Drawing graphs with *dot*

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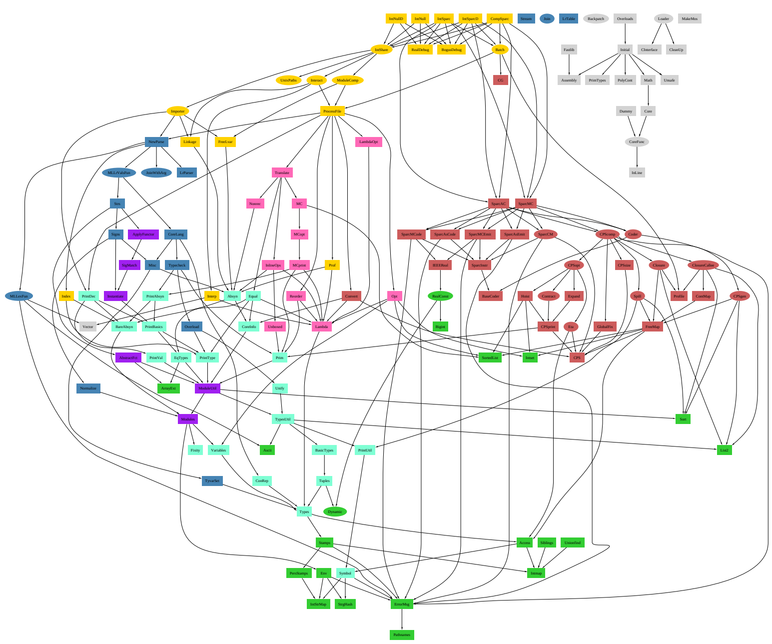
Abstract

dot draws directed graphs as hierarchies. It runs as a command line program, web visualization service, or with a compatible graphical interface. Its features include well-tuned layout algorithms for placing nodes and edge splines, edge labels, “record” shapes with “ports” for drawing data structures; cluster layouts; and an underlying file language for stream-oriented graph tools. Below is a reduced module dependency graph of an SML-NJ compiler that took 0.98 seconds of user time on a 1.4 Ghz AMD Athlon.



1 Basic Graph Drawing

dot draws directed graphs. It reads attributed graph text files and writes drawings, either as graph files or in a graphics format such as GIF, PNG, SVG or PostScript (which can be converted to PDF).

dot draws a graph in four main phases. Knowing this helps you to understand what kind of layouts *dot* makes and how you can control them. The layout procedure used by *dot* relies on the graph being acyclic. Thus, the first step is to break any cycles which occur in the input graph by reversing the internal direction of certain cyclic edges. The next step assigns nodes to discrete ranks or levels. In a top-to-bottom drawing, ranks determine Y coordinates. Edges that span more than one rank are broken into chains of "virtual" nodes and unit-length edges. The third step orders nodes within ranks to avoid crossings. The fourth step sets X coordinates of nodes to keep edges short, and the final step routes edge splines. This is the same general approach as most hierarchical graph drawing programs, based on the work of Warfield [War77], Carpano [Car80] and Sugiyama [STT81]. We refer the reader to [GKNV93] for a thorough explanation of *dot*'s algorithms.

dot accepts input in the *DOT* language (cf. Appendix A). This language describes three kinds of objects: graphs, nodes, and edges. The main (outermost) graph can be directed (`digraph`) or undirected `graph`. Because *dot* makes layouts of directed graphs, all the following examples use `digraph`. (A separate layout utility, *neato*, draws undirected graphs [Nor92].) Within a main graph, a `subgraph` defines a subset of nodes and edges.

Figure 1 is an example graph in the *DOT* language. Line 1 gives the graph name and type. The lines that follow create nodes, edges, or subgraphs, and set attributes. Names of all these objects may be C identifiers, numbers, or quoted C strings. Quotes protect punctuation and white space.

A node is created when its name first appears in the file. An edge is created when nodes are joined by the edge operator `->`. In the example, line 2 makes edges from *main* to *parse*, and from *parse* to *execute*. Running *dot* on this file (call it `graph1.dot`)

```
$ dot -Tps graph1.dot -o graph1.ps
```

yields the drawing of Figure 2. The command line option `-Tps` selects PostScript (EPSF) output. `graph1.ps` may be printed, displayed by a PostScript viewer, or embedded in another document.

It is often useful to adjust the representation or placement of nodes and edges in the layout. This is done by setting attributes of nodes, edges, or subgraphs in the input file. Attributes are name-value pairs of character strings. Figures 3 and 4 illustrate some layout attributes. In the listing of Figure 3, line 2 sets the graph's

```
digraph G {
    main -> parse -> execute;
    main -> init;
    main -> cleanup;
    execute -> make_string;
    execute -> printf
    init -> make_string;
    main -> printf;
    execute -> compare;
}
```

Figure 1: Small graph

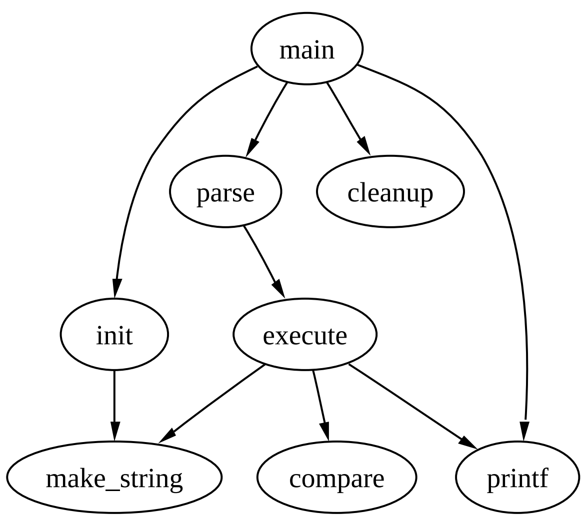


Figure 2: Drawing of small graph

size to 4,4 (in inches). This attribute controls the size of the drawing; if the drawing is too large, it is scaled as necessary to fit.

Node or edge attributes are set off in square brackets. In line 3, the node main is assigned shape box. The edge in line 4 is straightened by increasing its weight (the default is 1). The edge in line 6 is drawn as a dotted line. Line 8 makes edges from execute to make_string and printf. In line 10 the default edge color is set to red. This affects any edges created after this point in the file. Line 11 makes a bold edge labeled 100 times. In line 12, node make_string is given a multi-line label. Line 13 changes the default node to be a box filled with a shade of blue. The node compare inherits these values.

2 Drawing Attributes

The complete list of attributes that affect graph drawing is summarized in Tables 1, 2 and 3.

2.1 Node Shapes

Nodes are drawn, by default, with shape=ellipse, width=.75, height=.5 and labeled by the node name. Other common shapes include box, circle, record and plaintext. A complete list of node shapes is given in Appendix E. The node shape plaintext is of particularly interest in that it draws a node without any outline, an important convention in some kinds of diagrams. In cases where the graph structure is of main concern, and especially when the graph is moderately large, the point shape reduces nodes to display minimal content. When drawn, a node's actual size is the greater of the requested size and the area needed for its text label, unless fixedsize=true, in which case the width and height values are enforced.

Node shapes fall into two broad categories: polygon-based and record-based.[1] All node shapes except record and Mrecord are considered polygonal, and are modeled by the number of sides (ellipses and circles being special cases), and a few other geometric properties. Some of these properties can be specified in a graph. If regular=true, the node is forced to be regular. The parameter peripheries sets the number of boundary curves drawn. For example, a doublecircle has peripheries=2. The orientation attribute specifies a clockwise rotation of the polygon, measured in degrees.

[1]There is a way to implement custom node shapes, using shape=epsf and the shapefile attribute, and relying on PostScript output. The details are beyond the scope of this user's guide. Please contact the authors for further information.

```
digraph G {
    size ="4,4";
    main [shape=box];   /* this is a comment */
    main -> parse [weight=8];
    parse -> execute;
    main -> init [style=dotted];
    main -> cleanup;
    execute -> { make_string; printf}
    init -> make_string;
    edge [color=red];   // so is this
    main -> printf [style=bold,label="100 times"];
    make_string [label="make a\nstring"];
    node [shape=box,style=filled,color=".7 .3 1.0"];
    execute -> compare;
}
```

Figure 3: Fancy graph

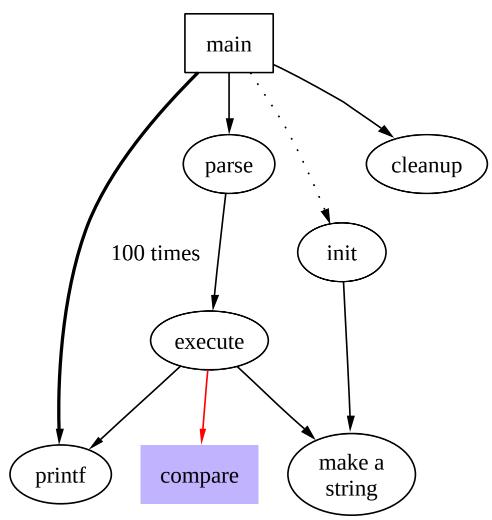


Figure 4: Drawing of fancy graph

The shape `polygon` exposes all the polygonal parameters, and is useful for creating many shapes that are not predefined. In addition to the parameters `regular`, `peripheries` and `orientation`, mentioned above, polygons are parameterized by number of sides `sides`, `skew` and `distortion`. `skew` is a floating point number (usually between -1.0 and 1.0) that distorts the shape by slanting it from top-to-bottom, with positive values moving the top of the polygon to the right. Thus, `skew` can be used to turn a box into a parallelogram. `distortion` shrinks the polygon from top-to-bottom, with negative values causing the bottom to be larger than the top. `distortion` turns a box into a trapezoid. A variety of these polygonal attributes are illustrated in Figures 6 and 5.

