A tutorial for the CAD program LayoutEditor

LayoutEditor is available from

www.layouteditor.net

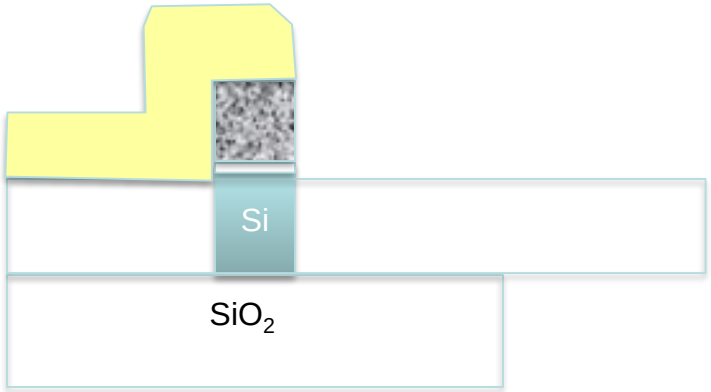
by Jürgen Thies, Juspertor UG, Munich

Common terminology

Layers	designate processing steps
Cells	are parts, or parts of parts
Top-level cell	contains the whole enchilada

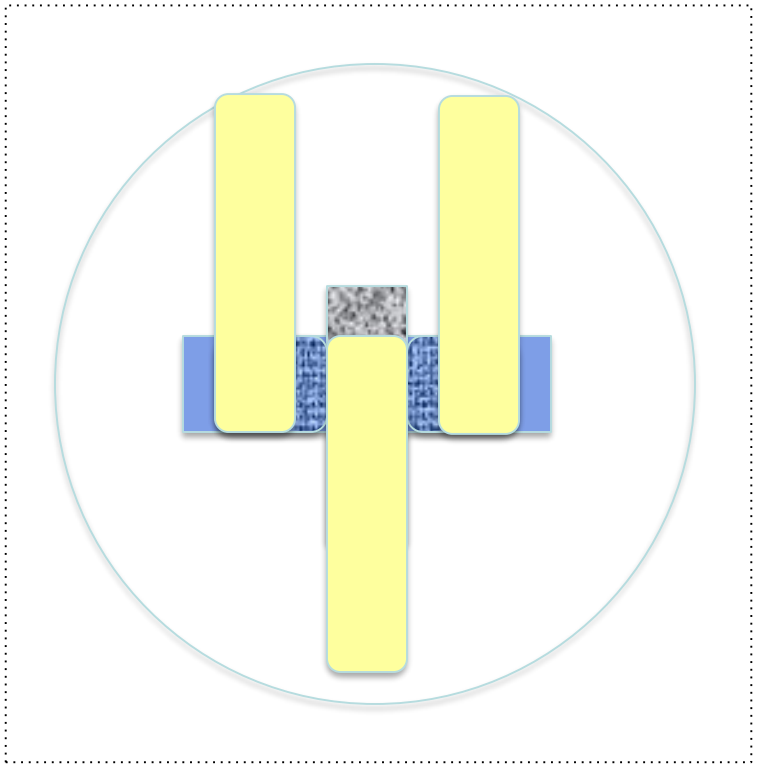
Typical example

Side view



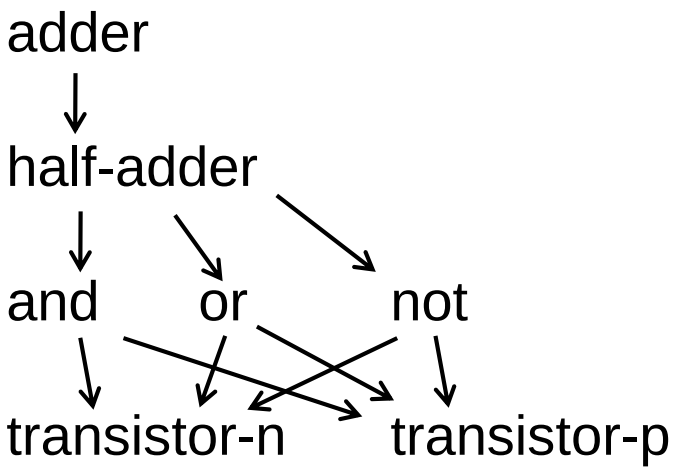
Top view

CELL “TRANSISTOR”



Fill/isolation oxide	LAYER 2
Gate oxide	LAYER 3
Gate polysilicon	LAYER 4
Implant dopants	LAYER 5
Metal wiring	LAYER 6

Your design should be a hierarchy of cells



Each cell may contain shapes on many layers,
describing how to build separate devices.

To produce one mask plate for one processing step,
we pull out one LAYER.

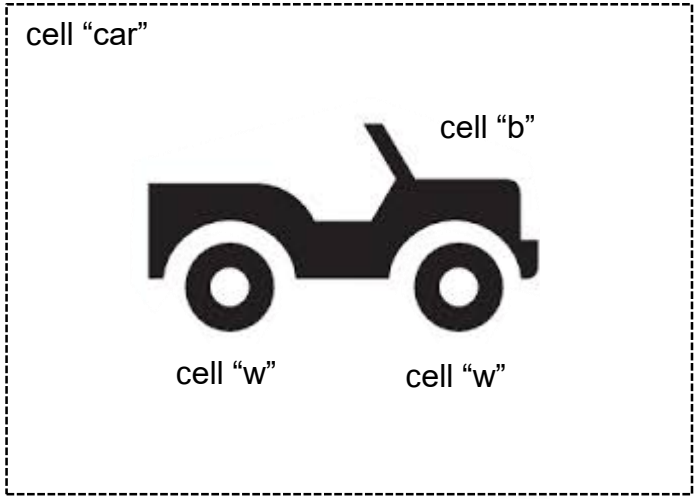
Get it? Cells = devices or parts
Layers = processing steps

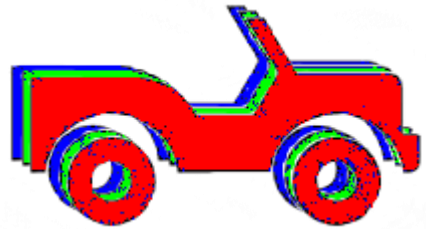
A lot of people don’t understand this, so pay attention:

CAD cells are parts of the final device

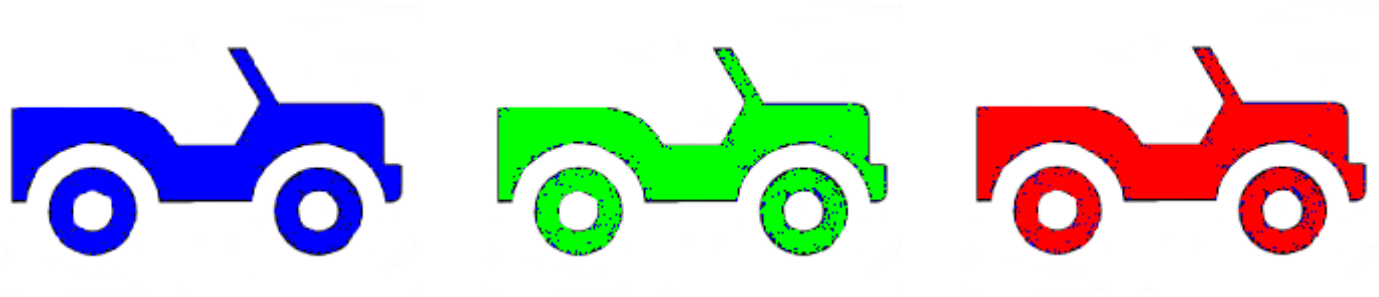
The cells are contained inside higher level cells.

Inside each cell are found layers which represent steps in the manufacturing process.





To build the device, the cells are “flattened” to remove hierarchy, then the layers are extracted into separate files.

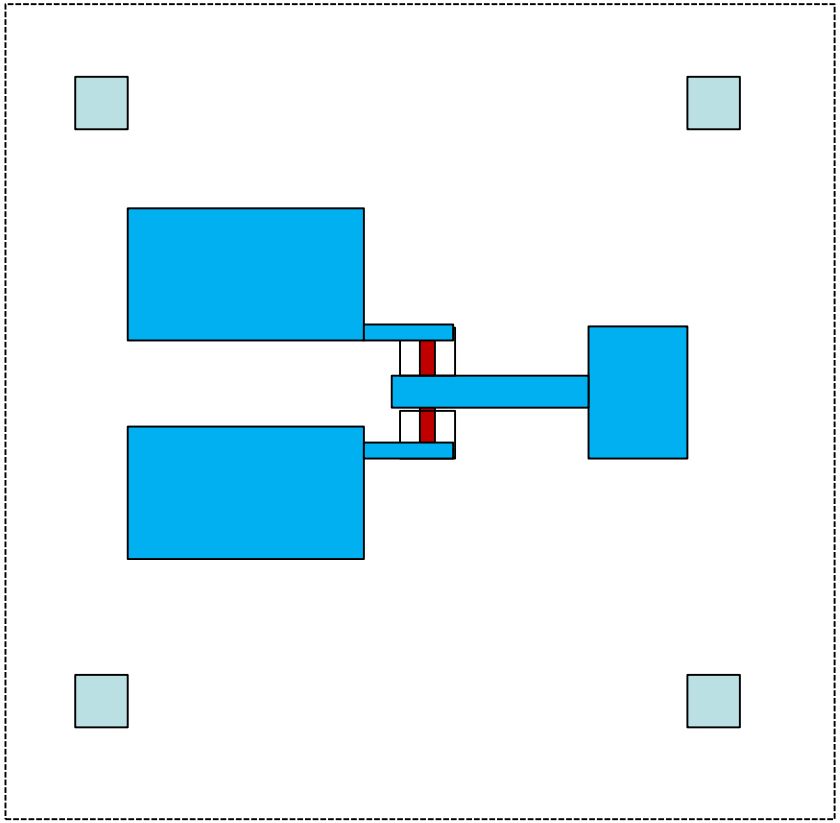


But not until later, and not with the CAD program.

There is a separate program for flattening and extracting layers, and then fracturing the shapes into simple forms that can be printed with the e-beam system.

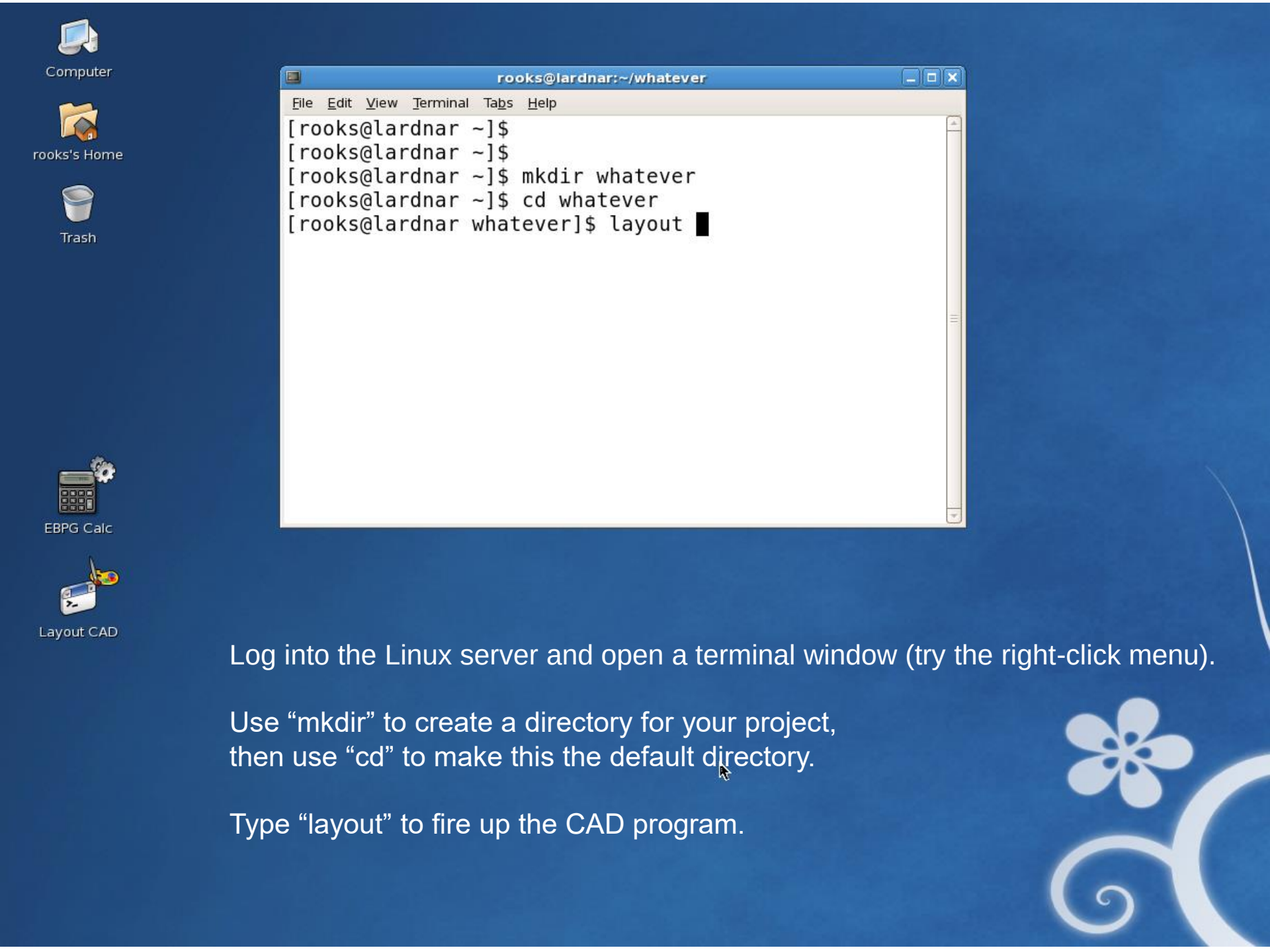
Remember this:

The top-level cell should look just like the final device.



e.g., alignment marks do not go into a separate FILE
they go on a separate LAYER. Do not make this typical, stupid mistake.

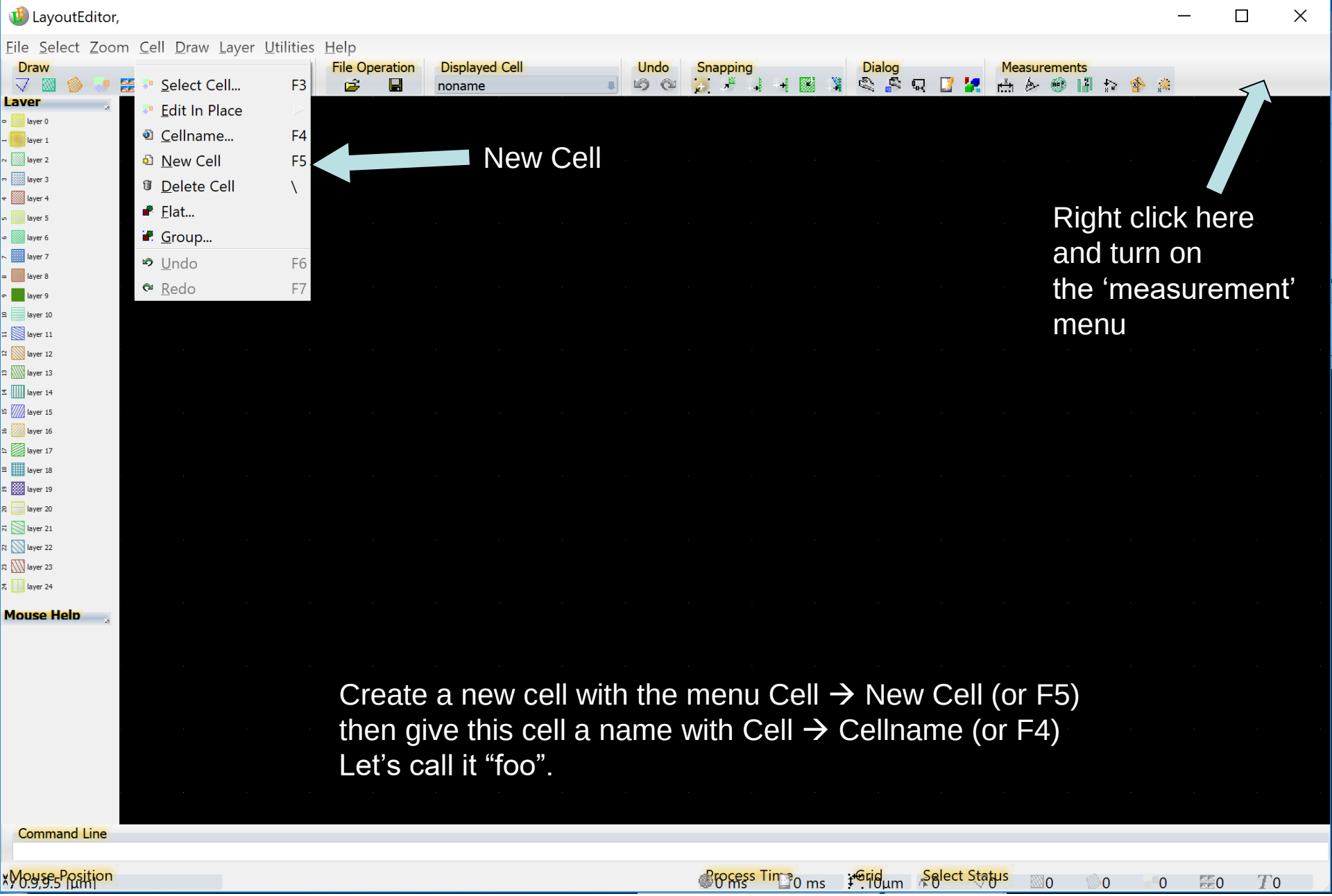
Now let’s get started with
the CAD program Layout.



Log into the Linux server and open a terminal window (try the right-click menu).

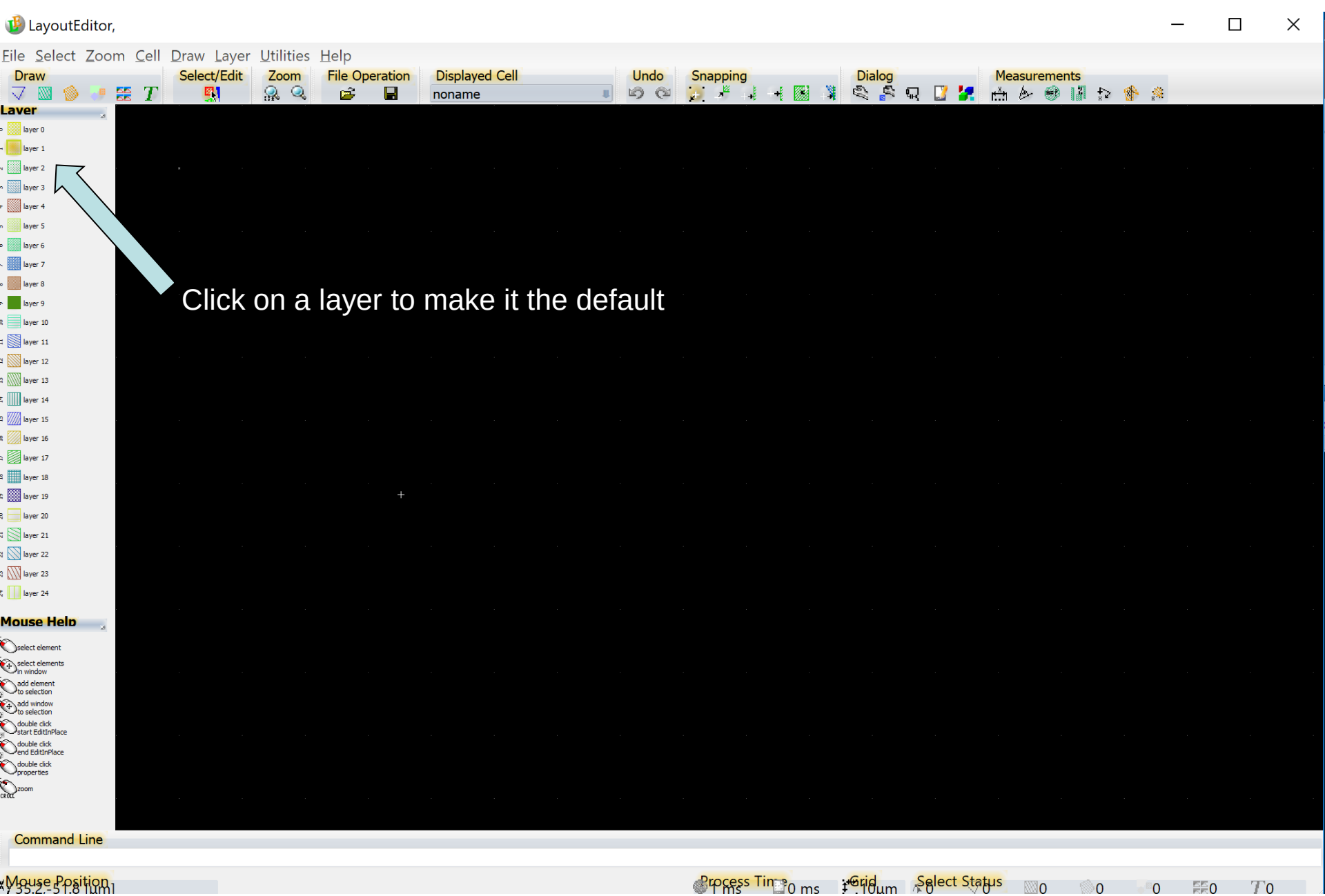
Use “mkdir” to create a directory for your project,
then use “cd” to make this the default directory.

