filename" thru macro

The macro may be either the name of a defined macro, or the body of a macro enclosed in braces. If no filename is given, copy copies the input until the next .PE.

The for and if statements provide loops and decision-making:
for var=expr to expr by expr do { anything }
if expr then { anything } else { anything }

The by and else clauses are optional. The expr in an if may use the usual relational operators or the tests str1 == (or ! =) str2 for two quoted strings.

The sh command executes any sequence of commands, after expanding any defined names:

sh ( anything )

In all of the above, any single character that does not occur within the body may be used to enclose a body, instead of braces, as in

define name X replacement text X

Text strings are first-class citizens: a statement beginning with a sequence of text strings is treated as an invisible box with the strings positioned at its center. The variable textht and textwid may be set to any values to control positioning. The height of \text{n} such strings is \text{n} \times \text{textht}.

It is possible to convert expressions to formatted strings:

\texttt{sprintf(\textquoteright\texttt{format}}, expr, expr, ...)\texttt{ is equivalent to a quoted string in any context. Variants of \texttt{\%f} and \texttt{\%g} are the only sensible format conversions.}

Built-in variables may be reset to default values with reset.

The undef statement removes a macro definition.

Arrowheads may be filled with the arrowhead variable; their positioning is improved on arcs.

The width and height of the generated picture may be set independently from the .PS line; the maximum height and width are set from maxpsht and maxpswid.

The state of troff’s fill or no-fill mode is preserved around a picture.

Input numbers may be expressed in \texttt{E} notation.

Numerous internal changes have been made as well. Any number of objects, text strings, etc., may be used; the only limit is total available memory. Output is now produced in inches instead of units for a particular typesetter, so the \texttt{-T} option has gone away.