Record-based nodes form the other class of node shapes. These include the shapes `record` and `Mrecord`. The two are identical except that the latter has rounded corners. These nodes represent recursive lists of fields, which are drawn as alternating horizontal and vertical rows of boxes. The recursive structure is determined by the node’s `label`, which has the following schema:

rlabel	$\rightarrow$	*field* (’|’ *field*)*
field	$\rightarrow$	*boxLabel* | ’’ *rlabel* ’’
boxLabel	$\rightarrow$	[’$<$’ *string* ’$>$’] [*string*]

Literal braces, vertical bars and angle brackets must be escaped. Spaces are interpreted as separators between tokens, so they must be escaped if they are to appear literally in the text. The first string in a *boxLabel* gives a name to the field, and serves as a port name for the box (cf. Section 3.1). The second string is used as a label for the field; it may contain the same escape sequences as multi-line labels (cf. Section 2.2. The example of Figures 7 and 8 illustrates the use and some properties of records.

2.2 Labels

As mentioned above, the default node label is its name. Edges are unlabeled by default. Node and edge labels can be set explicitly using the `label` attribute as shown in Figure 4.

Though it may be convenient to label nodes by name, at other times labels must be set explicitly. For example, in drawing a file directory tree, one might have several directories named `src`, but each one must have a unique node identifier. The inode number or full path name are suitable unique identifiers. Then the label of each node can be set to the file name within its directory.

```
digraph G {
    a -> b -> c;
    b -> d;
    a [shape=polygon,sides=5,peripheries=3,color=blue_light,style=filled];
    c [shape=polygon,sides=4,skew=.4,label="hello world"]
    d [shape=invtriangle];
    e [shape=polygon,sides=4,distortion=.7];
}
```

Figure 5: Graph with polygonal shapes

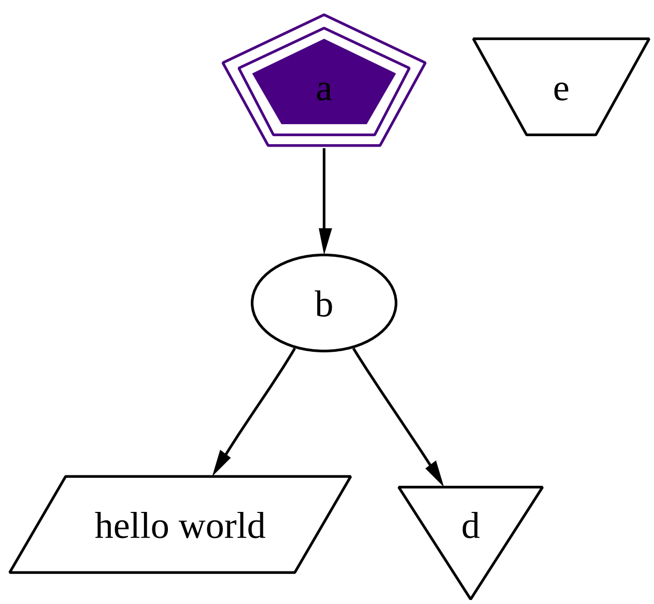


Figure 6: Drawing of polygonal node shapes

```
digraph structs {
node [shape=record];
    struct1 [shape=record,label="<f0> left|<f1> mid\ dle|<f2> right"];
    struct2 [shape=record,label="<f0> one|<f1> two"];
    struct3 [shape=record,label="hello\nworld |{ b |{c|<here> d|e}| f}| g | h"];
    struct1 -> struct2;
    struct1 -> struct3;
}
```

Figure 7: Records with nested fields

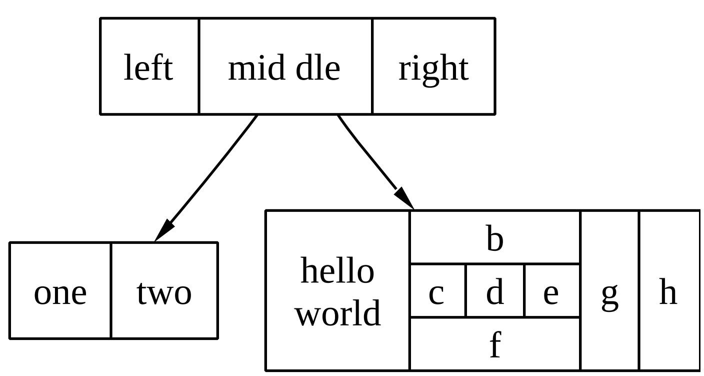


Figure 8: Drawing of records

Multi-line labels can be created by using the escape sequences `\n`, `\l`, `\r` to terminate lines that are centered, or left or right justified.[2]

The node shape `Mdiamond`, `Msquare` and `Mcircle` use the attributes `toplabel` and `bottomlabel` to specify additional labels appearing near the top and bottom of the nodes, respectively.

Graphs and cluster subgraphs may also have labels. Graph labels appear, by default, centered below the graph. Setting `labelloc=t` centers the label above the graph. Cluster labels appear within the enclosing rectangle, in the upper left corner. The value `labelloc=b` moves the label to the bottom of the rectangle. The setting `labeljust=r` moves the label to the right.

The default font is 14-point Times-Roman, in black. Other font families, sizes and colors may be selected using the attributes `fontname`, `fontsize` and `fontcolor`. Font names should be compatible with the target interpreter. It is best to use only the standard font families Times, Helvetica, Courier or Symbol as these are guaranteed to work with any target graphics language. For example, `Times-Italic`, `Times-Bold`, and `Courier` are portable; `AvanteGarde-DemiOblique` isn't.

For bitmap output, such as GIF or JPG, *dot* relies on having these fonts available during layout. The `fontpath` attribute can specify a list of directories[3] which should be searched for the font files. If this is not set, *dot* will use the DOTFONTPATH environment variable or, if this is not set, the GDFONTPATH environment variable. If none of these is set, *dot* uses a built-in list.

Edge labels are positioned near the center of the edge. Usually, care is taken to prevent the edge label from overlapping edges and nodes. It can still be difficult, in a complex graph, to be certain which edge a label belongs to. If the `decorate` attribute is set to true, a line is drawn connecting the label to its edge. Sometimes avoiding collisions among edge labels and edges forces the drawing to be bigger than desired. If `labelfloat=true`, *dot* does not try to prevent such overlaps, allowing a more compact drawing.

An edge can also specify additional labels, using `headlabel` and `taillabel`, which are be placed near the ends of the edge. The characteristics of these labels are specified using the attributes `labelfontname`, `labelfontsize` and `labelfontcolor`. These labels are placed near the intersection of the edge and the node and, as such, may interfere with them. To tune a drawing, the user can set the `labelangle` and `labeldistance` attributes. The former sets the angle, in degrees, which the label is rotated from the angle the edge makes incident with

[2] The escape sequence \N is an internal symbol for node names.

[3] For Unix-based systems, this is a concatenated list of pathnames, separated by colons. For Windows-based systems, the pathnames are separated by semi-colons.

the node. The latter sets a multiplicative scaling factor to adjust the distance that the label is from the node.

2.3 Graphics Styles

Nodes and edges can specify a `color` attribute, with black the default. This is the color used to draw the node's shape or the edge. A `color` value can be a hue-saturation-brightness triple (three floating point numbers between 0 and 1, separated by commas); one of the colors names listed in Appendix G (borrowed from some version of the X window system); or a red-green-blue (RGB) triple[4] (three hexadecimal number between 00 and FF, preceded by the character '#'). Thus, the values `"orchid"`, `"0.8396,0.4862,0.8549"` and `#DA70D6` are three ways to specify the same color. The numerical forms are convenient for scripts or tools that automatically generate colors. Color name lookup is case-insensitive and ignores non-alphanumeric characters, so `warmgrey` and `Warm_Grey` are equivalent.

We can offer a few hints regarding use of color in graph drawings. First, avoid using too many bright colors. A "rainbow effect" is confusing. It is better to choose a narrower range of colors, or to vary saturation along with hue. Second, when nodes are filled with dark or very saturated colors, labels seem to be more readable with `fontcolor=white` and `fontname=Helvetica`. (We also have PostScript functions for *dot* that create outline fonts from plain fonts.) Third, in certain output formats, you can define your own color space. For example, if using PostScript for output, you can redefine `nodecolor`, `edgecolor`, or `graphcolor` in a library file. Thus, to use RGB colors, place the following line in a file `lib.ps`.

```
/nodecolor {setrgbcolor} bind def
```

Use the `-l` command line option to load this file.

```
dot -Tps -l lib.ps file.dot -o file.ps
```

The `style` attribute controls miscellaneous graphics features of nodes and edges. This attribute is a comma-separated list of primitives with optional argument lists. The predefined primitives include `solid`, `dashed`, `dotted`, `bold` and `invis`. The first four control line drawing in node boundaries and edges and have the obvious meaning. The value `invis` causes the node or edge to be left undrawn. The style for nodes can also include `filled`, `diagonals` and

[4] A fourth form, RGBA, is also supported, which has the same format as RGB with an additional fourth hexadecimal number specifying alpha channel or transparency information.