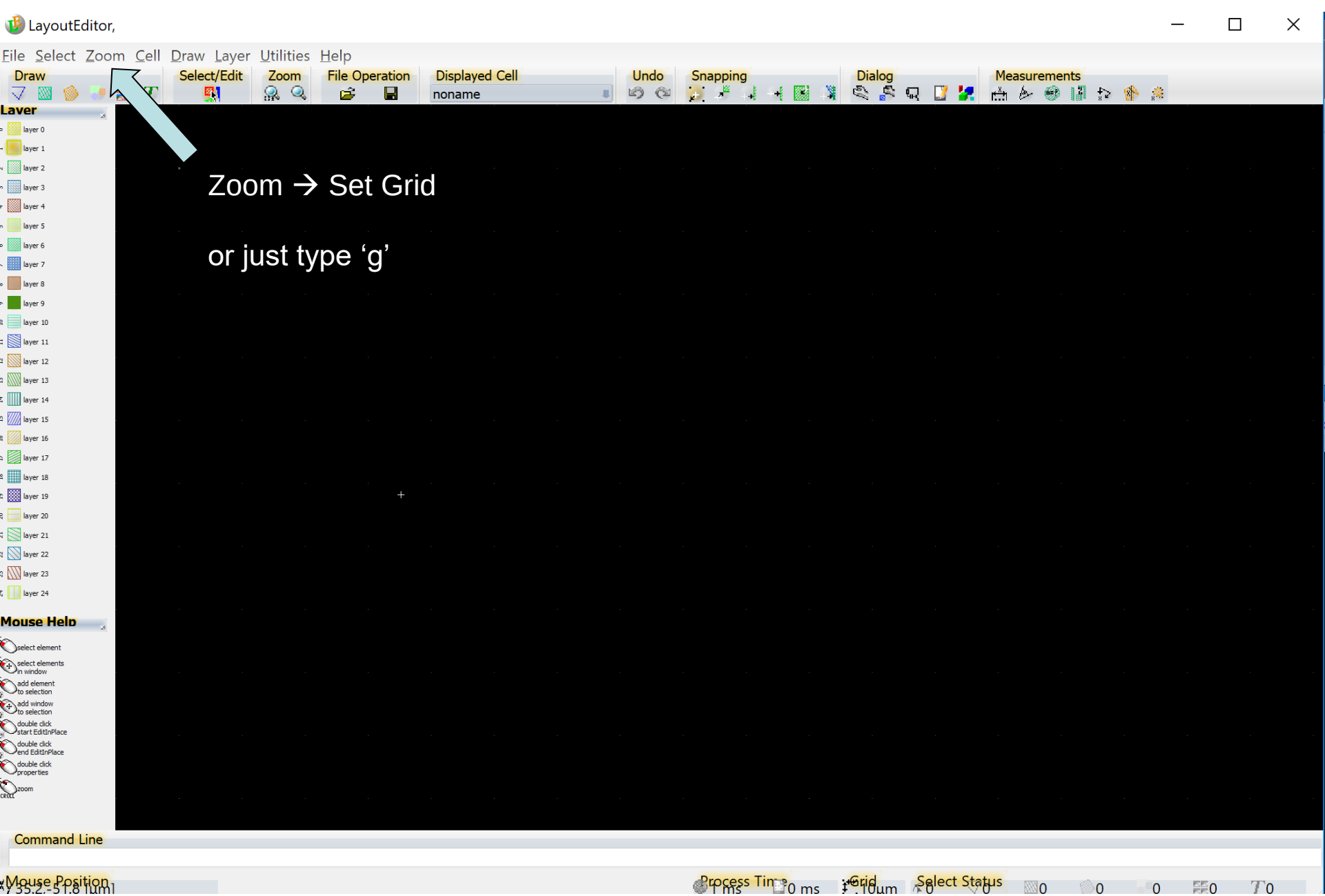
Type “layout” to fire up the CAD program.

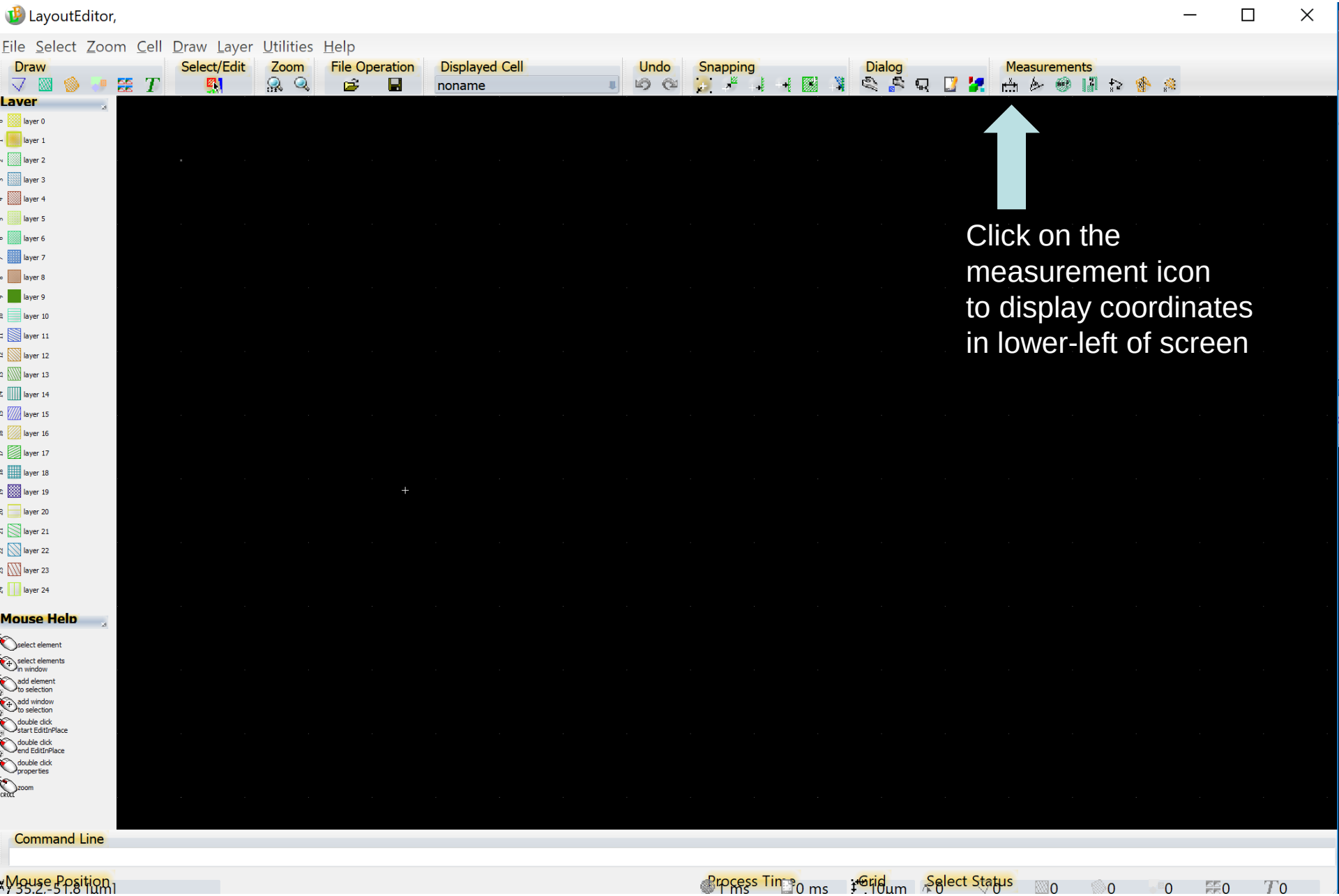


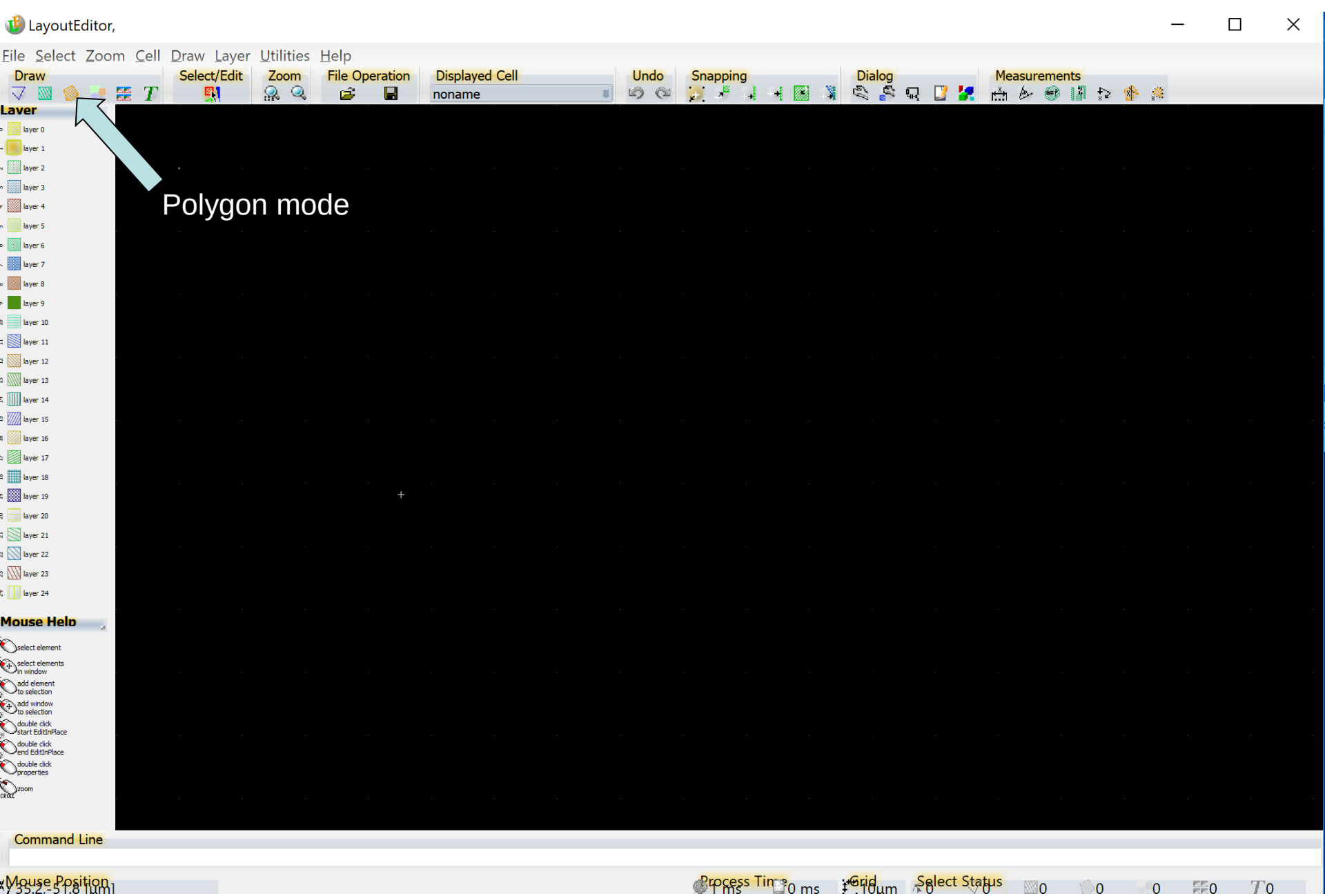
Create a new cell with the menu Cell → New Cell (or F5)
then give this cell a name with Cell → Cellname (or F4)
Let's call it "foo".

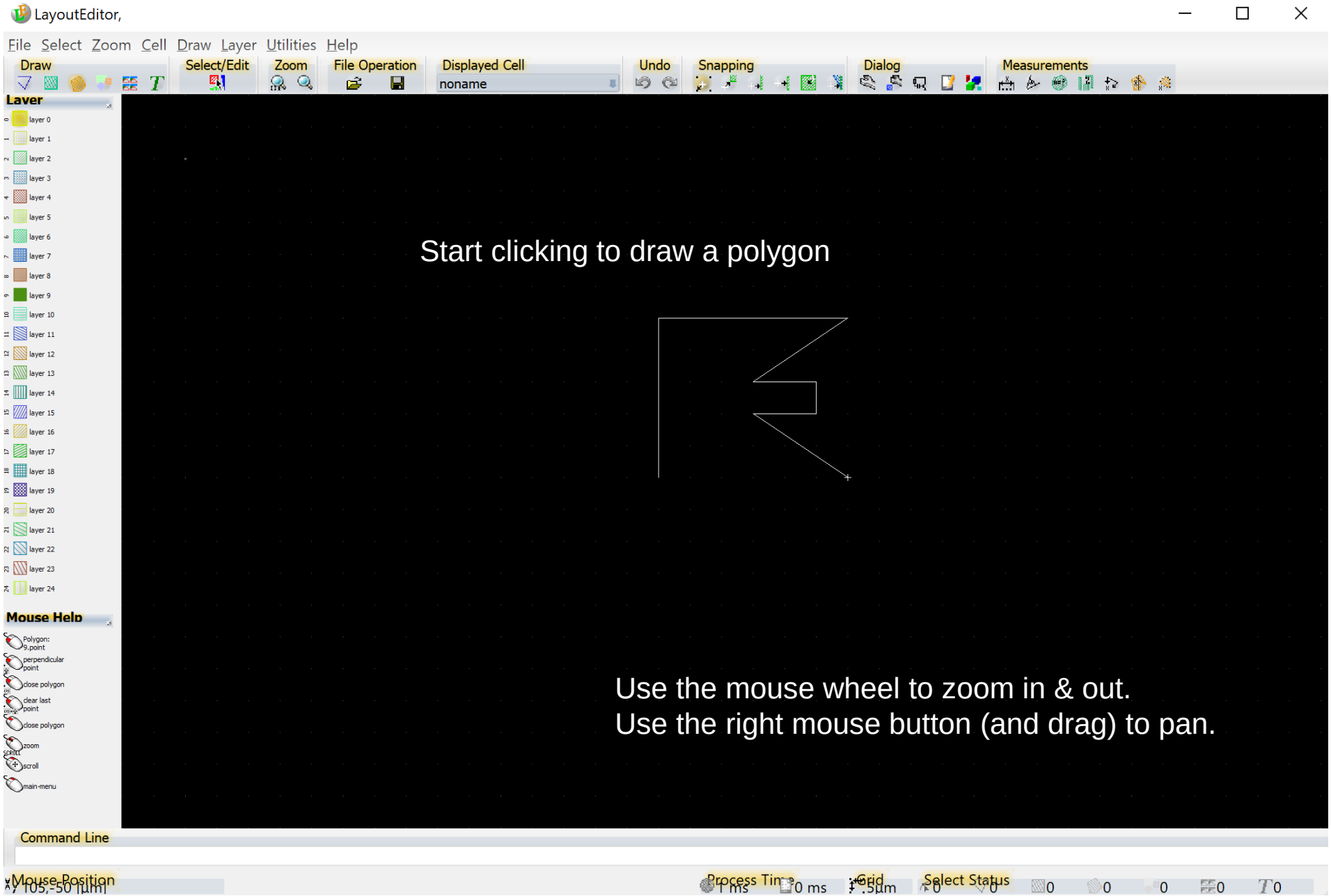
Well yes, it still says "noname" under "Displayed Cell" because I forgot to actually change the name.

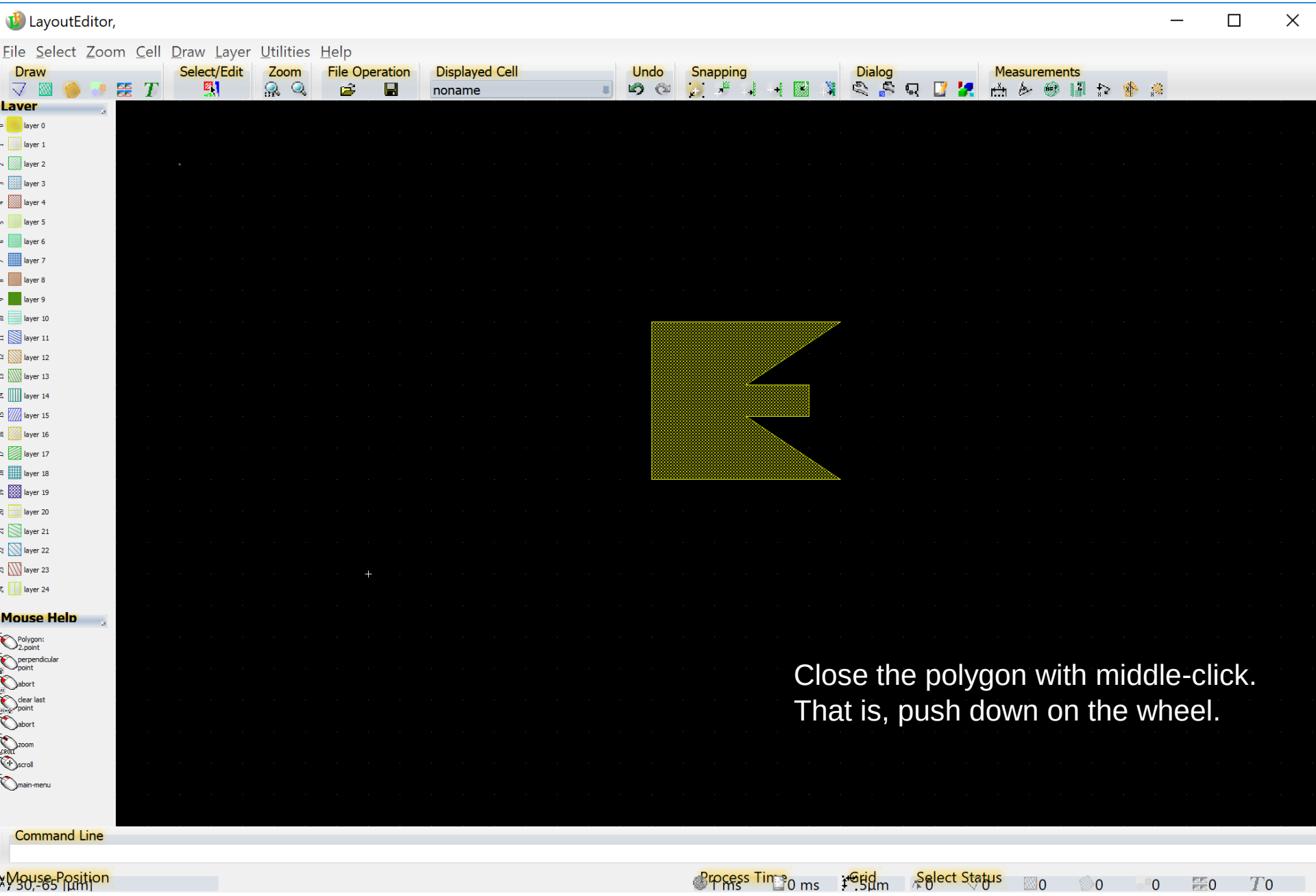

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
select element
select elements in window
add element to selection
add window to selection
double click start EditInPlace
double click end EditInPlace
double click properties
zoom
Click on a layer to make it the default
Command Line
Mouse Position
Process Time
Grid
Select Status