Name	Default	Values
`bottomlabel`		auxiliary label for nodes of `shape` M*
`color`	`black`	node shape color
`comment`		any string (format-dependent)
`distortion`	`0.0`	node distortion for `shape=polygon`
`fillcolor`	`lightgrey/black`	node fill color
`fixedsize`	false	label text has no affect on node size
`fontcolor`	`black`	type face color
`fontname`	`Times-Roman`	font family
`fontsize`	`14`	point size of label
`group`		name of node's group
`height`	`.5`	height in inches
`label`	node name	any string
`layer`	overlay range	`all`, *id* or *id:id*
`orientation`	`0.0`	node rotation angle
`peripheries`	`shape-dependent`	number of node boundaries
`regular`	false	force polygon to be regular
`shape`	`ellipse`	node shape; see Section 2.1 and Appendix E
`shapefile`		external EPSF or SVG custom shape file
`sides`	`4`	number of sides for `shape=polygon`
`skew`	`0.0`	skewing of node for `shape=polygon`
`style`		graphics options, e.g. `bold, dotted, filled`; cf. Section 2.3
`toplabel`		auxiliary label for nodes of `shape` M*
`URL`		URL associated with node (format-dependent)
`width`	`.75`	width in inches
`z`	`0.0`	z coordinate for VRML output

Table 1: Node attributes

Name	Default	Values
`arrowhead`	normal	style of arrowhead at head end
`arrowsize`	`1.0`	scaling factor for arrowheads
`arrowtail`	normal	style of arrowhead at tail end
`color`	`black`	edge stroke color
`comment`		any string (format-dependent)
`constraint`	true	use edge to affect node ranking
`decorate`		if set, draws a line connecting labels with their edges
`dir`	`forward`	`forward`, `back`, `both`, or `none`
`fontcolor`	`black`	type face color
`fontname`	`Times-Roman`	font family
`fontsize`	`14`	point size of label
`headlabel`		label placed near head of edge
`headport`		`n,ne,e,se,s,sw,w,nw`
`headURL`		URL attached to head label if output format is `ismap`
`label`		edge label
`labelangle`	`-25.0`	angle in degrees which head or tail label is rotated off edge
`labeldistance`	`1.0`	scaling factor for distance of head or tail label from node
`labelfloat`	false	lessen constraints on edge label placement
`labelfontcolor`	`black`	type face color for head and tail labels
`labelfontname`	`Times-Roman`	font family for head and tail labels
`labelfontsize`	`14`	point size for head and tail labels
`layer`	overlay range	`all`, *id* or *id:id*
`lhead`		name of cluster to use as head of edge
`ltail`		name of cluster to use as tail of edge
`minlen`	`1`	minimum rank distance between head and tail
`samehead`		tag for head node; edge heads with the same tag are merged onto the same port
`sametail`		tag for tail node; edge tails with the same tag are merged onto the same port
`style`		graphics options, e.g. `bold, dotted, filled`; cf. Section 2.3
`taillabel`		label placed near tail of edge
`tailport`		`n,ne,e,se,s,sw,w,nw`
`tailURL`		URL attached to tail label if output format is `ismap`
`weight`	`1`	integer cost of stretching an edge

Table 2: Edge attributes

Name	Default	Values
`bgcolor`		background color for drawing, plus initial fill color
`center`	false	center drawing on `page`
`clusterrank`	`local`	may be `global` or `none`
`color`	`black`	for clusters, outline color, and fill color if `fillcolor` not defined
`comment`		any string (format-dependent)
`compound`	false	allow edges between clusters
`concentrate`	false	enables edge concentrators
`fillcolor`	`black`	cluster fill color
`fontcolor`	`black`	type face color
`fontname`	`Times-Roman`	font family
`fontpath`		list of directories to such for fonts
`fontsize`	`14`	point size of label
`label`		any string
`labeljust`	left-justified	”r” for right-justified cluster labels
`labelloc`	top	”r” for right-justified cluster labels
`layers`		*id:id:id...*
`margin`	`.5`	margin included in `page`, inches
`mclimit`	`1.0`	scale factor for mincross iterations
`nodesep`	`.25`	separation between nodes, in inches.
`nslimit`		if set to *f*, bounds network simplex iterations by *(f)(number of nodes)* when setting x-coordinates
`nslimit1`		if set to *f*, bounds network simplex iterations by *(f)(number of nodes)* when ranking nodes
`ordering`		if `out` out edge order is preserved
`orientation`	`portrait`	if `rotate` is not used and the value is `landscape`, use landscape orientation
`page`		unit of pagination, *e.g.* `"8.5,11"`
`pagedir`	`BL`	traversal order of pages
`quantum`		if `quantum` ¿ 0.0, node label dimensions will be rounded to integral multiples of `quantum`
`rank`		`same`, `min`, `max`, `source` or `sink`
`rankdir`	`TB`	`LR` (left to right) or `TB` (top to bottom)
`ranksep`	`.75`	separation between ranks, in inches.
`ratio`		approximate aspect ratio desired, `fill` or `auto`
`remincross`		if true and there are multiple clusters, re-run crossing minimization
`rotate`		If 90, set orientation to landscape
`samplepoints`	`8`	number of points used to represent ellipses and circles on output (cf. Appendix C
`searchsize`	`30`	maximum edges with negative cut values to check when looking for a minimum one during network simplex
`size`		maximum drawing size, in inches
`style`		graphics options, e.g. `filled` for clusters
`URL`		URL associated with graph (format-dependent)

Table 3: Graph attributes

rounded. filled shades inside the node using the color fillcolor. If this is not set, the value of color is used. If this also is unset, light grey[5] is used as the default. The diagonals style causes short diagonal lines to be drawn between pairs of sides near a vertex. The rounded style rounds polygonal corners.

User-defined style primitives can be implemented as custom PostScript procedures. Such primitives are executed inside the gsave context of a graph, node, or edge, before any of its marks are drawn. The argument lists are translated to PostScript notation. For example, a node with style="setlinewidth(8)" is drawn with a thick outline. Here, setlinewidth is a PostScript built-in, but user-defined PostScript procedures are called the same way. The definition of these procedures can be given in a library file loaded using -l as shown above.

Edges have a dir attribute to set arrowheads. dir may be forward (the default), back, both, or none. This refers only to where arrowheads are drawn, and does not change the underlying graph. For example, setting dir=back causes an arrowhead to be drawn at the tail and no arrowhead at the head, but it does not exchange the endpoints of the edge. The attributes arrowhead and arrowtail specify the style of arrowhead, if any, which is used at the head and tail ends of the edge. Allowed values are normal, inv, dot, invdot, odot, invodot and none (cf. Appendix F). The attribute arrowsize specifies a multiplicative factor affecting the size of any arrowhead drawn on the edge. For example, arrowsize=2.0 makes the arrow twice as long and twice as wide.

In terms of style and color, clusters act somewhat like large box-shaped nodes, in that the cluster boundary is drawn using the cluster's color attribute and, in general, the appearance of the cluster is affected the style, color and fillcolor attributes.

If the root graph has a bgcolor attribute specified, this color is used as the background for the entire drawing, and also serves as the default fill color.

2.4 Drawing Orientation, Size and Spacing

Two attributes that play an important role in determining the size of a *dot* drawing are nodesep and ranksep. The first specifies the minimum distance, in inches, between two adjacent nodes on the same rank. The second deals with rank separation, which is the minimum vertical space between the bottoms of nodes in one rank and the tops of nodes in the next. The ranksep attribute sets the rank separation, in inches. Alternatively, one can have ranksep=equally. This guarantees that all of the ranks are equally spaced, as measured from the centers of nodes on adjacent ranks. In this case, the rank separation between two ranks is at least the

[5] The default is black if the output format is MIF, or if the shape is point.

default rank separation. As the two uses of `ranksep` are independent, both can be set at the same time. For example, `ranksep="1.0 equally"` causes ranks to be equally spaced, with a minimum rank separation of 1 inch.

Often a drawing made with the default node sizes and separations is too big for the target printer or for the space allowed for a figure in a document. There are several ways to try to deal with this problem. First, we will review how *dot* computes the final layout size.

A layout is initially made internally at its "natural" size, using default settings (unless `ratio=compress` was set, as described below). There is no bound on the size or aspect ratio of the drawing, so if the graph is large, the layout is also large. If you don't specify `size` or `ratio`, then the natural size layout is printed.

The easiest way to control the output size of the drawing is to set `size="`x`,`y`"` in the graph file (or on the command line using `-G`). This determines the size of the final layout. For example, `size="7.5,10"` fits on an 8.5x11 page (assuming the default page orientation) no matter how big the initial layout.

`ratio` also affects layout size. There are a number of cases, depending on the settings of `size` and `ratio`.

Case 1. `ratio` was not set. If the drawing already fits within the given `size`, then nothing happens. Otherwise, the drawing is reduced uniformly enough to make the critical dimension fit.

If `ratio` was set, there are four subcases.

Case 2a. If `ratio=`x where x is a floating point number, then the drawing is scaled up in one dimension to achieve the requested ratio expressed as drawing $height/width$. For example, `ratio=2.0` makes the drawing twice as high as it is wide. Then the layout is scaled using `size` as in Case 1.

Case 2b. If `ratio=fill` and `size=`x, y was set, then the drawing is scaled up in one dimension to achieve the ratio y/x. Then scaling is performed as in Case 1. The effect is that all of the bounding box given by `size` is filled.

Case 2c. If `ratio=compress` and `size=`x, y was set, then the initial layout is compressed to attempt to fit it in the given bounding box. This trades off layout quality, balance and symmetry in order to pack the layout more tightly. Then scaling is performed as in Case 1.

Case 2d. If `ratio=auto` and the `page` attribute is set and the graph cannot be drawn on a single page, then `size` is ignored and *dot* computes an "ideal" size. In particular, the size in a given dimension will be the smallest integral multiple of the page size in that dimension which is at least half the current size. The two dimensions are then scaled independently to the new size.

If `rotate=90` is set, or `orientation=landscape`, then the drawing is rotated 90° into landscape mode. The X axis of the layout would be along the Y axis of each page. This does not affect *dot*'s interpretation of `size`, `ratio` or `page`.

At this point, if `page` is not set, then the final layout is produced as one page.

If `page=`x, y is set, then the layout is printed as a sequence of pages which can tiled or assembled into a mosaic. Common settings are `page="8.5,11"` or `page="11,17"`. These values refer to the full size of the physical device; the actual area used will be reduced by the margin settings. (For printer output, the default is 0.5 inches; for bitmap-output, the X and Y margins are 10 and 2 points, respectively.) For tiled layouts, it may be helpful to set smaller margins. This can be done by using the `margin` attribute. This can take a single number, used to set both margins, or two numbers separated by a comma to set the x and y margins separately. As usual, units are in inches. Although one can set `margin=0`, unfortunately, many bitmap printers have an internal hardware margin that cannot be overridden.

The order in which pages are printed can be controlled by the `pagedir` attribute. Output is always done using a row-based or column-based ordering, and `pagedir` is set to a two-letter code specifying the major and minor directions. For example, the default is `BL`, specifying a bottom-to-top (`B`) major order and a left-to-right (`L`) minor order. Thus, the bottom row of pages is emitted first, from left to right, then the second row up, from left to right, and finishing with the top row, from left to right. The top-to-bottom order is represented by `T` and the right-to-left order by `R`.

If `center=true` and the graph can be output on one page, using the default page size of 8.5 by 11 inches if `page` is not set, the graph is repositioned to be centered on that page.

A common problem is that a large graph drawn at a small size yields unreadable node labels. To make larger labels, something has to give. There is a limit to the amount of readable text that can fit on one page. Often you can draw a smaller graph by extracting an interesting piece of the original graph before running *dot*. We have some tools that help with this.

sccmap decompose the graph into strongly connected components

tred compute transitive reduction (remove edges implied by transitivity)

gpr graph processor to select nodes or edges, and contract or remove the rest of the graph

unflatten improve aspect ratio of trees by staggering the lengths of leaf edges

With this in mind, here are some thing to try on a given graph:

1. Increase the node `fontsize`.

2. Use smaller `ranksep` and `nodesep`.

3. Use `ratio=auto`.

4. Use `ratio=compress` and give a reasonable `size`.

5. A sans serif font (such as Helvetica) may be more readable than Times when reduced.

2.5 Node and Edge Placement

Attributes in *dot* provide many ways to adjust the large-scale layout of nodes and edges, as well as fine-tune the drawing to meet the user's needs and tastes. This section discusses these attributes[6].

Sometimes it is natural to make edges point from left to right instead of from top to bottom. If `rankdir=LR` in the top-level graph, the drawing is rotated in this way. `TB` (top to bottom) is the default. (`BT` seems potentially useful for drawing upward-directed graphs, but hasn't been implemented. In some graphs, you could achieve the same effect by reversing the endpoints of edges and setting their `dir=back`.) We note that the setting of `rankdir` is complementary to how the final drawing may be rotated by `orientation` or `rotate`.

In graphs with time-lines, or in drawings that emphasize source and sink nodes, you may need to constrain rank assignments. The `rank` of a subgraph may be set to `samerank`, `minrank`, `source`, `maxrank` or `sink`. A value `samerank` causes all the nodes in the subgraph to occur on the same rank. If set to `minrank`, all the nodes in the subgraph are guaranteed to be on a rank at least as small as any other node in the layout[7]. This can be made strict by setting `rank=source`, which forces the nodes in the subgraph to be on some rank strictly smaller than the rank of any other nodes (except those also specified by `minrank` or `source` subgraphs). The values `maxrank` or `sink` play an analogous role for the maximum rank. Note that these constraints induce equivalence classes of nodes. If one subgraph forces nodes `A` and `B` to be on the same rank, and another subgraph forces nodes `C` and `B` to share a rank, then all nodes in both subgraphs must be drawn on the same rank. Figures 9 and 10 illustrate using subgraphs for controlling rank assignment.

In some graphs, the left-to-right ordering of nodes is important. If a subgraph has `ordering=out`, then out-edges within the subgraph that have the same tail

[6]For completeness, we note that *dot* also provides access to various parameters which play technical roles in the layout algorithms. These include `mclimit`, `nslimit`, `nslimit1`, `remincross` and `searchsize`.

[7]Recall that the minimum rank occurs at the top of a drawing.

```
digraph asde91 {
    ranksep=.75; size = "7.5,7.5";

    {
        node [shape=plaintext, fontsize=16];
        /* the time-line graph */
        past -> 1978 -> 1980 -> 1982 -> 1983 -> 1985 -> 1986 ->
                1987 -> 1988 -> 1989 -> 1990 -> "future";
        /* ancestor programs */
        "Bourne sh"; "make"; "SCCS"; "yacc"; "cron"; "Reiser cpp";
        "Cshell"; "emacs"; "build"; "vi"; "<curses>"; "RCS"; "C*";
    }

    { rank = same;
        "Software IS"; "Configuration Mgt"; "Architecture & Libraries";
        "Process";
    };

    node [shape=box];
    { rank = same; "past"; "SCCS"; "make"; "Bourne sh"; "yacc"; "cron"; }
    { rank = same; 1978; "Reiser cpp"; "Cshell"; }
    { rank = same; 1980; "build"; "emacs"; "vi"; }
    { rank = same; 1982; "RCS"; "<curses>"; "IMX"; "SYNED"; }
    { rank = same; 1983; "ksh"; "IFS"; "TTU"; }
    { rank = same; 1985; "nmake"; "Peggy"; }
    { rank = same; 1986; "C*"; "ncpp"; "ksh-i"; "<curses-i>"; "PG2"; }
    { rank = same; 1987; "Ansi cpp"; "nmake 2.0"; "3D File System"; "fdelta";
        "DAG"; "CSAS";}
    { rank = same; 1988; "CIA"; "SBCS"; "ksh-88"; "PEGASUS/PML"; "PAX";
        "backtalk"; }
    { rank = same; 1989; "CIA++"; "APP"; "SHIP"; "DataShare"; "ryacc";
        "Mosaic"; }
    { rank = same; 1990; "libft"; "CoShell"; "DIA"; "IFS-i"; "kyacc"; "sfio";
        "yeast"; "ML-X"; "DOT";  }
    { rank = same; "future"; "Adv. Software Technology"; }

    "PEGASUS/PML" -> "ML-X";
    "SCCS" -> "nmake";
    "SCCS" -> "3D File System";
    "SCCS" -> "RCS";
    "make" -> "nmake";
    "make" -> "build";
    .
    .
    .
}
```

Figure 9: Graph with constrained ranks

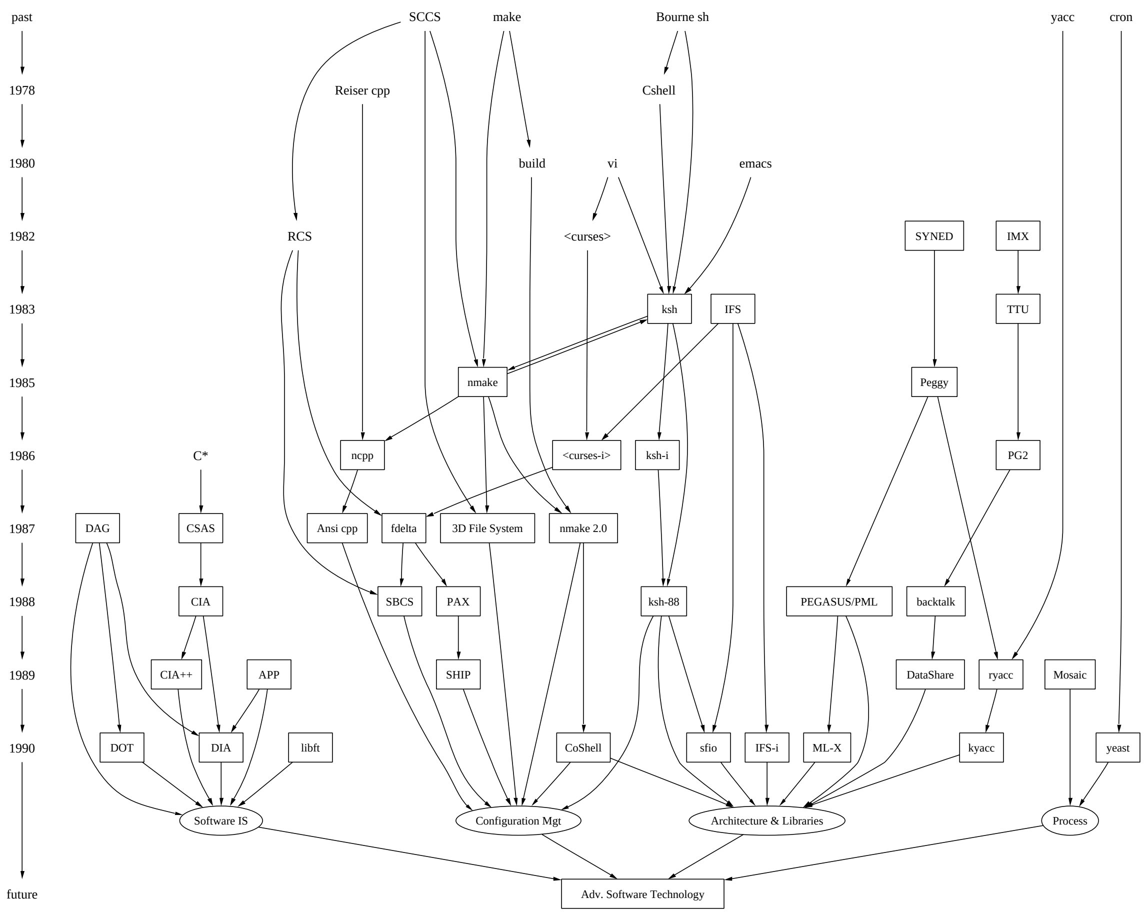


Figure 10: Drawing with constrained ranks

node wll fan-out from left to right in their order of creation. (Also note that flat edges involving the head nodes can potentially interfere with their ordering.)