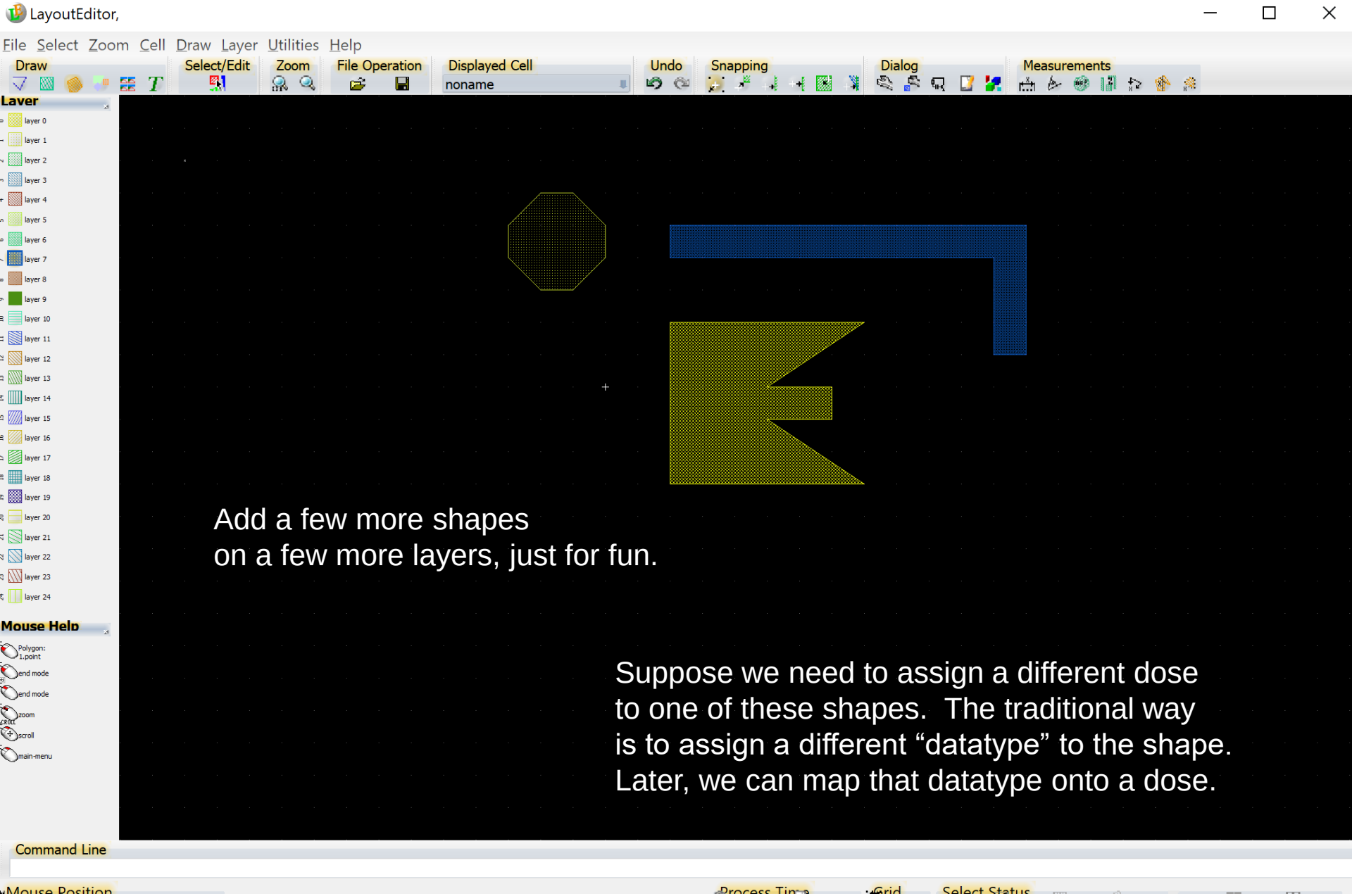

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Command Line
Mouse Position
Process Time
Grid
Select Status
Zoom → Set Grid
or just type 'g'

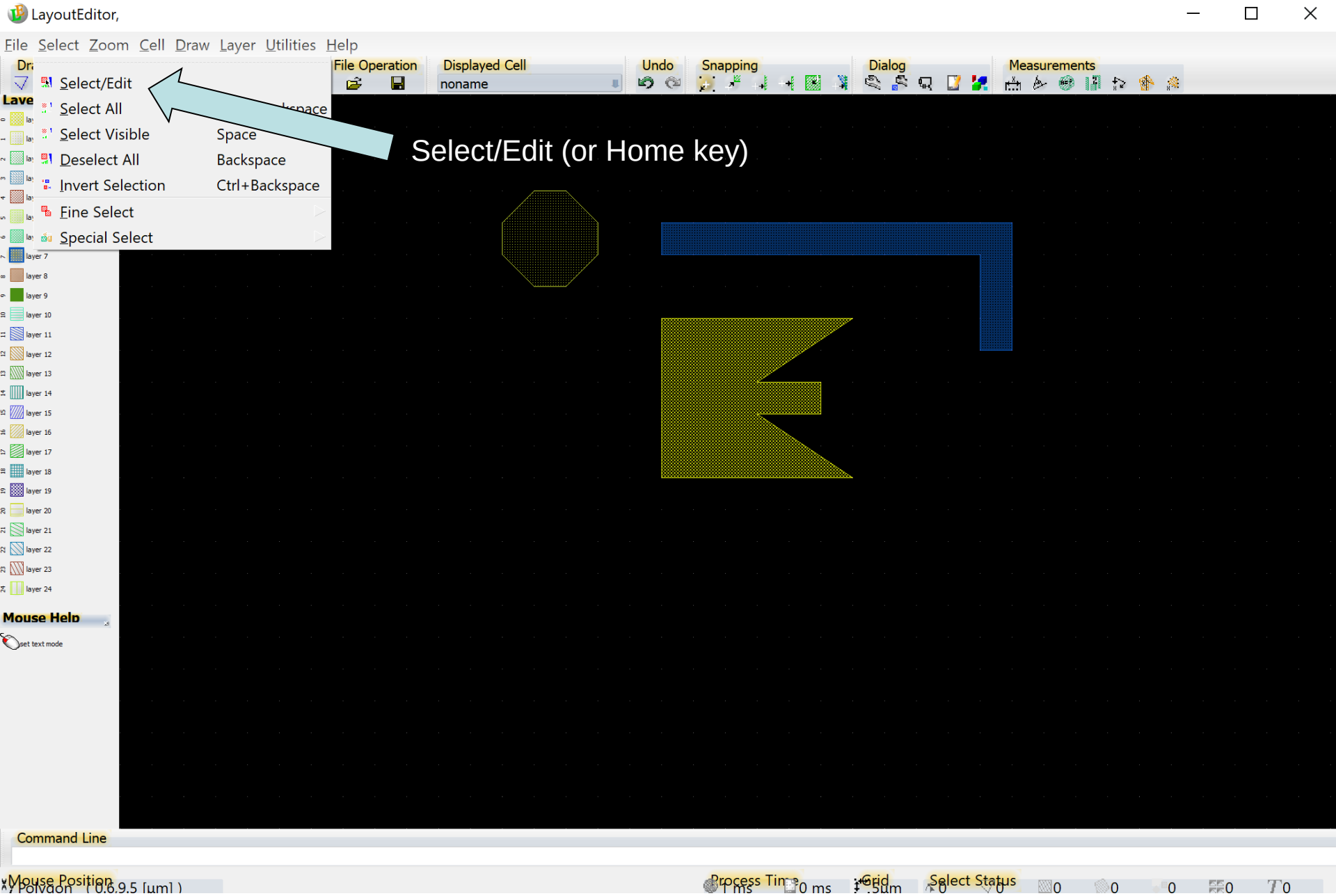

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Command Line
Mouse Position
Process Time
Grid
Select Status
Click on the measurement icon to display coordinates in lower-left of screen

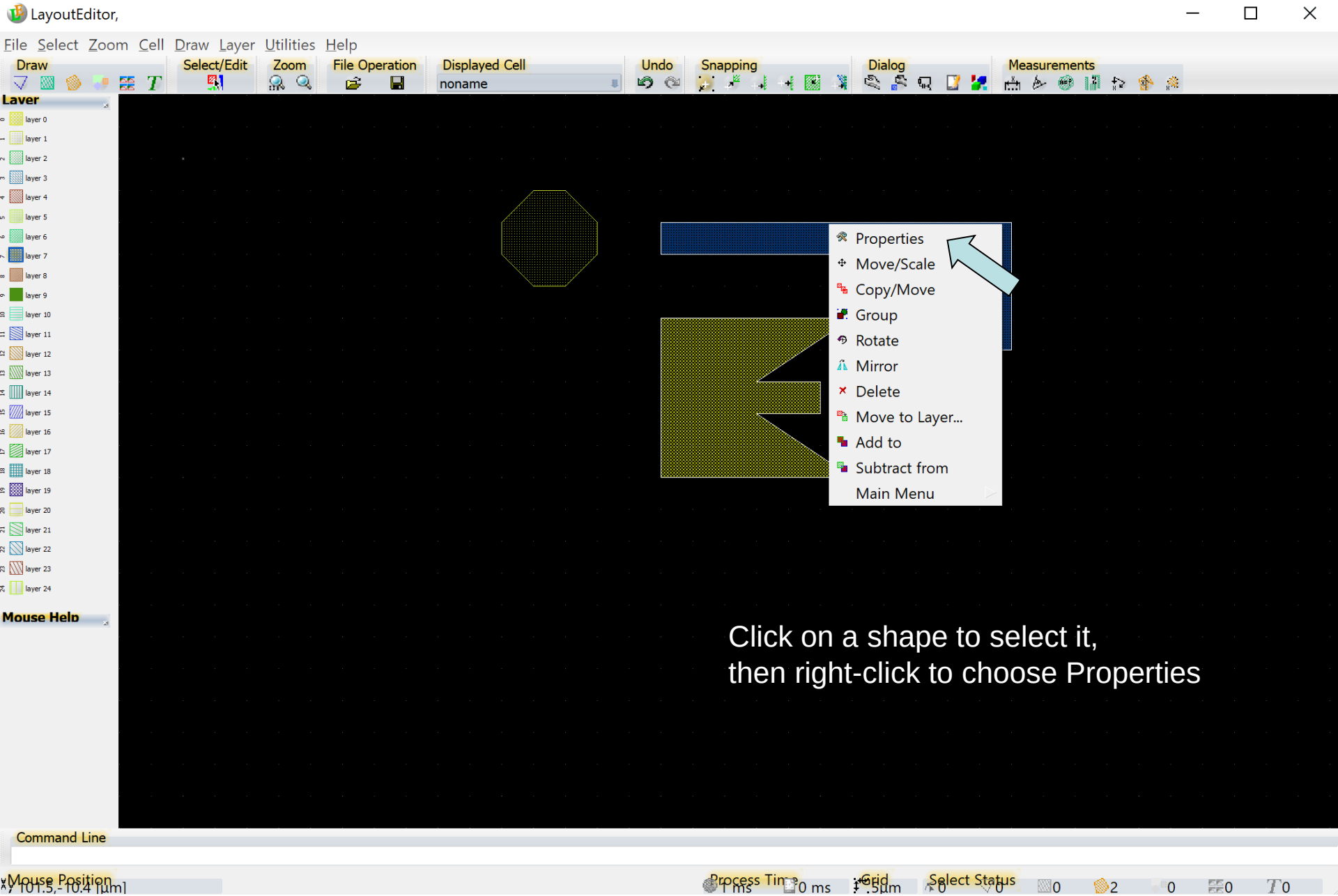

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
select element
select elements in window
add element to selection
add window to selection
double click start EditInPlace
double click end EditInPlace
double click properties
zoom
Polygon mode
Command Line
Mouse Position
Process Time
Grid
Select Status

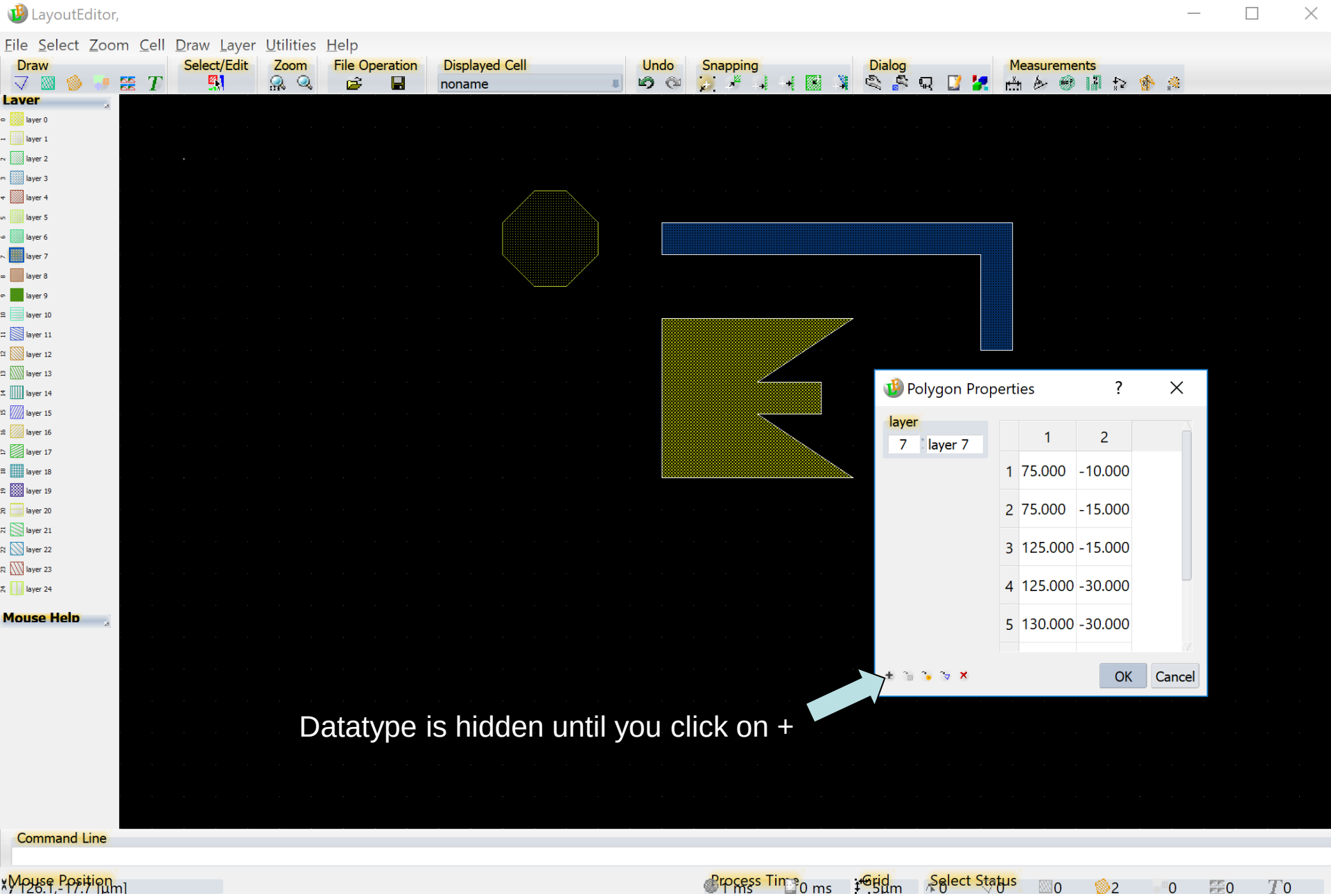

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
Polygon: 9.point
perpendicular point
close polygon
clear last point
close polygon
zoom
scroll
main-menu
Start clicking to draw a polygon
Use the mouse wheel to zoom in & out.
Use the right mouse button (and drag) to pan.
Command Line
Mouse Position
105,-50 [µm]
Process Time
1 ms
0 ms
Grid
.5µm
Select Status

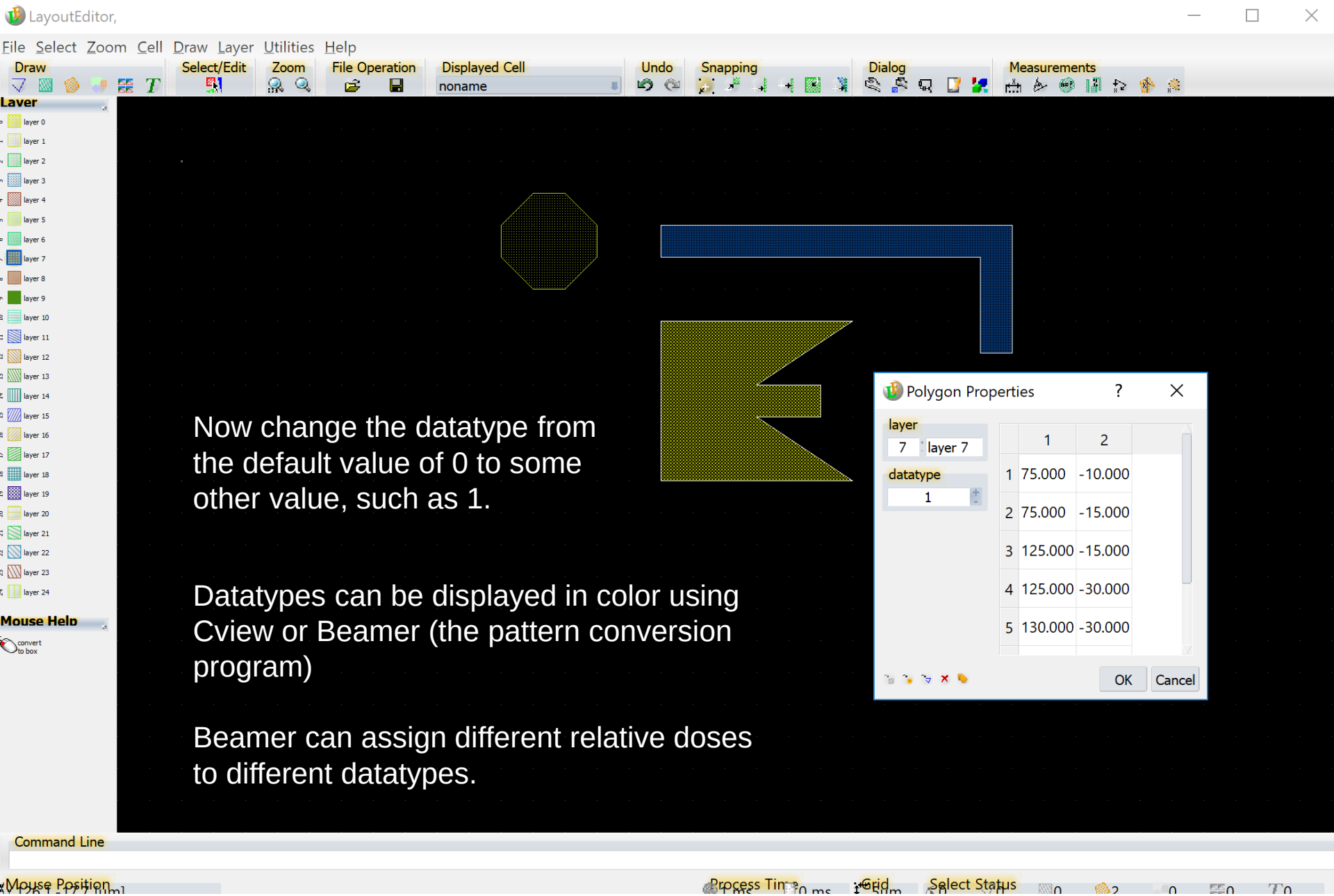

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
Polygon: 2.point
perpendicular point
abort
clear last point
abort
zoom
scroll
main-menu
Close the polygon with middle-click.
That is, push down on the wheel.
Command Line
Mouse Position
30,-65 [µm]
Process Time
1 ms
0 ms
Grid
.5µm
Select Status
0
0
0
0
0
0
0


LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
Polygon: 1.point
end mode
end mode
zoom
scroll
main-menu
Add a few more shapes
on a few more layers, just for fun.
Suppose we need to assign a different dose
to one of these shapes. The traditional way
is to assign a different “datatype” to the shape.
Later, we can map that datatype onto a dose.
Command Line


LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Select/Edit
Select All
Select Visible Space
Deselect All Backspace
Invert Selection Ctrl+Backspace
Fine Select
Special Select
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Select/Edit (or Home key)
Mouse Help
Command Line
Mouse Position
Process Time
Grid
Select Status


LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Properties
Move/Scale
Copy/Move
Group
Rotate
Mirror
Delete
Move to Layer...
Add to
Subtract from
Main Menu
Click on a shape to select it,
then right-click to choose Properties
Command Line
Mouse Position
Process Time
Grid
Select Status

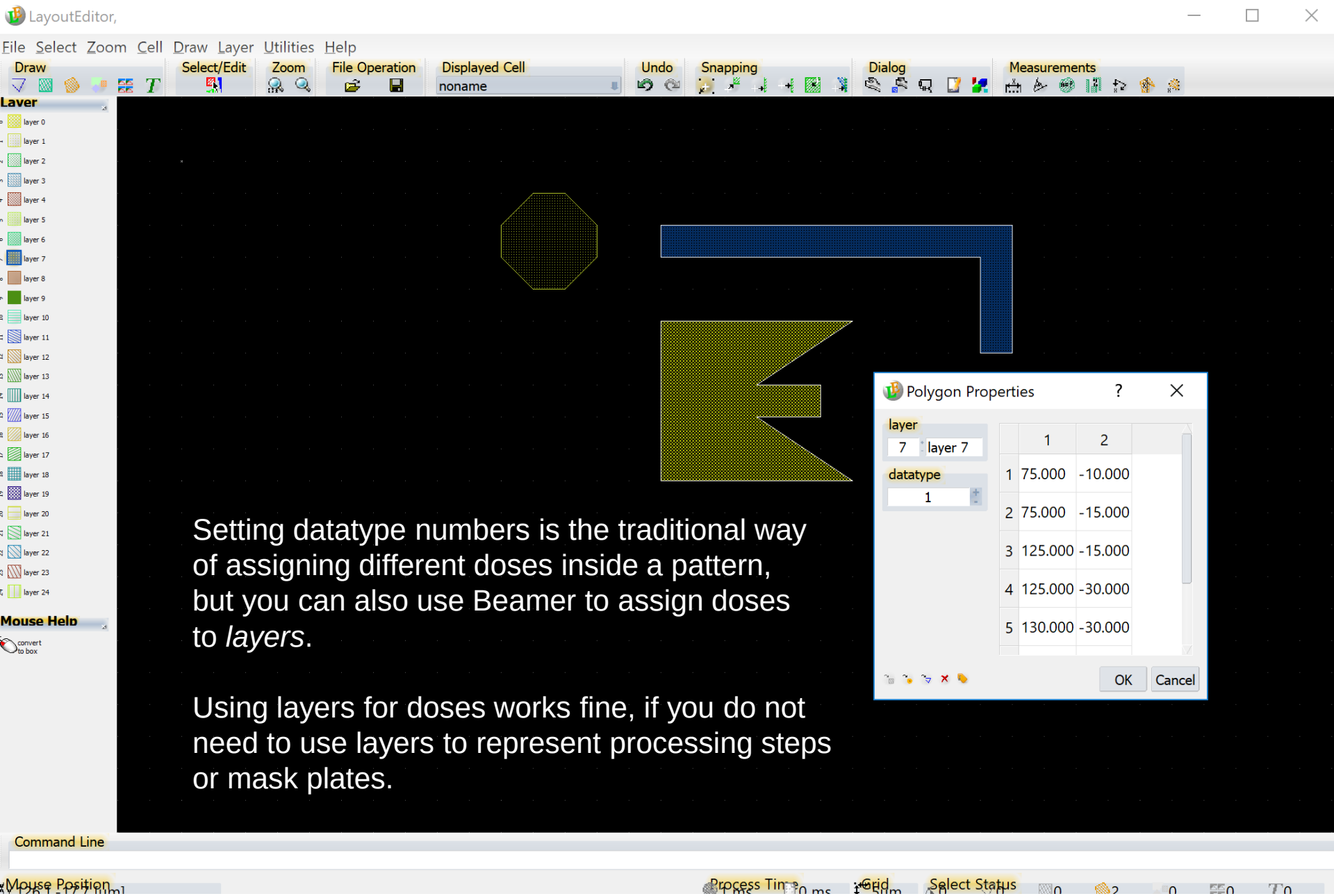

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Polygon Properties
layer
7
layer 7
1 2
1 75.000 -10.000
2 75.000 -15.000
3 125.000 -15.000
4 125.000 -30.000
5 130.000 -30.000
OK
Cancel
Datatype is hidden until you click on +
Command Line
Mouse Position
Process Time
Grid
Select Status

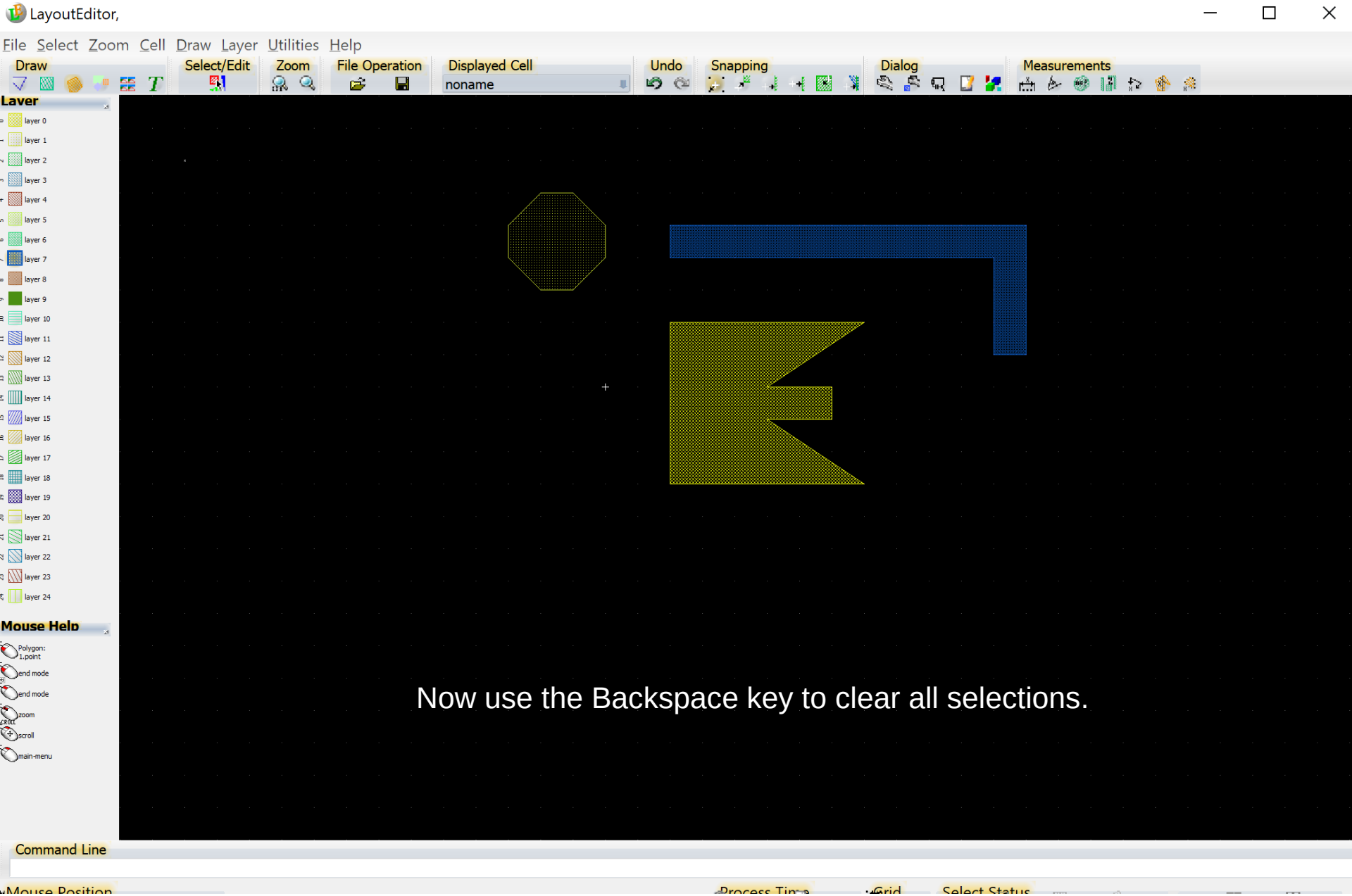


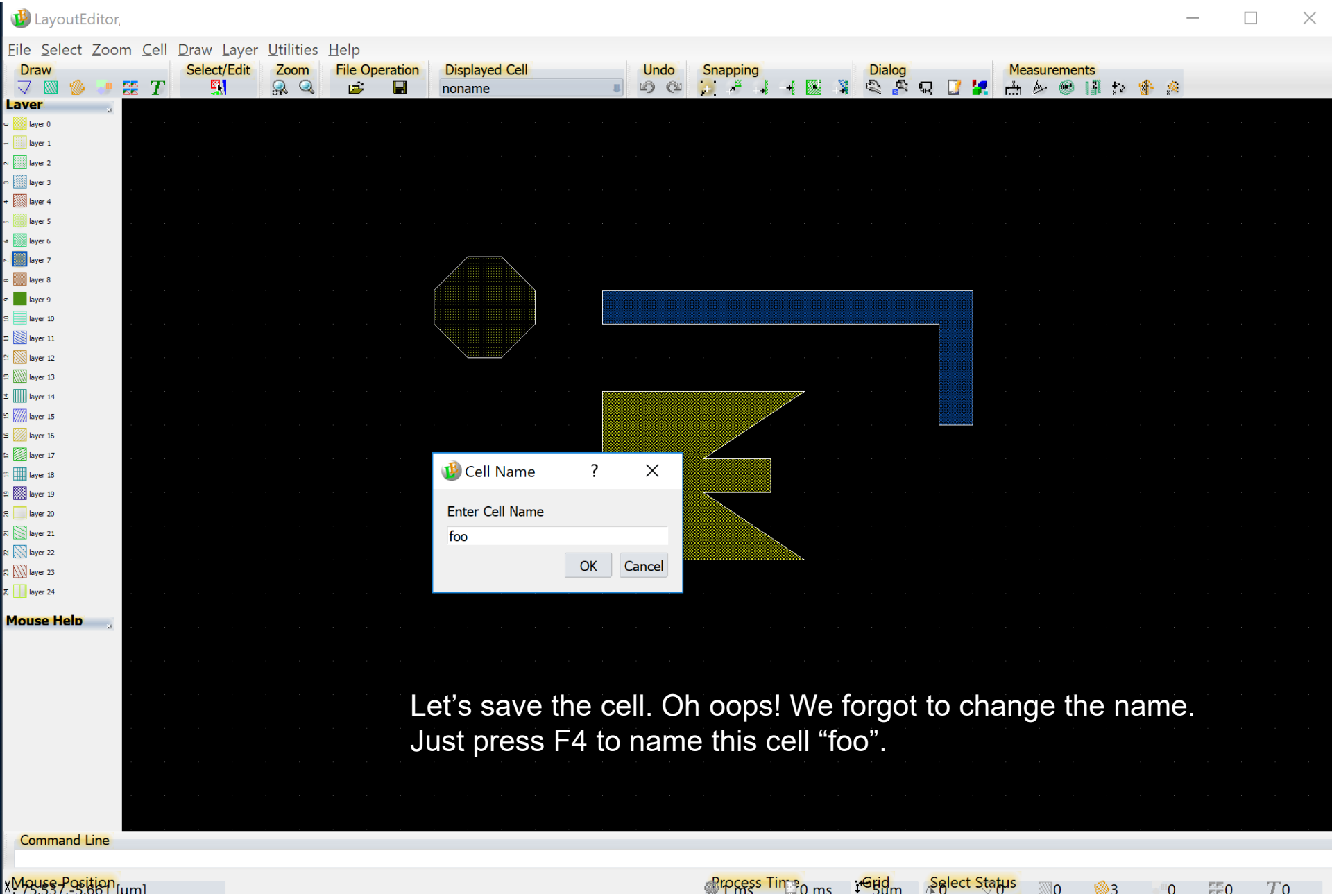
Now change the datatype from the default value of 0 to some other value, such as 1.

Datatypes can be displayed in color using Cview or Beamer (the pattern conversion program)

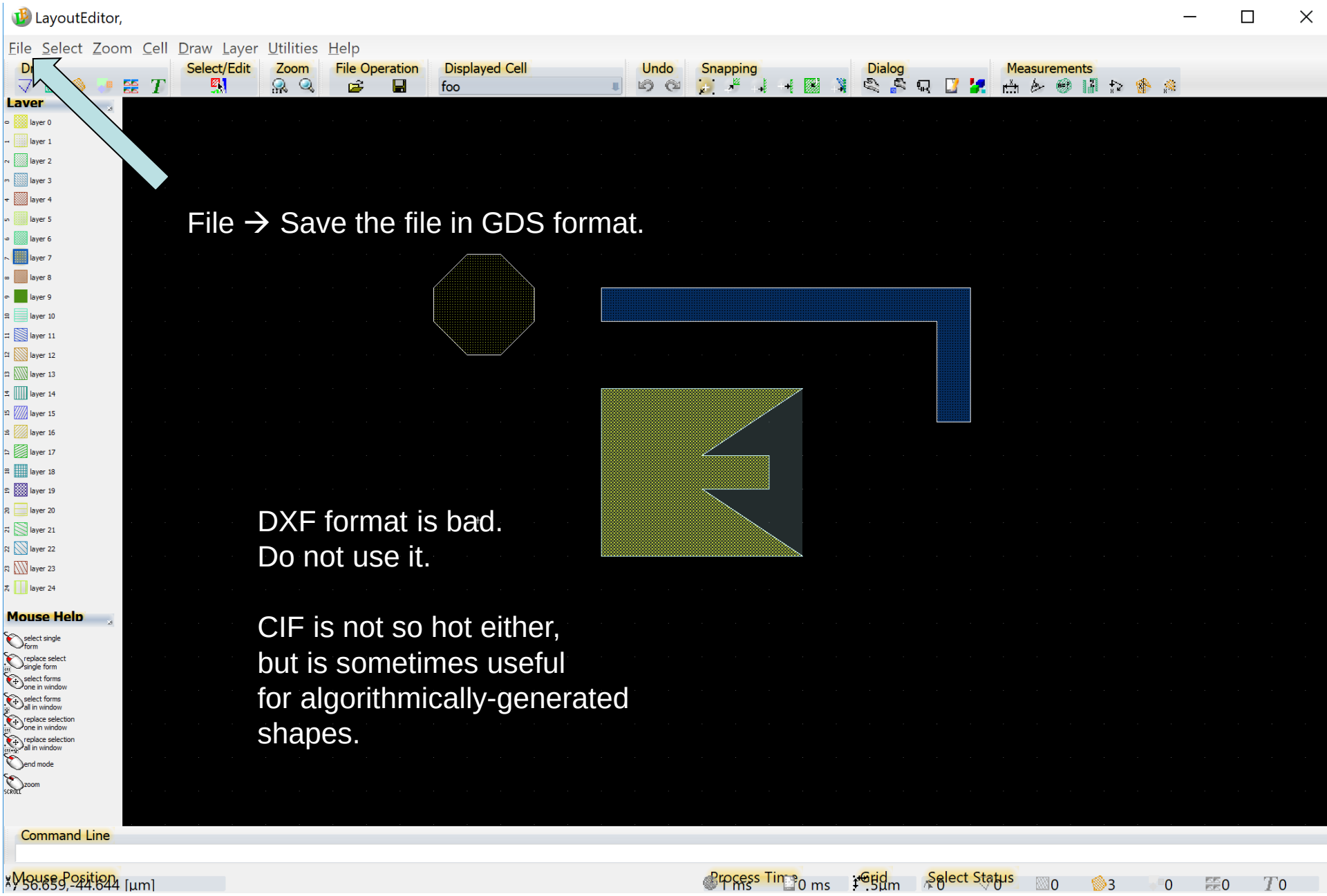
Beamer can assign different relative doses to different datatypes.

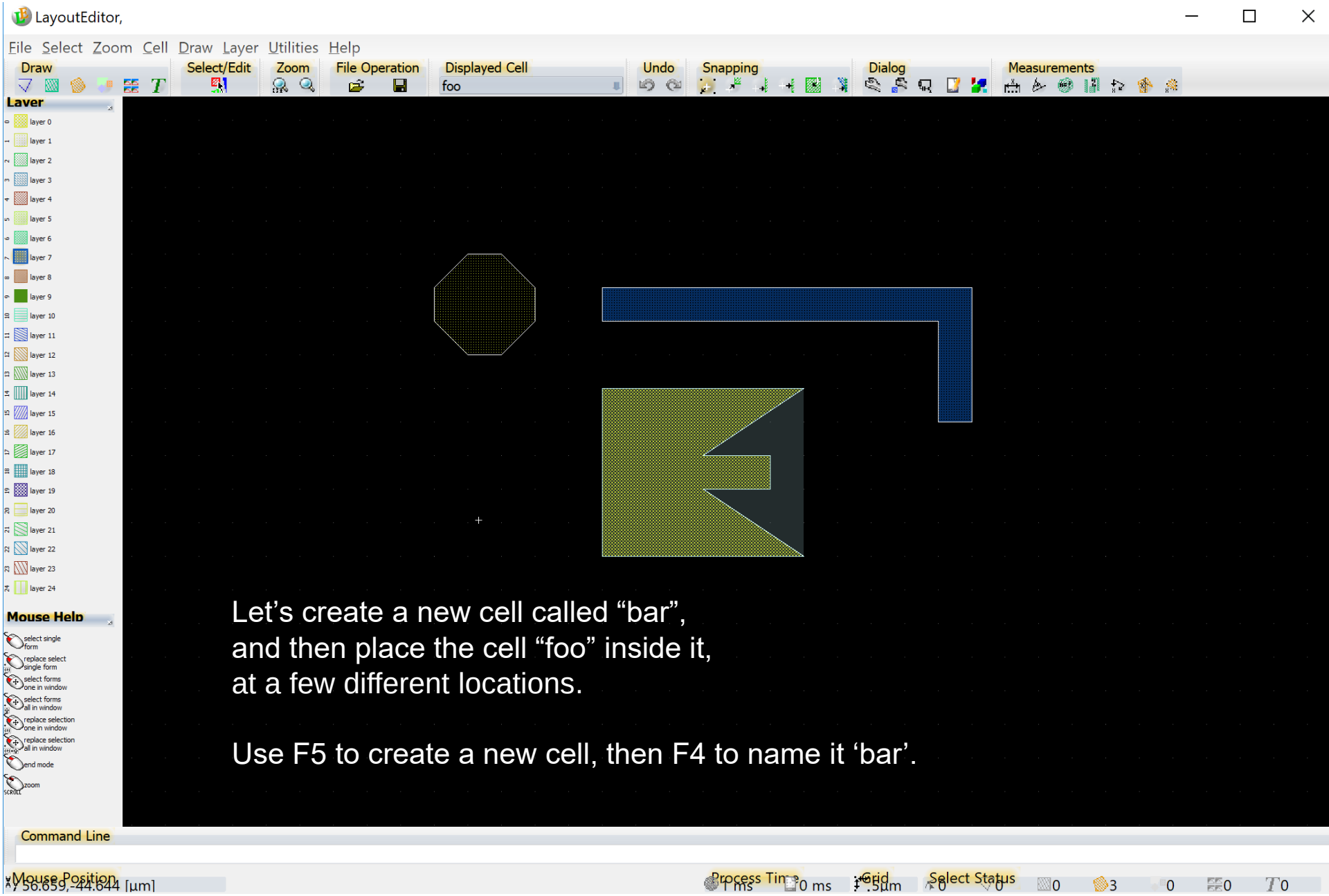

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Polygon Properties
layer
7
layer 7
datatype
1
1 2
1 75.000 -10.000
2 75.000 -15.000
3 125.000 -15.000
4 125.000 -30.000
5 130.000 -30.000
OK
Cancel
Setting datatype numbers is the traditional way of assigning different doses inside a pattern, but you can also use Beamer to assign doses to *layers*.
Using layers for doses works fine, if you do not need to use layers to represent processing steps or mask plates.
Command Line
Mouse Position
Process Time
Grid
Select Status