There are many ways to fine-tune the layout of nodes and edges. For example, if the nodes of an edge both have the same `group` attribute, *dot* tries to keep the edge straight and avoid having other edges cross it. The `weight` of an edge provides another way to keep edges straight. An edge's `weight` suggests some measure of an edge's importance; thus, the heavier the weight, the closer together its nodes should be. *dot* causes edges with heavier weights to be drawn shorter and straighter.

Edge weights also play a role when nodes are constrained to the same rank. Edges with non-zero weight between these nodes are aimed across the rank in the same direction (left-to-right, or top-to-bottom in a rotated drawing) as far as possible. This fact may be exploited to adjust node ordering by placing invisible edges (`style="invis"`) where needed.

The end points of edges adjacent to the same node can be constrained using the `samehead` and `sametail` attributes. Specifically, all edges with the same head and the same value of `samehead` are constrained to intersect the head node at the same point. The analogous property holds for tail nodes and `sametail`.

During rank assignment, the head node of an edge is constrained to be on a higher rank than the tail node. If the edge has `constraint=false`, however, this requirement is not enforced.

In certain circumstances, the user may desire that the end points of an edge never get too close. This can be obtained by setting the edge's `minlen` attribute. This defines the minimum difference between the ranks of the head and tail. For example, if `minlen=2`, there will always be at least one intervening rank between the head and tail. Note that this is not concerned with the geometric distance between the two nodes.

Fine-tuning should be approached cautiously. *dot* works best when it can makes a layout without much "help" or interference in its placement of individual nodes and edges. Layouts can be adjusted somewhat by increasing the `weight` of certain edges, or by creating invisible edges or nodes using `style=invis`, and sometimes even by rearranging the order of nodes and edges in the file. But this can backfire because the layouts are not necessarily stable with respect to changes in the input graph. One last adjustment can invalidate all previous changes and make a very bad drawing. A future project we have in mind is to combine the mathematical layout techniques of *dot* with an interactive front-end that allows user-defined hints and constraints.

3 Advanced Features

3.1 Node Ports

A node port is a point where edges can attach to a node. (When an edge is not attached to a port, it is aimed at the node's center and the edge is clipped at the node's boundary.)

Simple ports can be specified by using the `headport` and `tailport` attributes. These can be assigned one of the 8 compass points `"n"`, `"ne"`, `"e"`, `"se"`, `"s"`, `"sw"`, `"w"` or `"nw"`. The end of the node will then be aimed at that position on the node. Thus, if `tailport=se`, the edge will connect to the tail node at its southeast "corner".

Nodes with a `record` shape use the record structure to define ports. As noted above, this shape represents a record as recursive lists of boxes. If a box defines a port name, by using the construct `<` *port_name* `>` in the box label, the center of the box can be used a port. (By default, the edge is clipped to the box's boundary.) This is done by modifying the node name with the port name, using the syntax *node_name*`:`*port_name*, as part of an edge declaration. Figure 11 illustrates the declaration and use of port names in record nodes, with the resulting drawing shown in Figure 12.

DISCLAIMER: At present, simple ports don't work as advertised, even when they should. There is also the case where we might not want them to work, e.g., when the tailport=n and the headport=s. Finally, in theory, dot should be able to allow both types of ports on an edge, since the notions are orthogonal. There is still the question as to whether the two syntaxes could be combined, i.e., treat the compass points as reserved port names, and allow nodename:portname:compassname.

Figures 13 and 14 give another example of the use of record nodes and ports. This repeats the example of Figures 7 and 8 but now using ports as connectors for edges. Note that records sometimes look better if their input height is set to a small value, so the text labels dominate the actual size, as illustrated in Figure 11. Otherwise the default node size ($.75$ by $.5$) is assumed, as in Figure 14. The example of Figures 15 and 16 uses left-to-right drawing in a layout of a hash table.

3.2 Clusters

A cluster is a subgraph placed in its own distinct rectangle of the layout. A subgraph is recognized as a cluster when its name has the prefix `cluster`. (If the top-level graph has `clusterrank=none`, this special processing is turned off).

```
digraph g {
node [shape = record,height=.1];
node0[label = "<f0> |<f1> G|<f2> "];
node1[label = "<f0> |<f1> E|<f2> "];
node2[label = "<f0> |<f1> B|<f2> "];
node3[label = "<f0> |<f1> F|<f2> "];
node4[label = "<f0> |<f1> R|<f2> "];
node5[label = "<f0> |<f1> H|<f2> "];
node6[label = "<f0> |<f1> Y|<f2> "];
node7[label = "<f0> |<f1> A|<f2> "];
node8[label = "<f0> |<f1> C|<f2> "];
"node0":f2 -> "node4":f1;
"node0":f0 -> "node1":f1;
"node1":f0 -> "node2":f1;
"node1":f2 -> "node3":f1;
"node2":f2 -> "node8":f1;
"node2":f0 -> "node7":f1;
"node4":f2 -> "node6":f1;
"node4":f0 -> "node5":f1;
}
```

Figure 11: Binary search tree using records

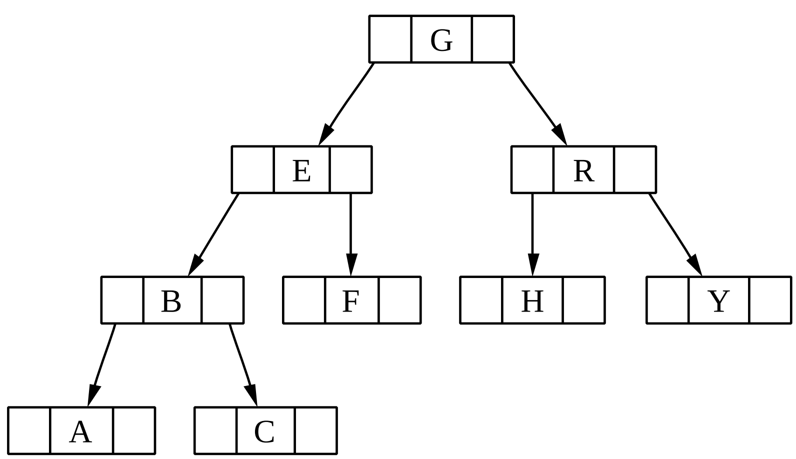


Figure 12: Drawing of binary search tree

```
digraph structs {
node [shape=record];
    struct1 [shape=record,label="<f0> left|<f1> middle|<f2> right"];
    struct2 [shape=record,label="<f0> one|<f1> two"];
    struct3 [shape=record,label="hello\nworld |{ b |{c|<here> d|e}| f}| g | h"];
    struct1:f1 -> struct2:f0;
    struct1:f2 -> struct3:here;
}
```

Figure 13: Records with nested fields (revisited)

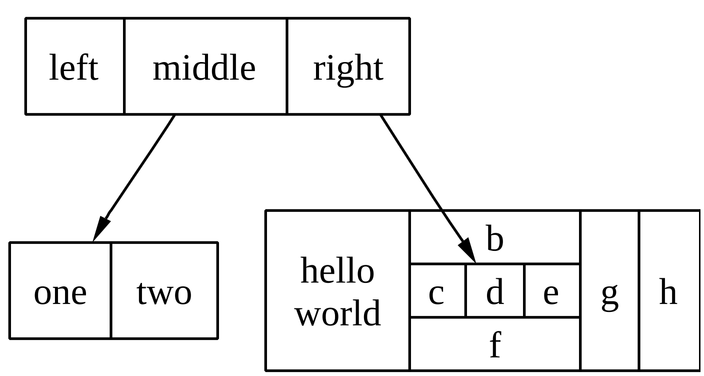


Figure 14: Drawing of records (revisited)

```
digraph G {
  nodesep=.05;
  rankdir=LR;
  node [shape=record,width=.1,height=.1];

  node0 [label = "<f0> |<f1> |<f2> |<f3> |<f4> |<f5> |<f6> | ",height=2.5];
  node [width = 1.5];
  node1 [label = "{<n> n14 | 719 |<p> }"];
  node2 [label = "{<n> a1  | 805 |<p> }"];
  node3 [label = "{<n> i9  | 718 |<p> }"];
  node4 [label = "{<n> e5  | 989 |<p> }"];
  node5 [label = "{<n> t20 | 959 |<p> }"] ;
  node6 [label = "{<n> o15 | 794 |<p> }"] ;
  node7 [label = "{<n> s19 | 659 |<p> }"] ;

  node0:f0 -> node1:n;
  node0:f1 -> node2:n;
  node0:f2 -> node3:n;
  node0:f5 -> node4:n;
  node0:f6 -> node5:n;
  node2:p -> node6:n;
  node4:p -> node7:n;
}
```

Figure 15: Hash table graph file

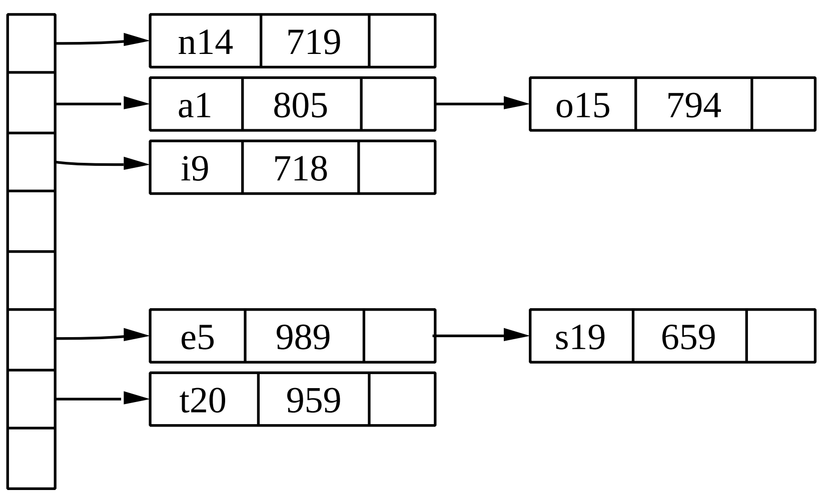


Figure 16: Drawing of hash table

Labels, font characteristics and the `labelloc` attribute can be set as they would be for the top-level graph, though cluster labels appear above the graph by default. For clusters, the label is left-justified by default; if `labeljust="r"`, the label is right-justified. The `color` attribute specifies the color of the enclosing rectangle. In addition, clusters may have `style="filled"`, in which case the rectangle is filled with the color specified by `fillcolor` before the cluster is drawn. (If `fillcolor` is not specified, the cluster's `color` attribute is used.)

Clusters are drawn by a recursive technique that computes a rank assignment and internal ordering of nodes within clusters. Figure 17 through 19 are cluster layouts and the corresponding graph files.

```
digraph G {
    subgraph cluster0 {
        node [style=filled,color=white];
        style=filled;
        color=lightgrey;
        a0 -> a1 -> a2 -> a3;
        label = "process #1";
    }

    subgraph cluster1 {
        node [style=filled];
        b0 -> b1 -> b2 -> b3;
        label = "process #2";
        color=blue
    }
    start -> a0;
    start -> b0;
    a1 -> b3;
    b2 -> a3;
    a3 -> a0;
    a3 -> end;
    b3 -> end;

    start [shape=Mdiamond];
    end [shape=Msquare];
}
```

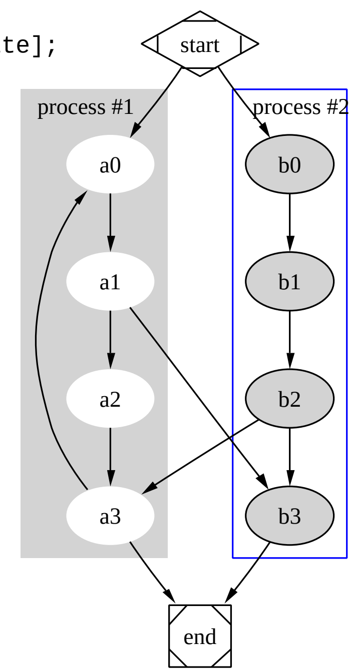


Figure 17: Process diagram with clusters

If the top-level graph has the `compound` attribute set to true, *dot* will allow edges connecting nodes and clusters. This is accomplished by an edge defining an `lhead` or `ltail` attribute. The value of these attributes must be the name of a cluster containing the head or tail node, respectively. In this case, the edge is clipped at the cluster boundary. All other edge attributes, such as `arrowhead` or `dir`, are applied to the truncated edge. For example, Figure 20 shows a graph using the `compound` attribute and the resulting diagram.

3.3 Concentrators

Setting `concentrate=true` on the top-level graph enables an edge merging technique to reduce clutter in dense layouts. Edges are merged when they run parallel, have a common endpoint and have length greater than 1. A beneficial side-effect in fixed-sized layouts is that removal of these edges often permits larger, more readable labels. While concentrators in *dot* look somewhat like Newbery's [New89], they are found by searching the edges in the layout, not by detecting complete bipartite graphs in the underlying graph. Thus the *dot* approach runs much faster but doesn't collapse as many edges as Newbery's algorithm.

4 Command Line Options

By default, *dot* operates in filter mode, reading a graph from `stdin`, and writing the graph on `stdout` in the *DOT* format with layout attributes appended. *dot* supports a variety of command-line options:

`-T`*format* sets the format of the output. Allowed values for *format* are:

`canon` Prettyprint input; no layout is done.

`dot` Attributed *DOT*. Prints input with layout information attached as attributes, cf. Appendix C.

`fig` FIG output.

`gd` GD format. This is the internal format used by the GD Graphics Library. An alternate format is `gd2`.

`gif` GIF output.

`hpgl` HP-GL/2 vector graphic printer language for HP wide bed plotters.

`imap` Produces HTML map files for client and server-side image maps. This can be combined with a graphical form of the output, e.g., using `-Tgif` or

```
digraph G {
  size="8,6"; ratio=fill; node[fontsize=24];

  ciafan->computefan; fan->increment; computefan->fan; stringdup->fatal;
  main->exit; main->interp_err; main->ciafan; main->fatal; main->malloc;
  main->strcpy; main->getopt; main->init_index; main->strlen; fan->fatal;
  fan->ref; fan->interp_err; ciafan->def; fan->free; computefan->stdprintf;
  computefan->get_sym_fields; fan->exit; fan->malloc; increment->strcmp;
  computefan->malloc; fan->stdsprintf; fan->strlen; computefan->strcmp;
  computefan->realloc; computefan->strlen; debug->sfprintf; debug->strcat;
  stringdup->malloc; fatal->sfprintf; stringdup->strcpy; stringdup->strlen;
  fatal->exit;

  subgraph "cluster_error.h" { label="error.h"; interp_err; }

  subgraph "cluster_sfio.h" { label="sfio.h"; sfprintf; }

  subgraph "cluster_ciafan.c" { label="ciafan.c"; ciafan; computefan;
      increment; }

  subgraph "cluster_util.c" { label="util.c"; stringdup; fatal; debug; }

  subgraph "cluster_query.h" { label="query.h"; ref; def; }

  subgraph "cluster_field.h" { get_sym_fields; }

  subgraph "cluster_stdio.h" { label="stdio.h"; stdprintf; stdsprintf; }

  subgraph "cluster_<libc.a>" { getopt; }

  subgraph "cluster_stdlib.h" { label="stdlib.h"; exit; malloc; free; realloc; }

  subgraph "cluster_main.c" { main; }

  subgraph "cluster_index.h" { init_index; }

  subgraph "cluster_string.h" { label="string.h"; strcpy; strlen; strcmp; strcat; }
}
```

Figure 18: Call graph file

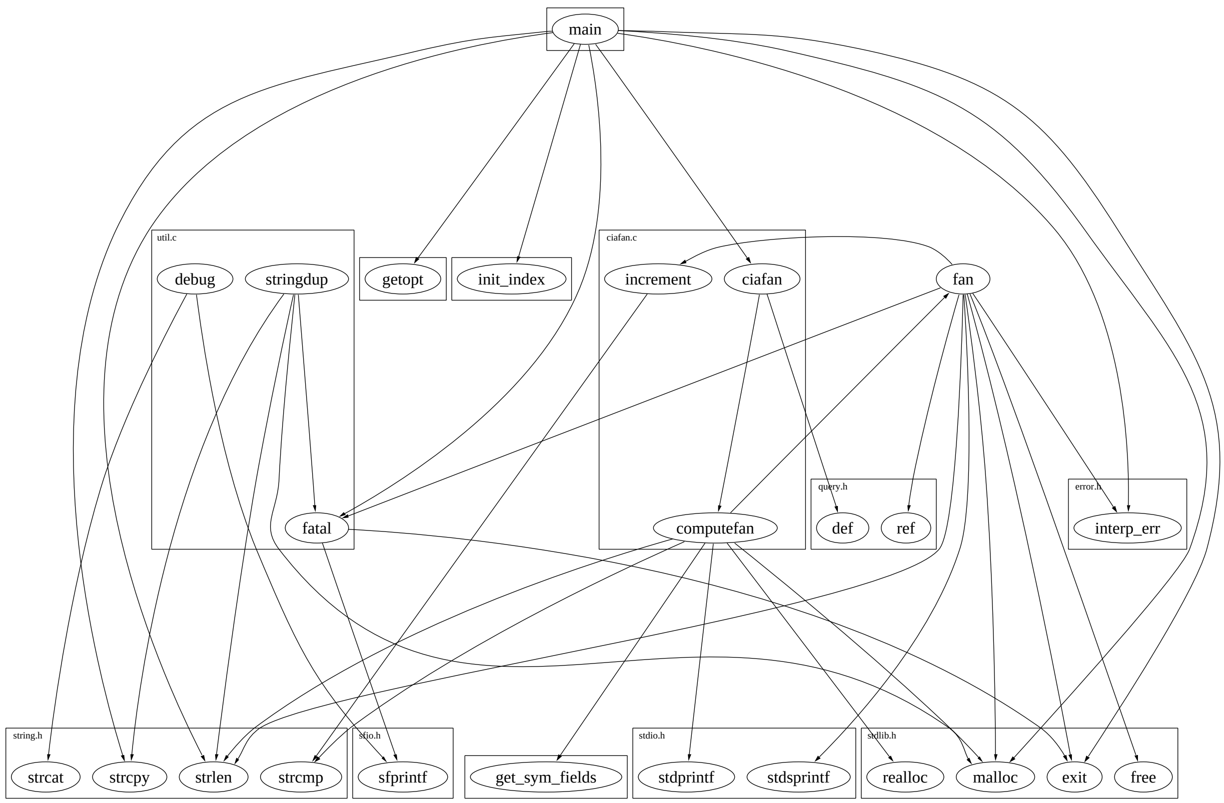


Figure 19: Call graph with labeled clusters

```
digraph G {
    compound=true;
    subgraph cluster0 {
      a -> b;
      a -> c;
      b -> d;
      c -> d;
    }
    subgraph cluster1 {
      e -> g;
      e -> f;
    }
    b -> f [lhead=cluster1];
    d -> e;
    c -> g [ltail=cluster0,
             lhead=cluster1];
    c -> e [ltail=cluster0];
    d -> h;
}
```