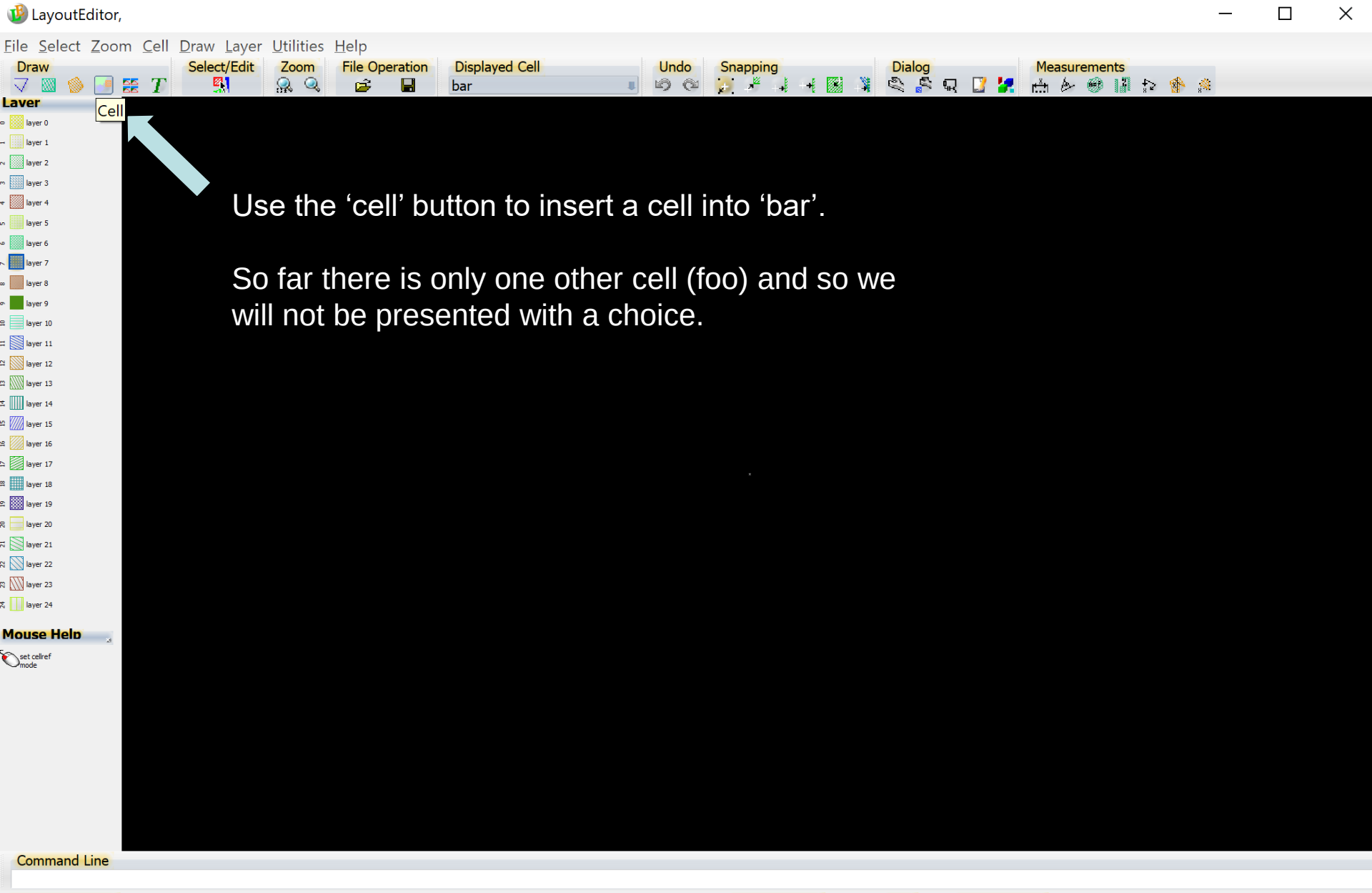

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
noname
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
Polygon: 1.point
end mode
end mode
zoom
scroll
main-menu
Now use the Backspace key to clear all selections.
Command Line



Let’s save the cell. Oh oops! We forgot to change the name.
Just press F4 to name this cell “foo”.

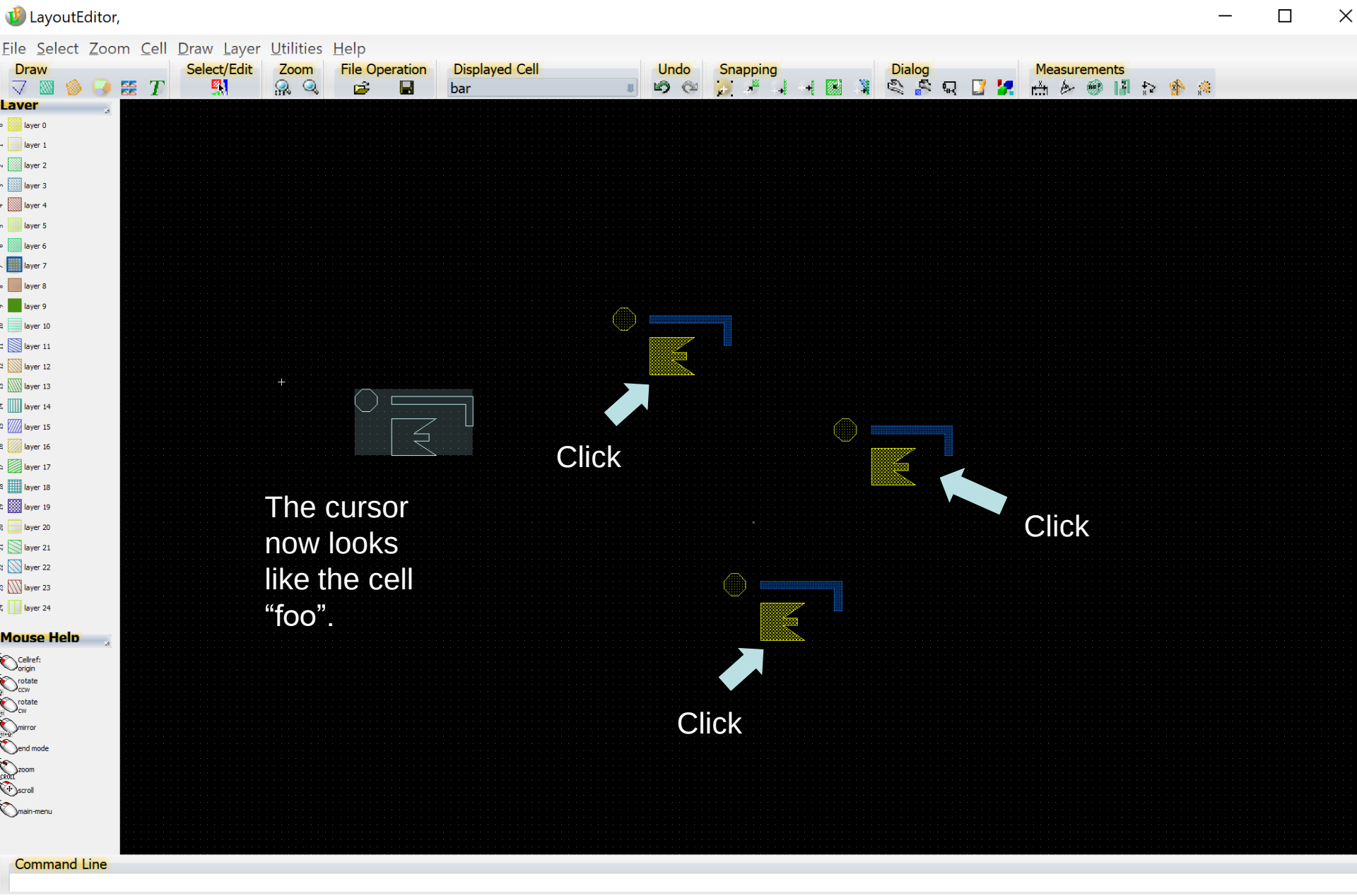

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Select/Edit
Zoom
File Operation
Displayed Cell
foo
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Command Line
Mouse Position
Process Time
Grid
Select Status
File → Save the file in GDS format.
DXF format is bad.
Do not use it.
CIF is not so hot either,
but is sometimes useful
for algorithmically-generated
shapes.

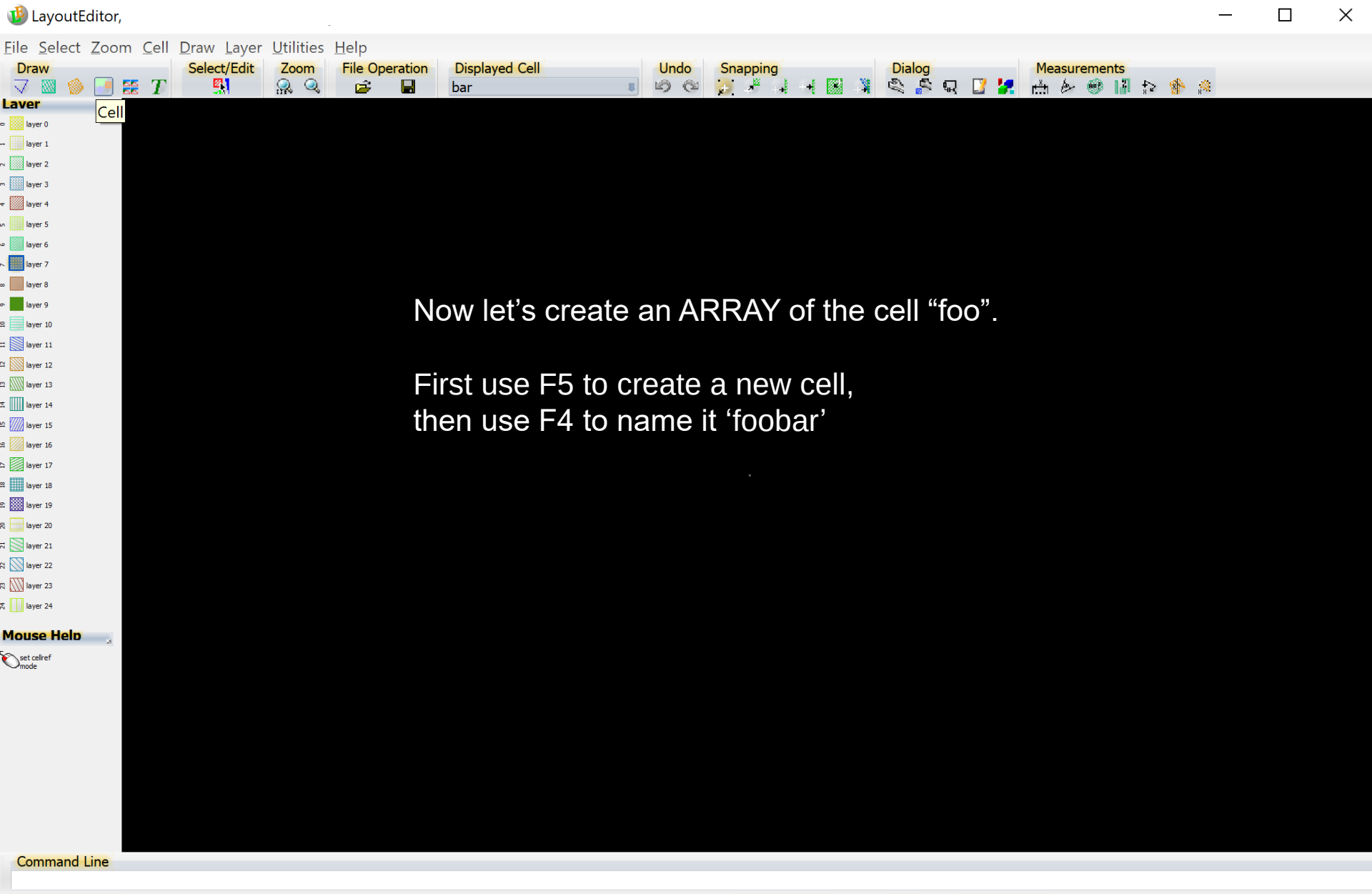

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
foo
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Command Line
Mouse Position
Process Time
Grid
Select Status
Let's create a new cell called "bar",
and then place the cell "foo" inside it,
at a few different locations.
Use F5 to create a new cell, then F4 to name it 'bar'.



Use the ‘cell’ button to insert a cell into ‘bar’.

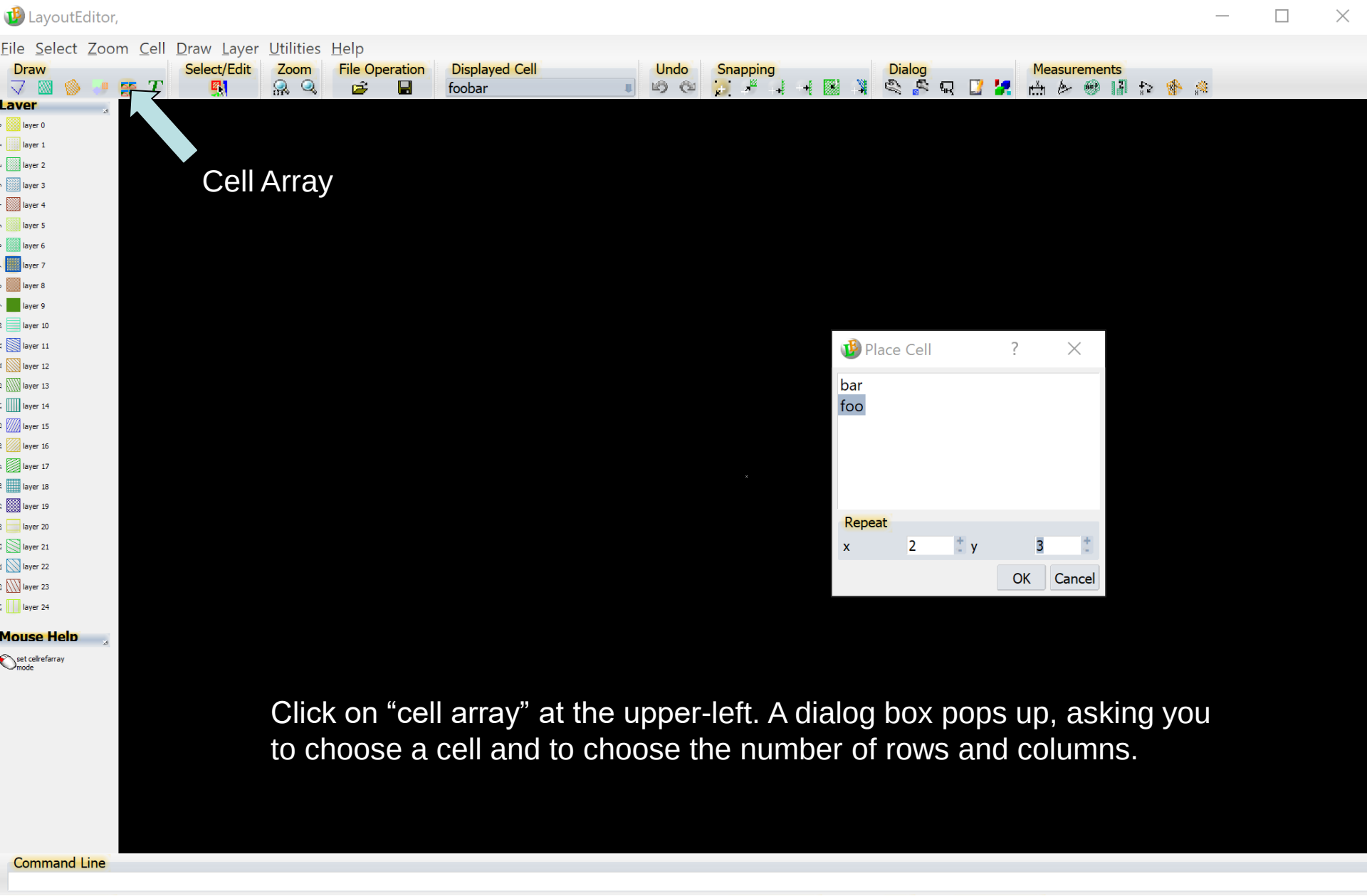
So far there is only one other cell (foo) and so we will not be presented with a choice.


LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
bar
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Command Line
The cursor now looks like the cell "foo".
Click
Click
Click

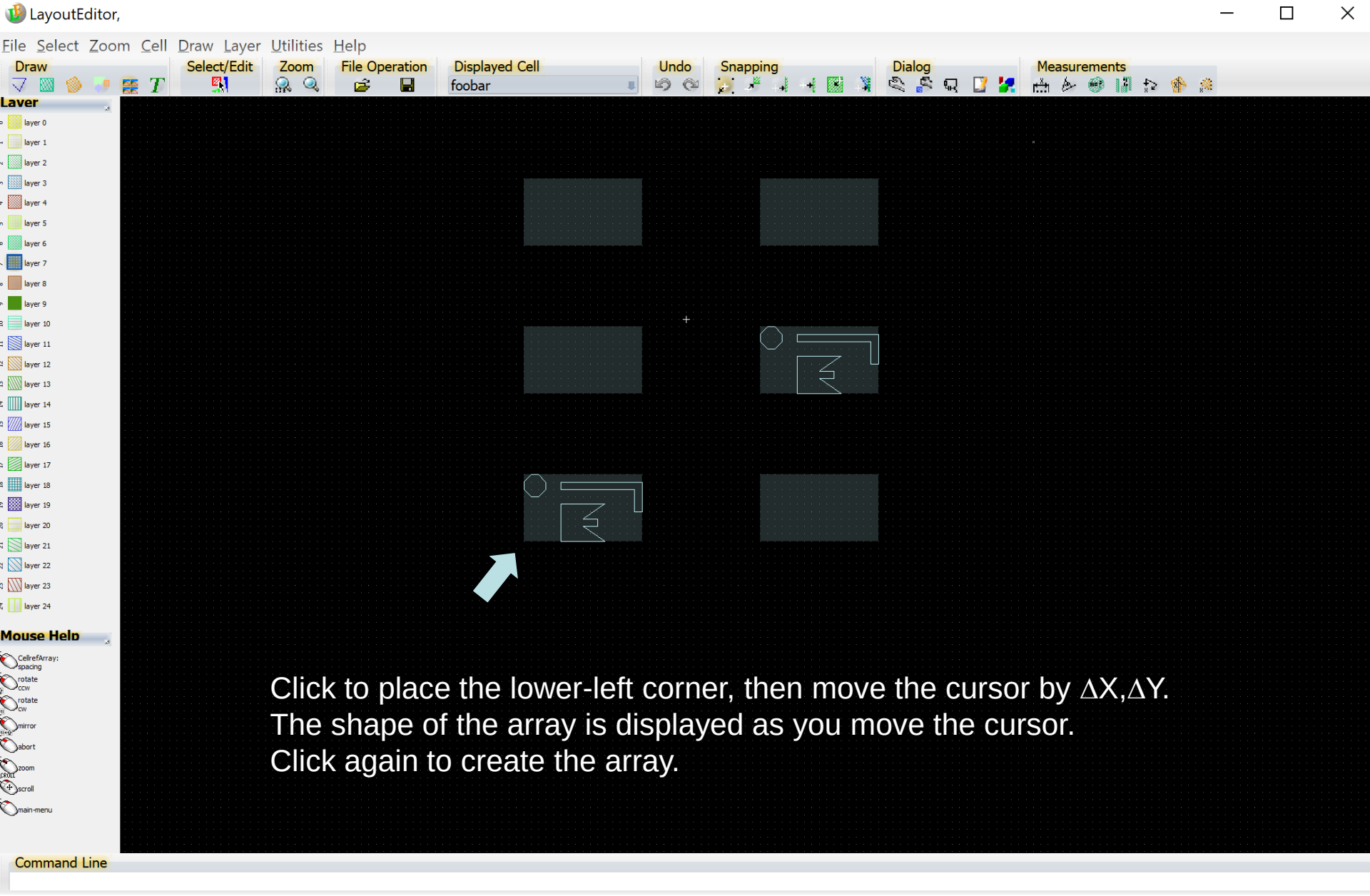


Now let’s create an ARRAY of the cell “foo”.

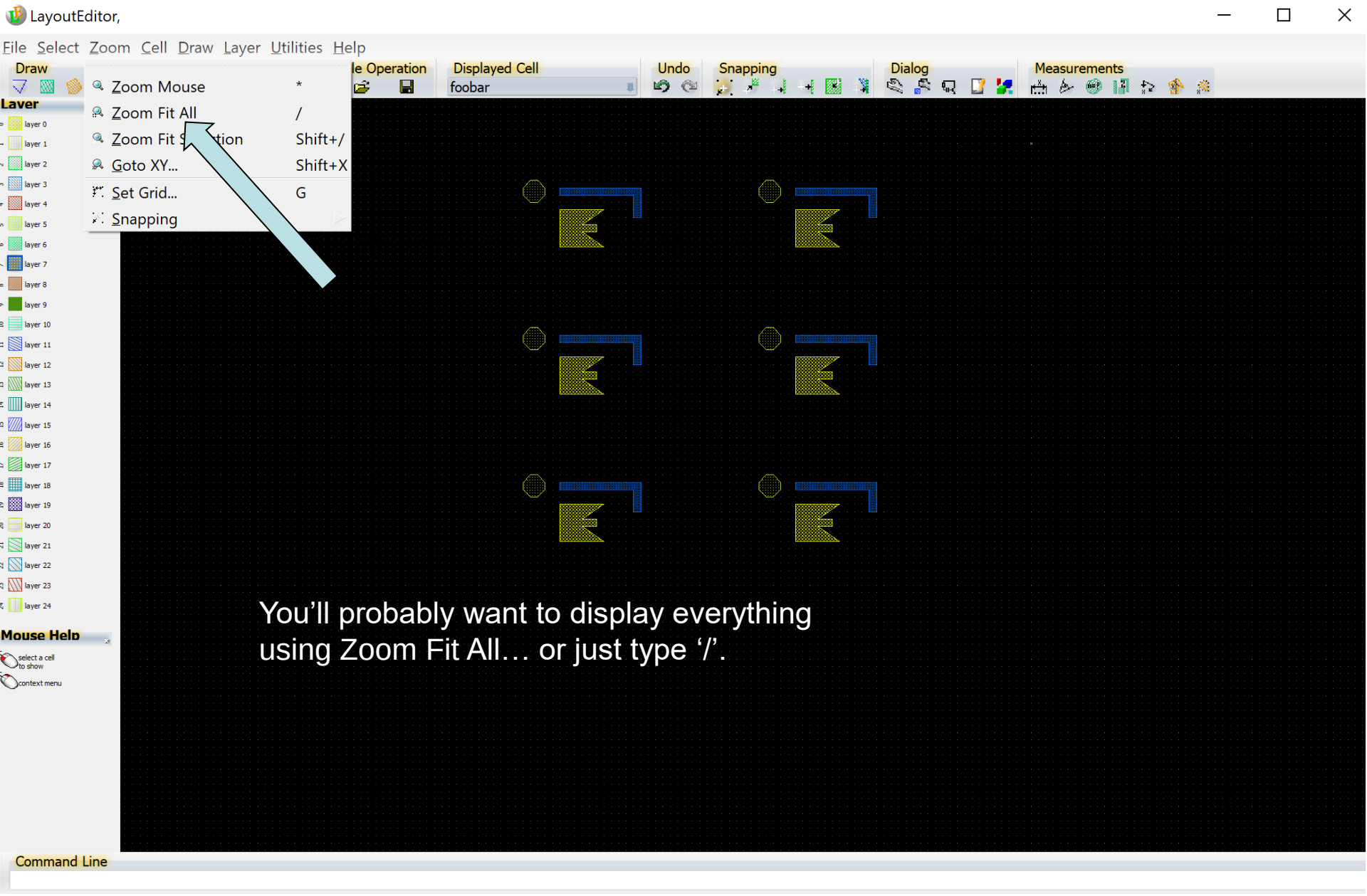
First use F5 to create a new cell,
then use F4 to name it ‘foobar’



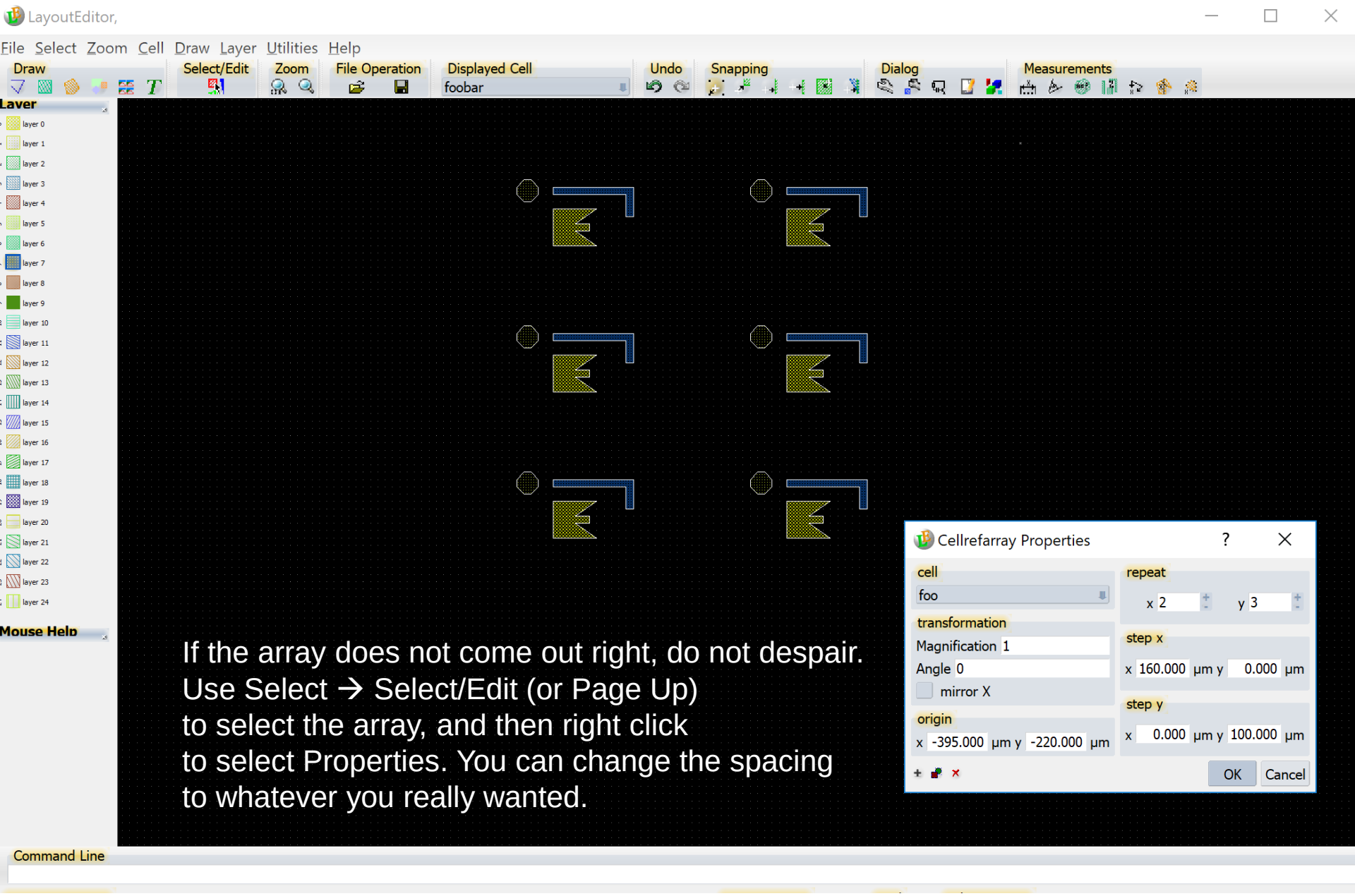
Click on “cell array” at the upper-left. A dialog box pops up, asking you to choose a cell and to choose the number of rows and columns.



Click to place the lower-left corner, then move the cursor by ΔX,ΔY.
The shape of the array is displayed as you move the cursor.
Click again to create the array.



You'll probably want to display everything using Zoom Fit All… or just type '/'.



If the array does not come out right, do not despair.
Use Select → Select/Edit (or Page Up)
to select the array, and then right click
to select Properties. You can change the spacing
to whatever you really wanted.

LayoutEditor,

File Select Zoom Cell Draw Layer Utilities Help

Draw | Select/Edit | Zoom | File Operation | Displayed Cell foobar | Undo | Snapping | Dialog | Measurements

Layer

layer 0, layer 1, layer 2, layer 3, layer 4, layer 5, layer 6, layer 7, layer 8, layer 9, layer 10, layer 11, layer 12, layer 13, layer 14, layer 15, layer 16, layer 17, layer 18, layer 19, layer 20, layer 21, layer 22, layer 23, layer 24

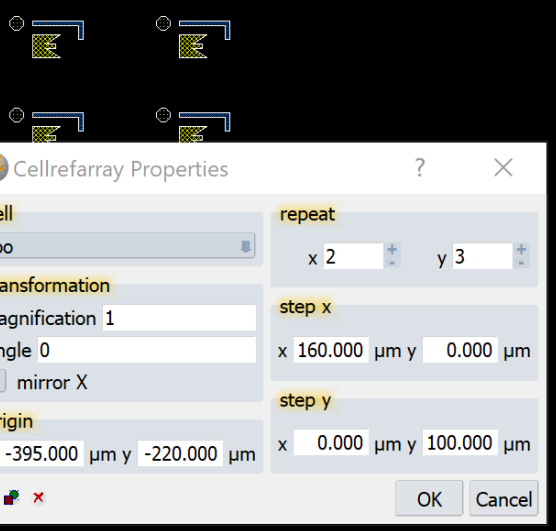
Mouse Help

BUT FIRST, A WARNING ABOUT A BUG IN LAYOUT

Note that you can also change the magnification and angle of the array. Unfortunately, Layout has a bug which creates invalid GDS format if you do that.

DO NOT CHANGE MAGNIFICATION OR ANGLE HERE.

Instead, you can change the magnification and angle of a *cell* reference, then use that cell as the element of an array. No problem!



This bug will show up as a fault in BEAMER, causing distorted or missing patterns. If you run into this bug (because of some else's dopey design) then you can fix it with the utility "flatten".

Command Line

A REPETITIVE WARNING ABOUT A LAYOUT BUG

The CAD program "Layout" allows you to create rotated and scaled arrays, but the output GDS file is wrong. Beamer does not warn you about this problem, but instead will crash or spit out strange patterns.

One easy solution is to use rotated (or scaled) *cells* as elements of arrays, instead of using the array's attributes.

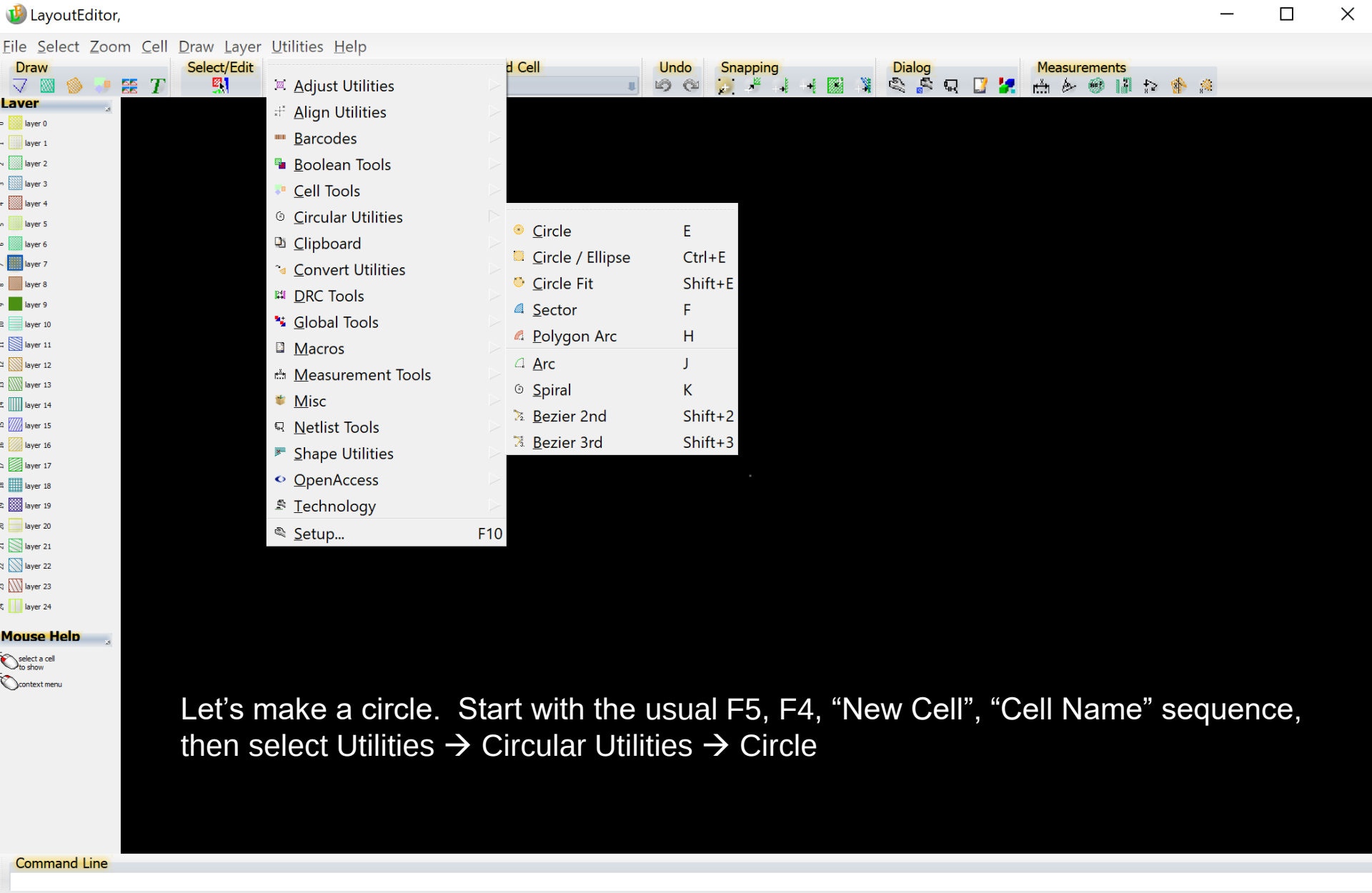
Another solution is to use the utility "flatten" to avoid these bugs. Simply run your_file.gds through flatten with

```
flatten your_file.gds cell_name
```

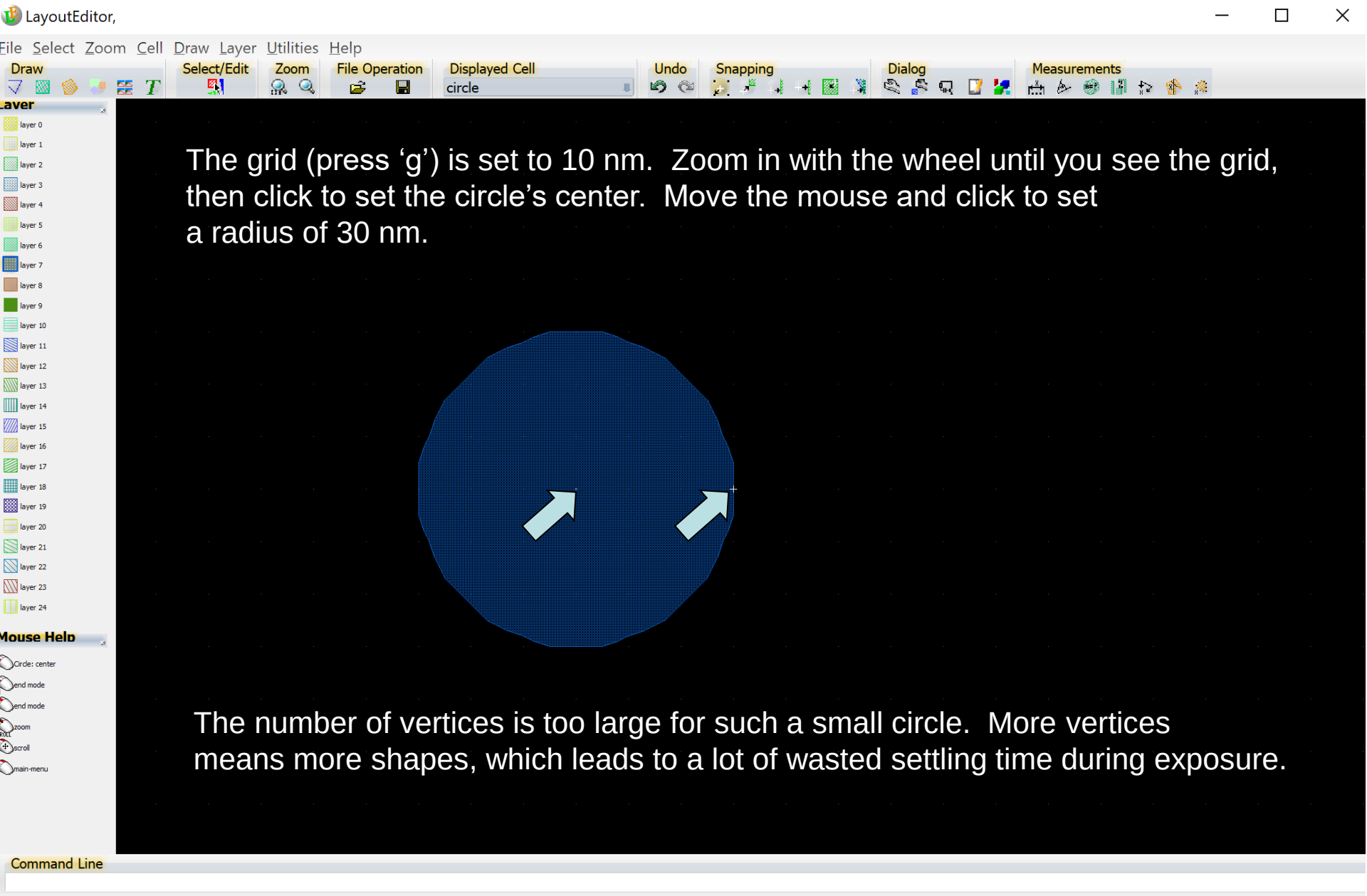
which creates the output file "flat.gds".

If you use Layout to create arrays that are both scaled *and* rotated, then that is too crazy for flatten to fix just yet.