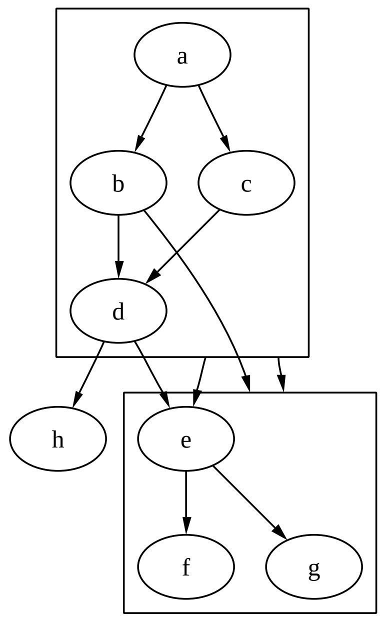


Figure 20: Graph with edges on clusters

`-Tjpg`, in web pages to attach links to nodes and edges. The format `ismap` is a predecessor of the `imap` format.

`jpg` JPEG output. `jpeg` is a synonym for `jpg`.

`mif` FrameMaker MIF format. In this format, graphs can be loaded into FrameMaker and edited manually. MIF is limited to 8 basic colors.

`mp` MetaPost output.

`pcl` PCL-5 output for HP laser writers.

`pic` PIC output.

`plain` Simple, line-based ASCII format. Appendix B describes this output. An alternate format is `plain-ext`, which provides port names on the head and tail nodes of edges.

`png` PNG (Portable Network Graphics) output.

`ps` PostScript (EPSF) output.

`ps2` PostScript (EPSF) output with PDF annotations. It is assumed that this output will be distilled into PDF.

`svg` SVG output. The alternate form `svgz` produces compressed SVG.

`vrml` VRML output.

`vtx` VTX format for r Confluents's Visual Thought.

`wbmp` Wireless BitMap (WBMP) format.

`-G`*name*`=`*value* sets a graph attribute default value. Often it is convenient to set size, pagination, and related values on the command line rather than in the graph file. The analogous flags `-N` or `-E` set default node or edge attributes. Note that file contents override command line arguments.

`-l`*libfile* specifies a device-dependent graphics library file. Multiple libraries may be given. These names are passed to the code generator at the beginning of output.

`-o`*outfile* writes output into file *outfile*.

`-v` requests verbose output. In processing large layouts, the verbose messages may give some estimate of *dot*'s progress.

`-V` prints the version number and exits.

5 Miscellaneous

In the top-level graph heading, a graph may be declared a `strict digraph`. This forbids the creation of self-arcs and multi-edges; they are ignored in the input file.

Nodes, edges and graphs may have a `URL` attribute. In certain output formats (`ps2`, `imap`, `ismap` or `svg`), this information is integrated in the output so that nodes, edges and clusters become active links when displayed with the appropriate tools. Typically, URLs attached to top-level graphs serve as base URLs, supporting relative URLs on components. When the output format is `imap`, a similar processing takes place with the `headURL` and `tailURL` attributes.

For certain formats (`ps`, `fig`, `mif`, `mp`, `vtx` or `svg`), `comment` attributes can be used to embed human-readable notations in the output.

6 Conclusions

dot produces pleasing hierarchical drawings and can be applied in many settings.

Since the basic algorithms of *dot* work well, we have a good basis for further research into problems such as methods for drawing large graphs and on-line (animated) graph drawing.

7 Acknowledgments

We thank Emden Gansner and Phong Vo for their advice about graph drawing algorithms and programming. The graph library uses Phong's splay tree dictionary library. Also, the users of *dag*, the predecessor of *dot*, gave us many good suggestions. Emden Gansner, Guy Jacobson, and Randy Hackbarth reviewed earlier drafts of this manual, and Emden contributed substantially to the current revision. John Ellson wrote the generalized polygon shape and spent considerable effort to make it robust and efficient. He also wrote the GIF and ISMAP generators and other tools to bring *graphviz* to the web.

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A Graph File Grammar

The following is an abstract grammar for the *DOT* language. Terminals are shown in bold font and nonterminals in italics. Literal characters are given in single quotes. Parentheses (and) indicate grouping when needed. Square brackets [and] enclose optional items. Vertical bars | separate alternatives.

graph	→	[**strict**] (**digraph** | **graph**)*id* '' *stmt-list* ''
stmt-list	→	[*stmt* [';'] [*stmt-list*]]
stmt	→	*attr-stmt* | *node-stmt* | *edge-stmt* | *subgraph* | *id* '=' *id*
attr-stmt	→	(**graph** | **node** | **edge** *attr-list*
attr-list	→	'[' [*a-list*]']' [*attr-list*]
a-list	→	*id* '=' *id*[','][*attr-list*]
node-stmt	→	*node-id* [*attrs-list*]
node-id	→	*id* [*port*]
port	→	*port-location* [*port-angle*]| *port-angle* [*port-location*]
port-location	→	':' *id* | ':' '(' *id* ',' *id* ')'
port-angle	→	'@' *id*
edge-stmt	→	(*node-id* | *subgraph*) *edgeRHS* [*attr-list*]
edgeRHS	→	*edgeop* (*node-id* | *subgraph*) [*edgeRHS*]
subgraph	→	[**subgraph** *id*]'' *stmt-list* '' | **subgraph** *id*

An *id* is any alphanumeric string not beginning with a digit, but possibly including underscores; or a number; or any quoted string possibly containing escaped quotes.

An *edgeop* is `->` in directed graphs and `--` in undirected graphs.

The language supports C++-style comments: `/* */` and `//`.

Semicolons aid readability but are not required except in the rare case that a named subgraph with no body immediate precedes an anonymous subgraph, because under precedence rules this sequence is parsed as a subgraph with a heading and a body.

Complex attribute values may contain characters, such as commas and white space, which are used in parsing the *DOT* language. To avoid getting a parsing error, such values need to be enclosed in double quotes.

B Plain Output File Format (`-Tplain`)

The "plain" output format of *dot* lists node and edge information in a simple, line-oriented style which is easy to parse by front-end components. All coordinates and lengths are unscaled and in inches.
The first line is:

`graph` *scalefactor width height*

The *width* and *height* values give the width and the height of the drawing; the lower-left corner of the drawing is at the origin. The *scalefactor* indicates how much to scale all coordinates in the final drawing.
The next group of lines lists the nodes in the format:

`node` *name x y xsize ysize label style shape color fillcolor*

The *name* is a unique identifier. If it contains whitespace or punctuation, it is quoted. The *x* and *y* values give the coordinates of the center of the node; the *width* and *height* give the width and the height. The remaining parameters provide the node's `label`, `style`, `shape`, `color` and `fillcolor` attributes, respectively. If the node does not have a `style` attribute, `"solid"` is used.
The next group of lines lists edges:

`edge` *tail head* n x_1 y_1 x_2 y_2 $\ldots$ x_n y_n [*label lx ly*] *style color*

n is the number of coordinate pairs that follow as B-spline control points. If the edge is labeled, then the label text and coordinates are listed next. The edge description is completed by the edge's `style` and `color`. As with nodes, if a `style` is not defined, `"solid"` is used.
The last line is always:

`stop`

C Attributed *DOT* Format (`-Tdot`)

This is the default output format. It reproduces the input, along with layout information for the graph. Coordinate values increase up and to the right. Positions are represented by two integers separated by a comma, representing the X and Y coordinates of the location specified in points (1/72 of an inch). A position refers to the center of its associated object. Lengths are given in inches.

A `bb` attribute is attached to the graph, specifying the bounding box of the drawing. If the graph has a label, its position is specified by the `lp` attribute.

Each node gets `pos`, `width` and `height` attributes. If the node is a record, the record rectangles are given in the `rects` attribute. If the node is polygonal and the `vertices` attribute is defined in the input graph, this attribute contains the vertices of the node. The number of points produced for circles and ellipses is governed by the `samplepoints` attribute.

Every edge is assigned a `pos` attribute, which consists of a list of $3n + 1$ locations. These are B-spline control points: points p_0, p_1, p_2, p_3 are the first Bezier spline, p_3, p_4, p_5, p_6 are the second, etc. Currently, edge points are listed top-to-bottom (or left-to-right) regardless of the orientation of the edge. This may change.

In the `pos` attribute, the list of control points might be preceded by a start point p_s and/or an end point p_e. These have the usual position representation with a `"s,"` or `"e,"` prefix, respectively. A start point is present if there is an arrow at p_0. In this case, the arrow is from p_0 to p_s, where p_s is actually on the node's boundary. The length and direction of the arrowhead is given by the vector $(p_s - p_0)$. If there is no arrow, p_0 is on the node's boundary. Similarly, the point p_e designates an arrow at the other end of the edge, connecting to the last spline point.