AND NOW WE RETURN TO THE TUTORIAL…

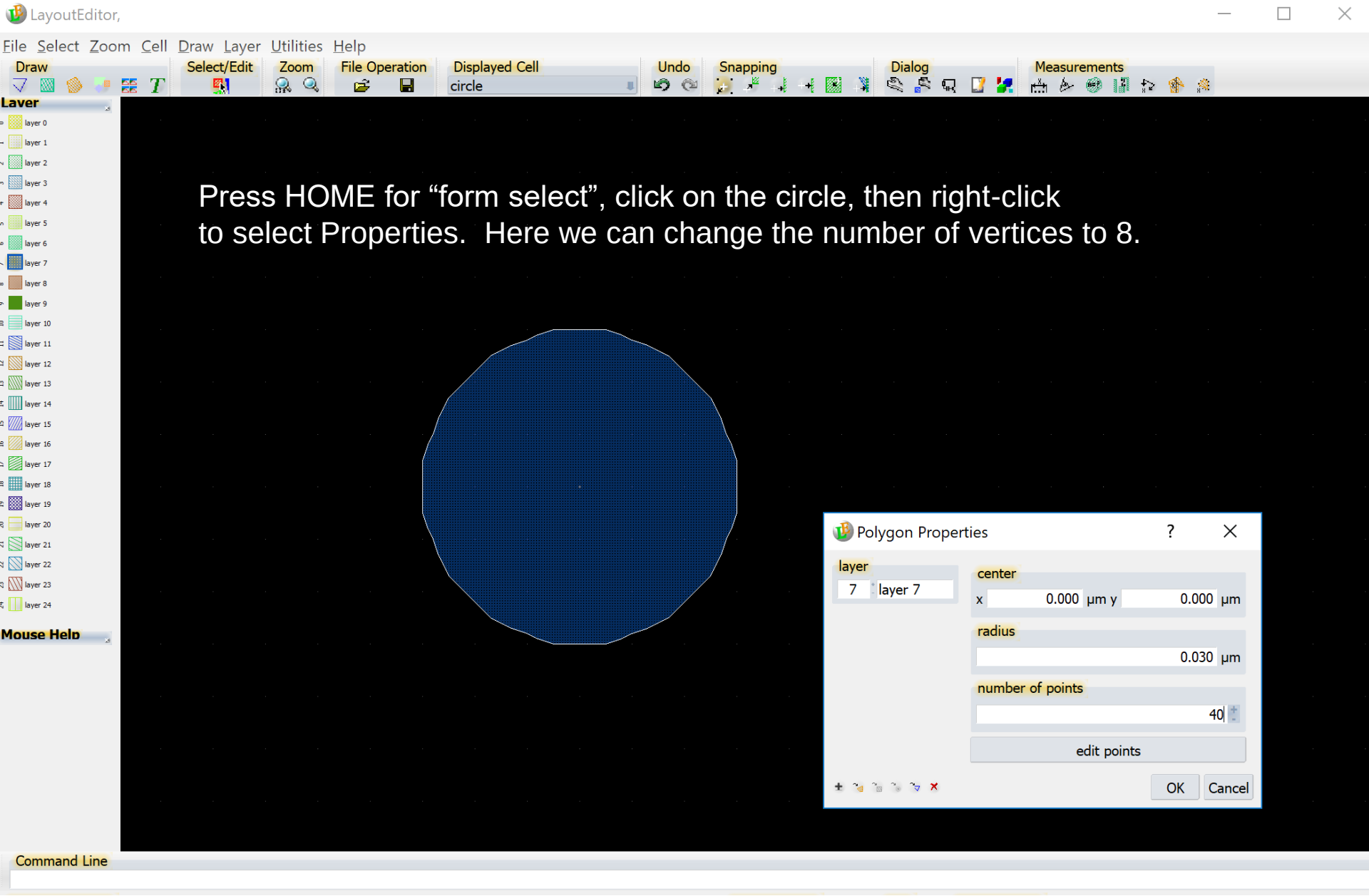


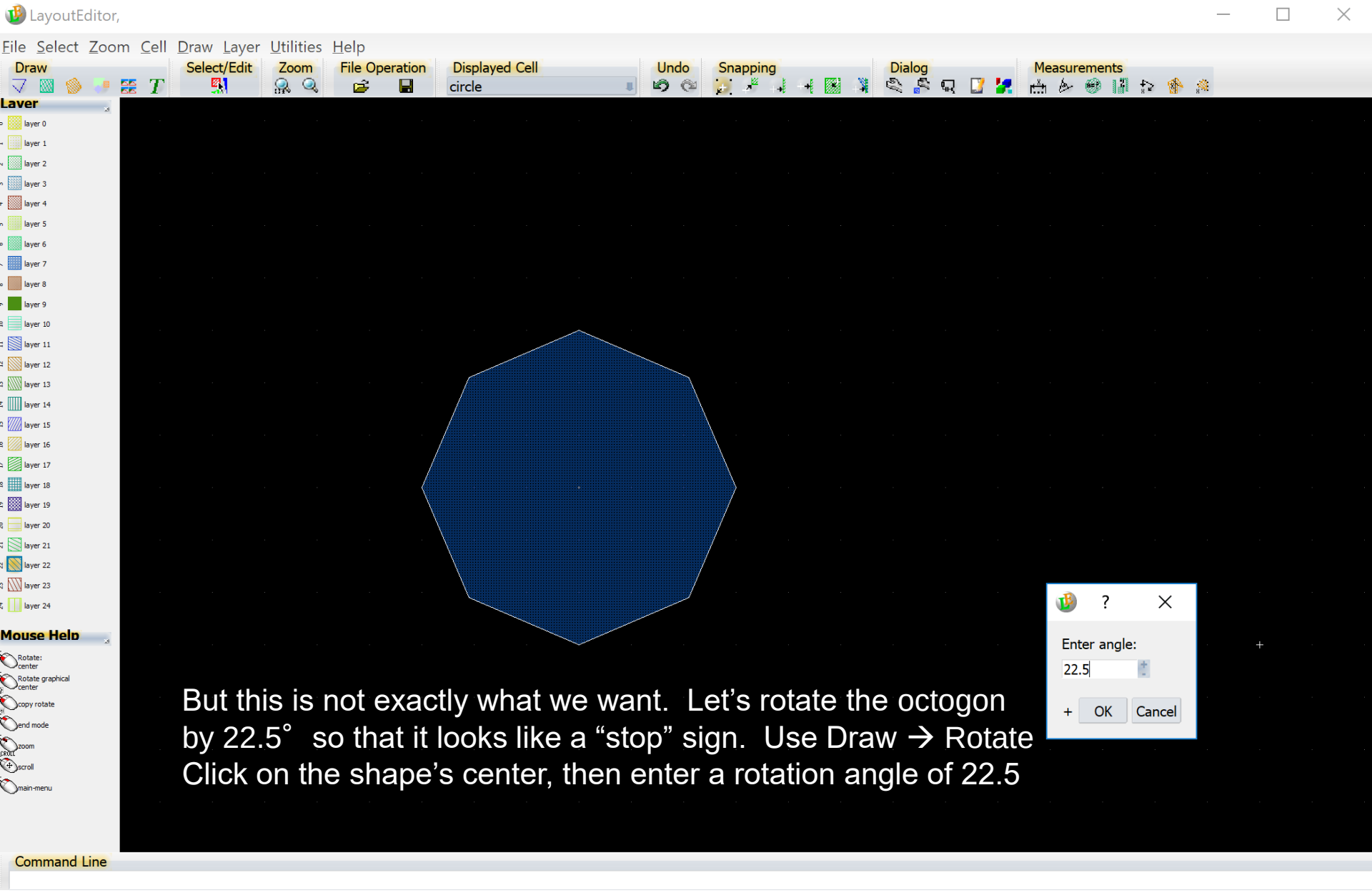
Let's make a circle. Start with the usual F5, F4, "New Cell", "Cell Name" sequence, then select Utilities → Circular Utilities → Circle



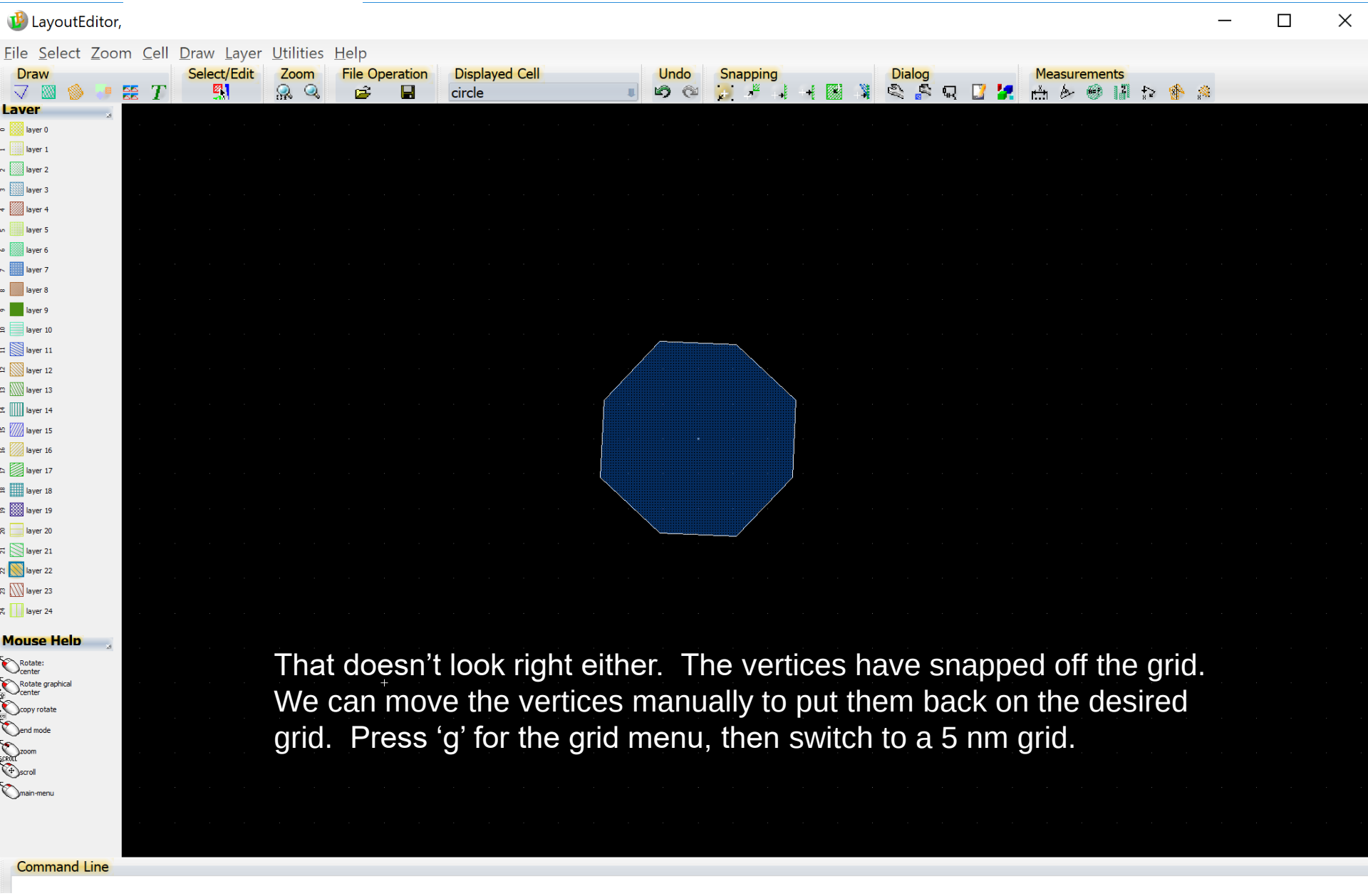
The grid (press ‘g’) is set to 10 nm. Zoom in with the wheel until you see the grid, then click to set the circle’s center. Move the mouse and click to set a radius of 30 nm.

The number of vertices is too large for such a small circle. More vertices means more shapes, which leads to a lot of wasted settling time during exposure.

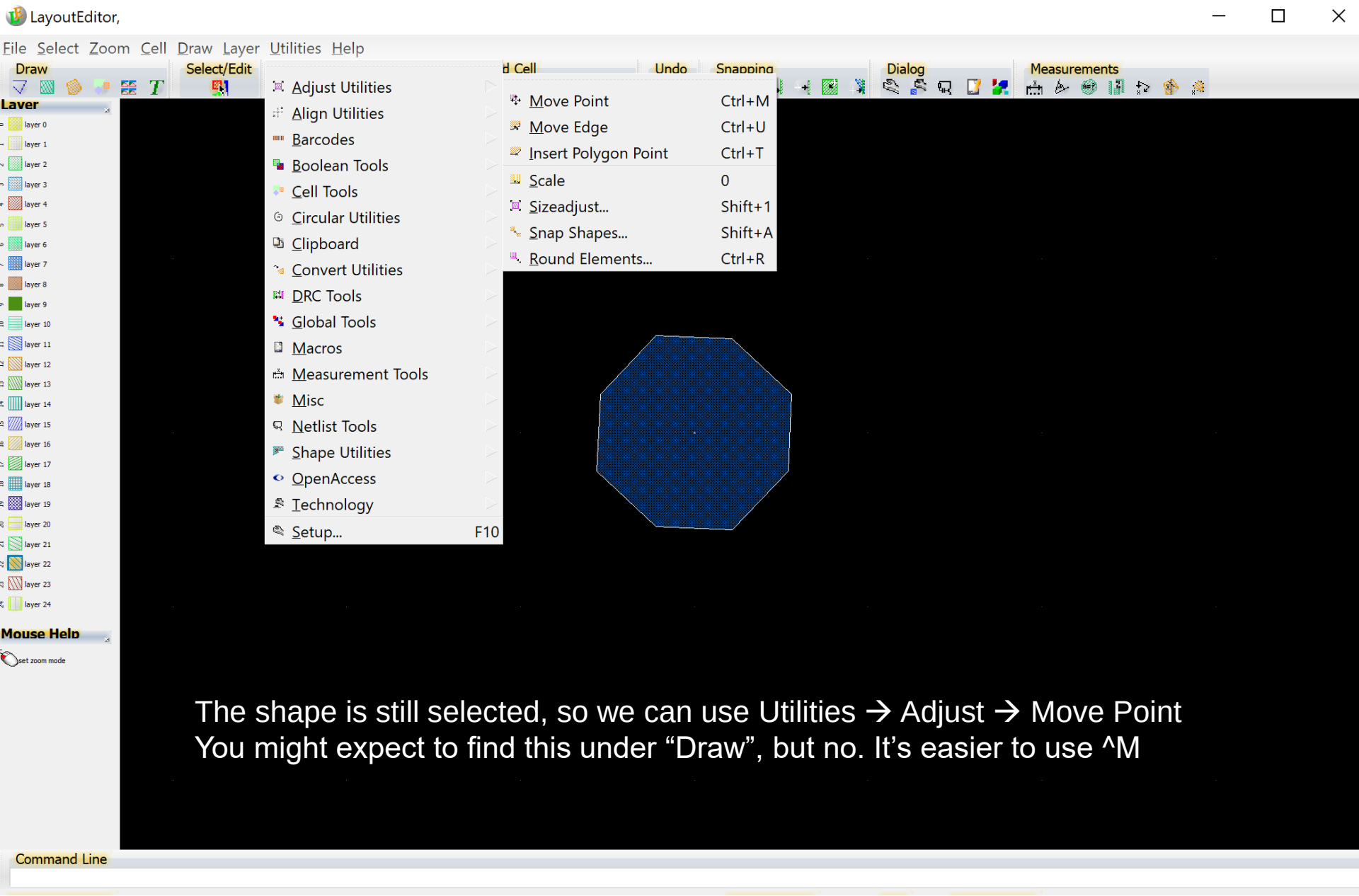

LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
circle
Undo
Snapping
Dialog
Measurements
Layer
Mouse Help
Press HOME for “form select”, click on the circle, then right-click
to select Properties. Here we can change the number of vertices to 8.
Polygon Properties
layer
7
layer 7
center
x 0.000 µm y 0.000 µm
radius
0.030 µm
number of points
40
edit points
OK
Cancel
Command Line



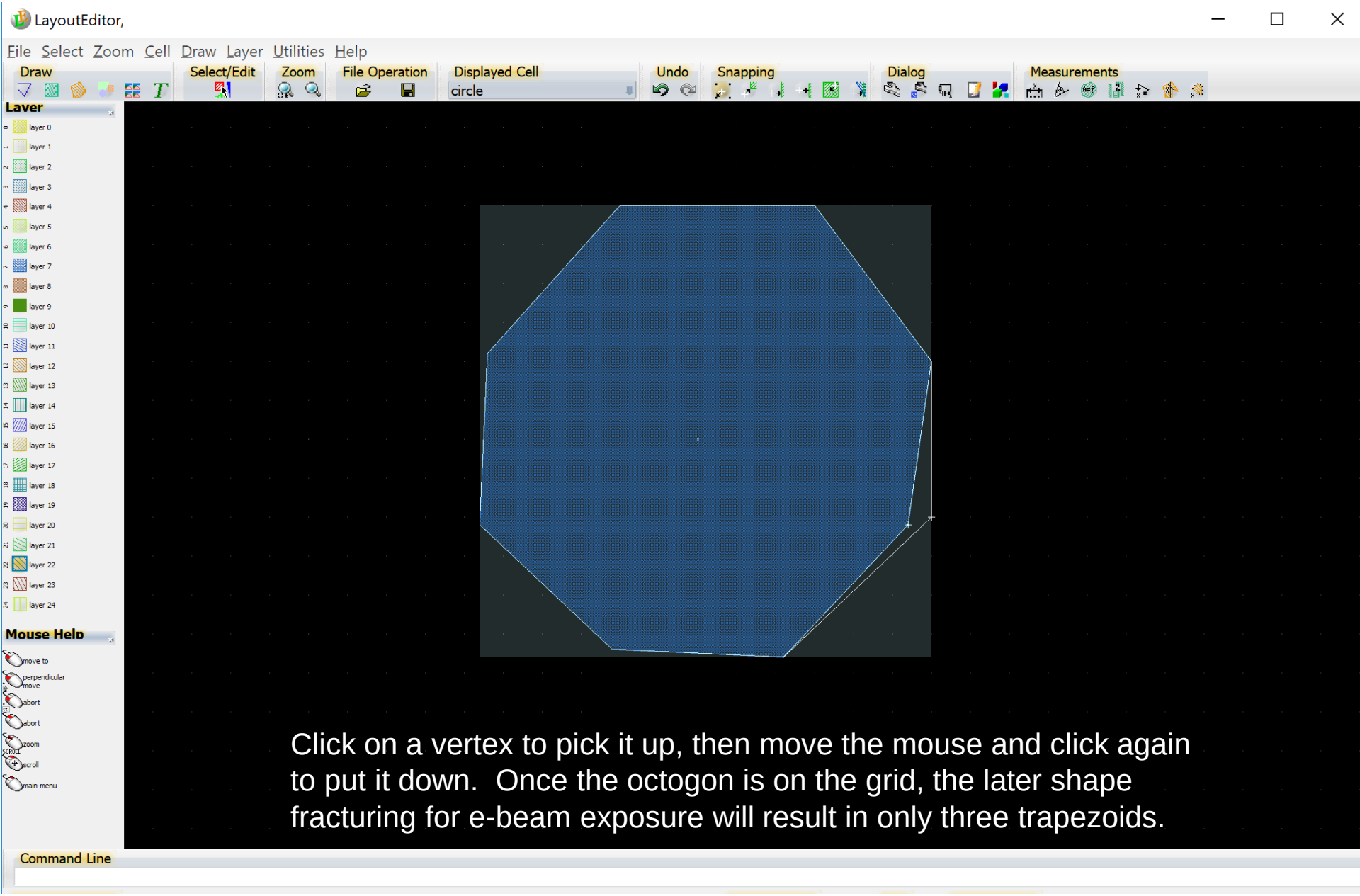
But this is not exactly what we want. Let's rotate the octogon by 22.5° so that it looks like a "stop" sign. Use Draw → Rotate Click on the shape's center, then enter a rotation angle of 22.5