If the edge has a label, the label position is given in `lp`.

D Layers

dot has a feature for drawing parts of a single diagram on a sequence of overlapping "layers." Typically the layers are overhead transparencies. To activate this feature, one must set the top-level graph's `layers` attribute to a list of identifiers. A node or edge can then be assigned to a layer or range of layers using its `layer` attribute.. `all` is a reserved name for all layers (and can be used at either end of a range, e.g `design:all` or `all:code`). For example:

```
layers = "spec:design:code:debug:ship";
node90 [layer = "code"];
node91 [layer = "design:debug"];
node90 -> node91 [layer = "all"];
node92 [layer = "all:code"];
```

In this graph, `node91` is in layers `design`, `code` and `debug`, while `node92` is in layers `spec`, `design` and `code`.

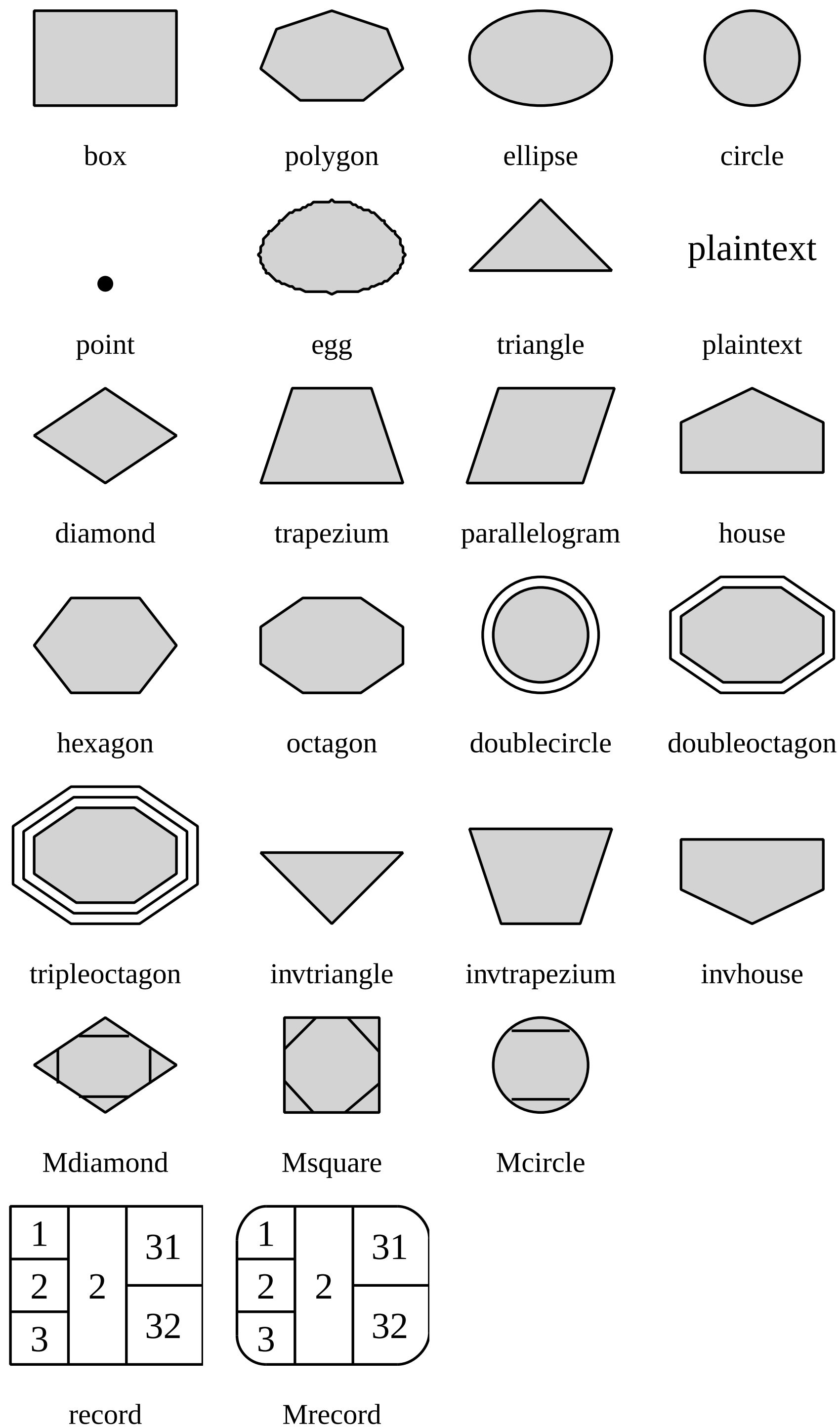
In a layered graph, if a node or edge has no layer assignment, but incident edges or nodes do, then its layer specification is inferred from these. To change the default so that nodes and edges with no layer appear on all layers, insert near the beginning of the graph file:

```
node [layer=all];
edge [layer=all];
```

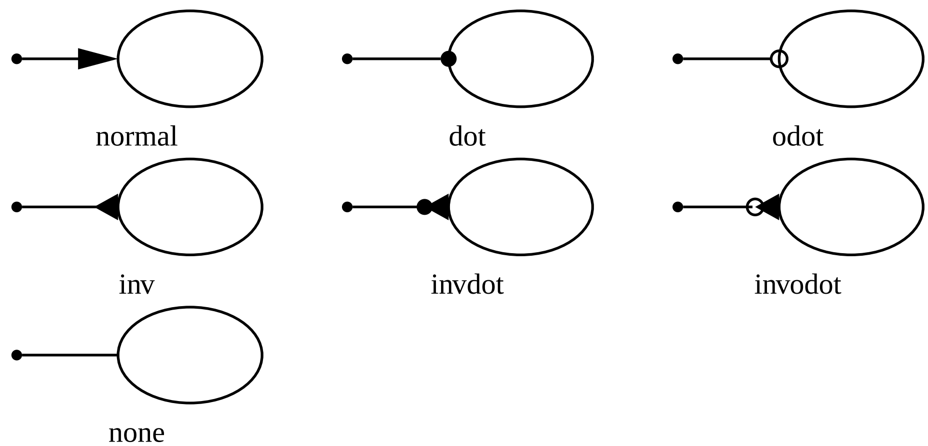
There is currently no way to specify a set of layers that are not a continuous range.

When PostScript output is selected, the color sequence for layers is set in the array `layercolorseq`. This array is indexed starting from 1, and every element must be a 3-element array which can interpreted as a color coordinate. The adventurous may learn further from reading *dot*'s PostScript output.

E Node Shapes



F Arrowhead Types



G Color Names

Whites
antiquewhite[1-4]
azure[1-4]
bisque[1-4]
blanchedalmond
cornsilk[1-4]
floralwhite
gainsboro
ghostwhite
honeydew[1-4]
ivory[1-4]
lavender
lavenderblush[1-4]
lemonchiffon[1-4]
linen
mintcream
mistyrose[1-4]
moccasin
navajowhite[1-4]
oldlace
papayawhip
peachpuff[1-4]
seashell[1-4]
snow[1-4]
thistle[1-4]
wheat[1-4]
white
whitesmoke

Greys
darkslategray[1-4]
dimgray
gray
gray[0-100]
lightgray
lightslategray
slategray[1-4]

Blacks
black

Reds
coral[1-4]
crimson
darksalmon
deeppink[1-4]
firebrick[1-4]
hotpink[1-4]
indianred[1-4]
lightpink[1-4]
lightsalmon[1-4]
maroon[1-4]
mediumvioletred
orangered[1-4]
palevioletred[1-4]
pink[1-4]
red[1-4]
salmon[1-4]
tomato[1-4]
violetred[1-4]

Browns
beige
brown[1-4]
burlywood[1-4]
chocolate[1-4]
darkkhaki
khaki[1-4]
peru
rosybrown[1-4]
saddlebrown
sandybrown
sienna[1-4]
tan[1-4]

Oranges
darkorange[1-4]
orange[1-4]
orangered[1-4]

Yellows
darkgoldenrod[1-4]
gold[1-4]
goldenrod[1-4]
greenyellow
lightgoldenrod[1-4]
lightgoldenrodyellow
lightyellow[1-4]
palegoldenrod
yellow[1-4]
yellowgreen

Greens
chartreuse[1-4]
darkgreen
darkolivegreen[1-4]
darkseagreen[1-4]
forestgreen
green[1-4]
greenyellow
lawngreen
lightseagreen
limegreen
mediumseagreen
mediumspringgreen
mintcream
olivedrab[1-4]
palegreen[1-4]
seagreen[1-4]
springgreen[1-4]
yellowgreen

Cyans
aquamarine[1-4]
cyan[1-4]
darkturquoise
lightcyan[1-4]
mediumaquamarine
mediumturquoise
paleturquoise[1-4]
turquoise[1-4]

Blues
aliceblue
blue[1-4]
blueviolet
cadetblue[1-4]
cornflowerblue
darkslateblue
deepskyblue[1-4]
dodgerblue[1-4]
indigo
lightblue[1-4]
lightskyblue[1-4]
lightslateblue[1-4]
mediumblue
mediumslateblue
midnightblue
navy
navyblue
powderblue
royalblue[1-4]
skyblue[1-4]
slateblue[1-4]
steelblue[1-4]

Magentas
blueviolet
darkorchid[1-4]
darkviolet
magenta[1-4]
mediumorchid[1-4]
mediumpurple[1-4]
mediumvioletred
orchid[1-4]
palevioletred[1-4]
plum[1-4]
purple[1-4]
violet
violetred[1-4]