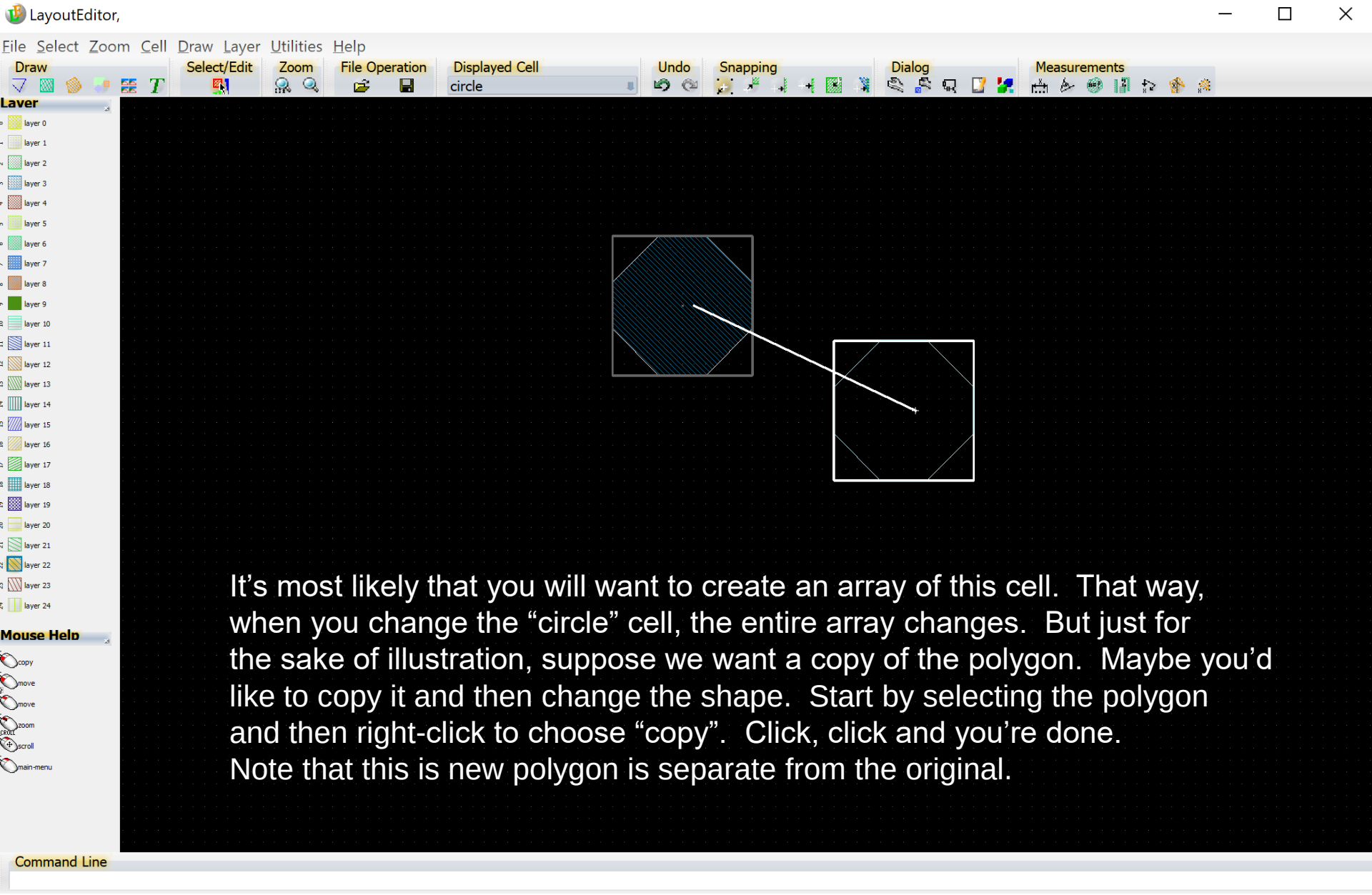
That doesn’t look right either. The vertices have snapped off the grid. We can move the vertices manually to put them back on the desired grid. Press ‘g’ for the grid menu, then switch to a 5 nm grid.



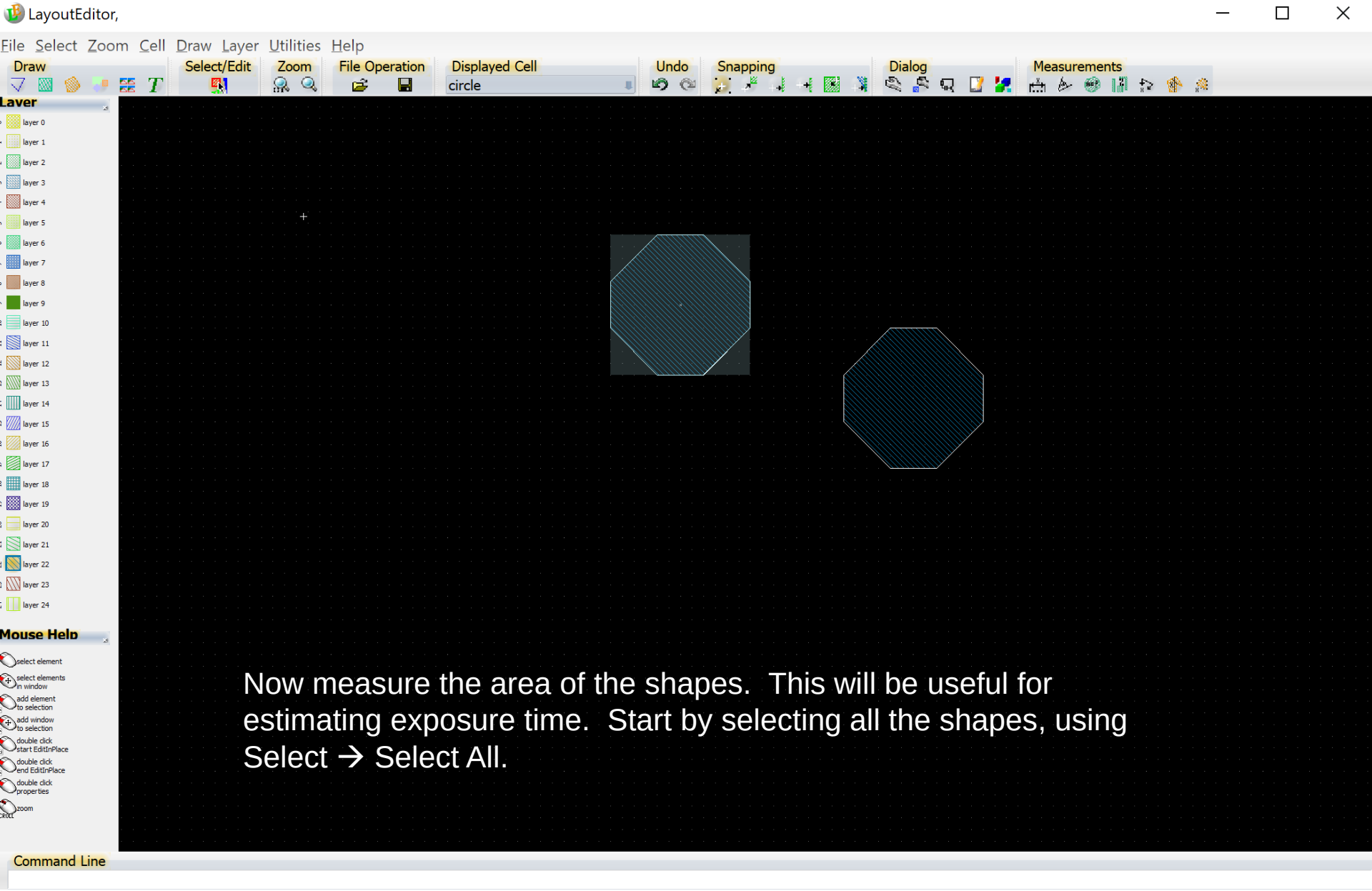
The shape is still selected, so we can use Utilities → Adjust → Move Point
You might expect to find this under “Draw”, but no. It’s easier to use ^M



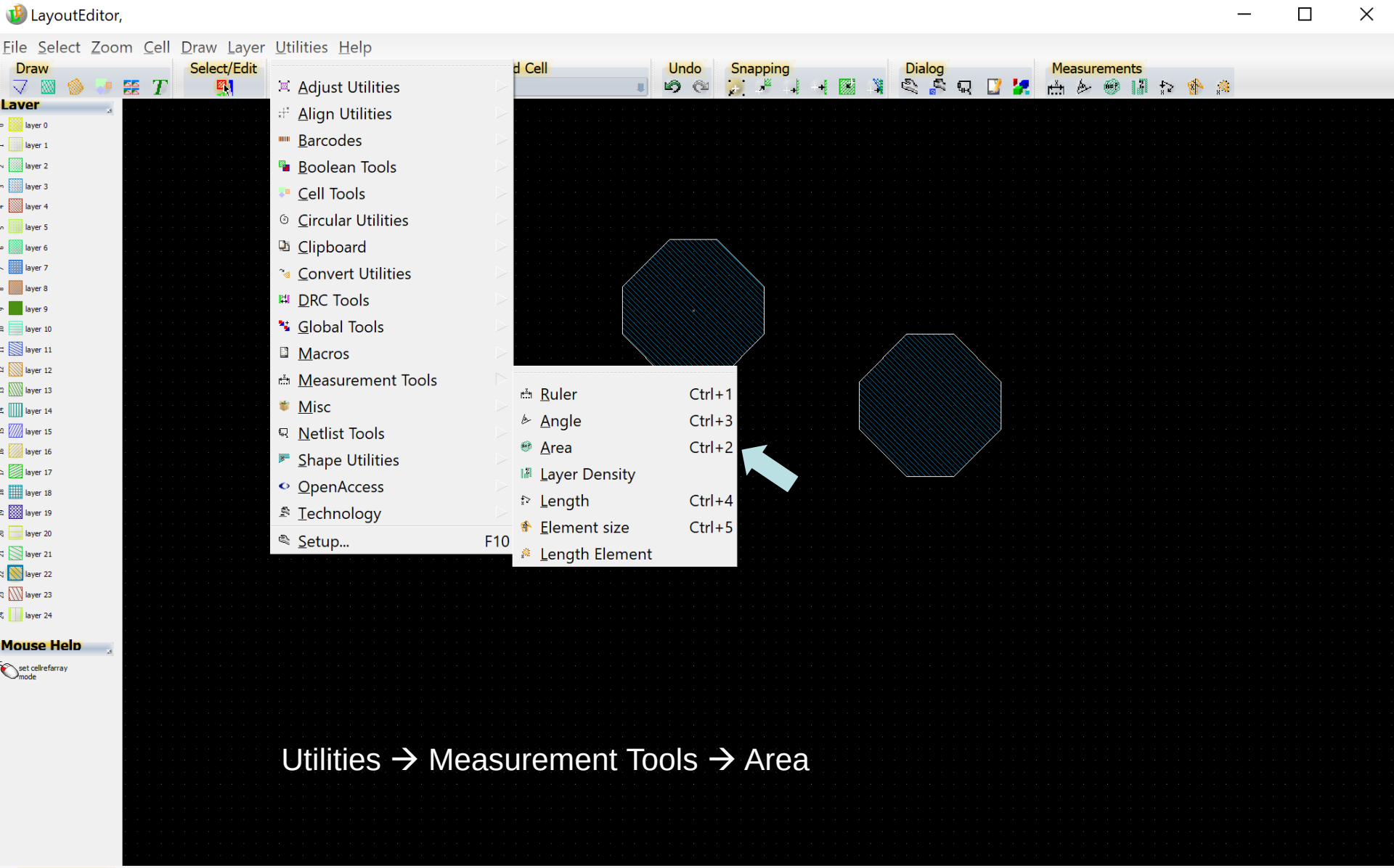
Click on a vertex to pick it up, then move the mouse and click again to put it down. Once the octogon is on the grid, the later shape fracturing for e-beam exposure will result in only three trapezoids.



It's most likely that you will want to create an array of this cell. That way, when you change the "circle" cell, the entire array changes. But just for the sake of illustration, suppose we want a copy of the polygon. Maybe you'd like to copy it and then change the shape. Start by selecting the polygon and then right-click to choose "copy". Click, click and you're done. Note that this is new polygon is separate from the original.



Now measure the area of the shapes. This will be useful for estimating exposure time. Start by selecting all the shapes, using Select → Select All.

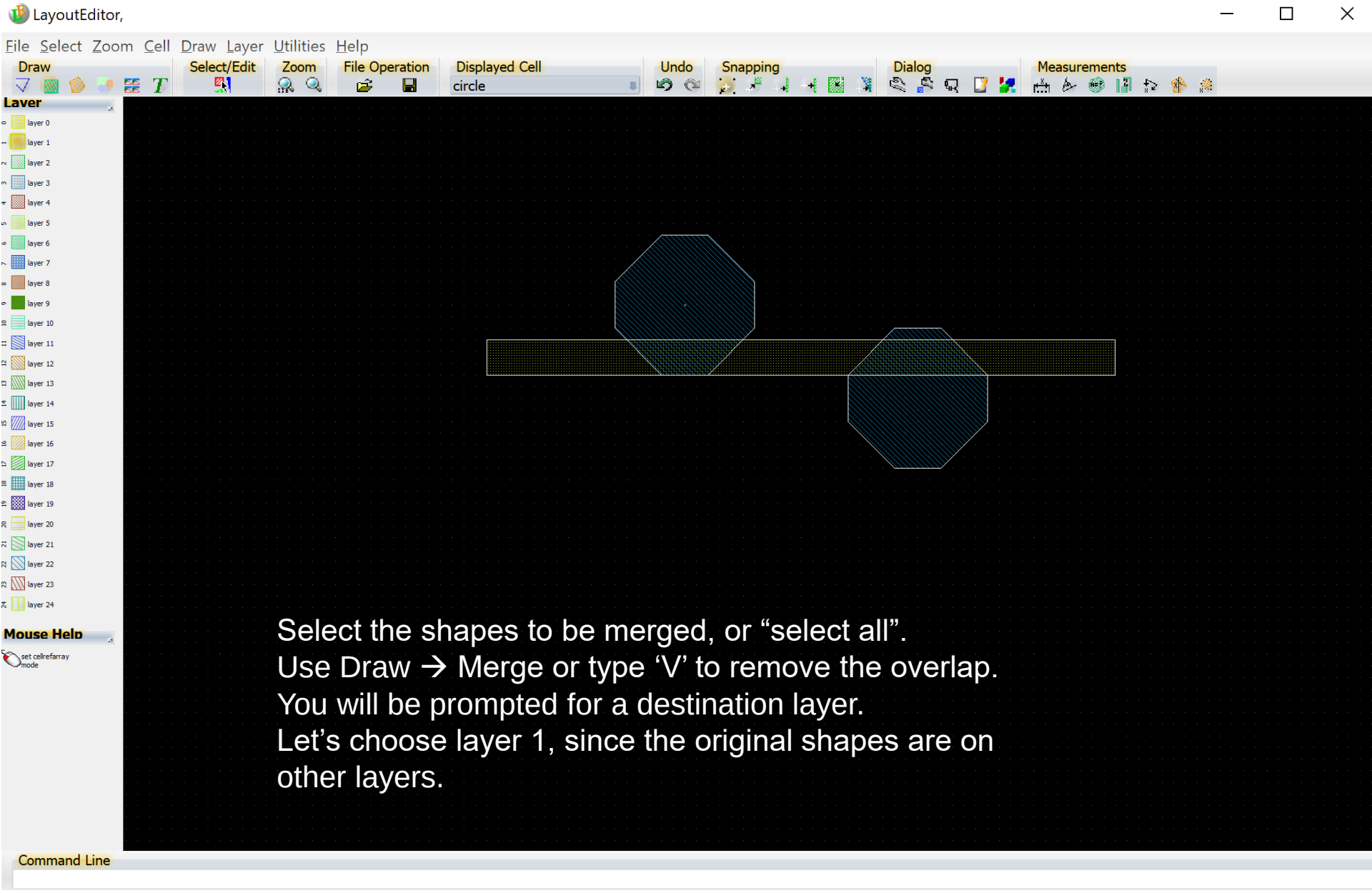


Utilities → Measurement Tools → Area

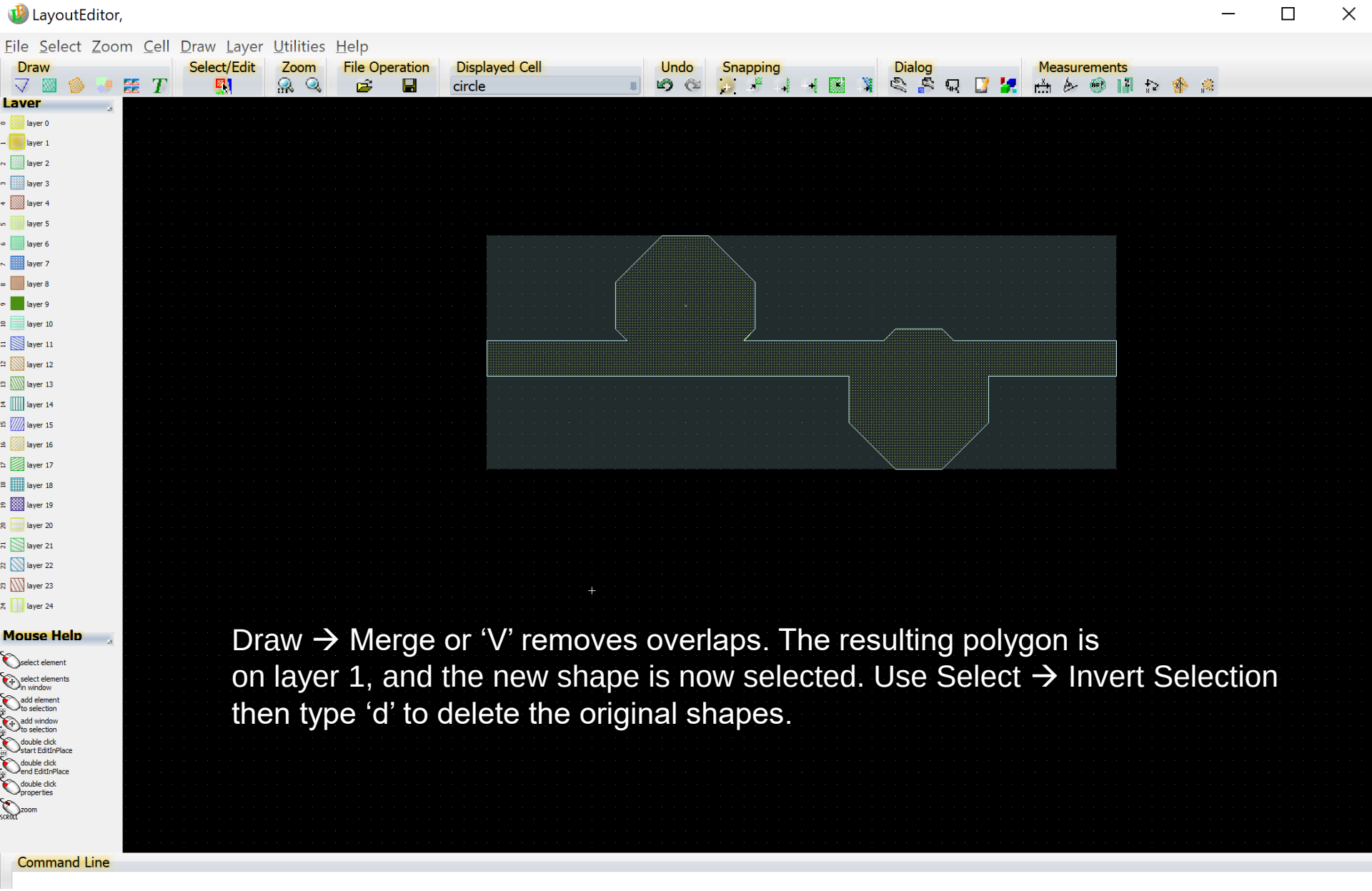
Overlap removal

Use the “merge” function to eliminate overlaps, thereby avoiding double exposures.

(Alternatively, you could use Beamer to remove all overlaps; but then you would lose all dose assignments.)



Select the shapes to be merged, or “select all”.
Use Draw → Merge or type ‘V’ to remove the overlap.
You will be prompted for a destination layer.
Let’s choose layer 1, since the original shapes are on other layers.



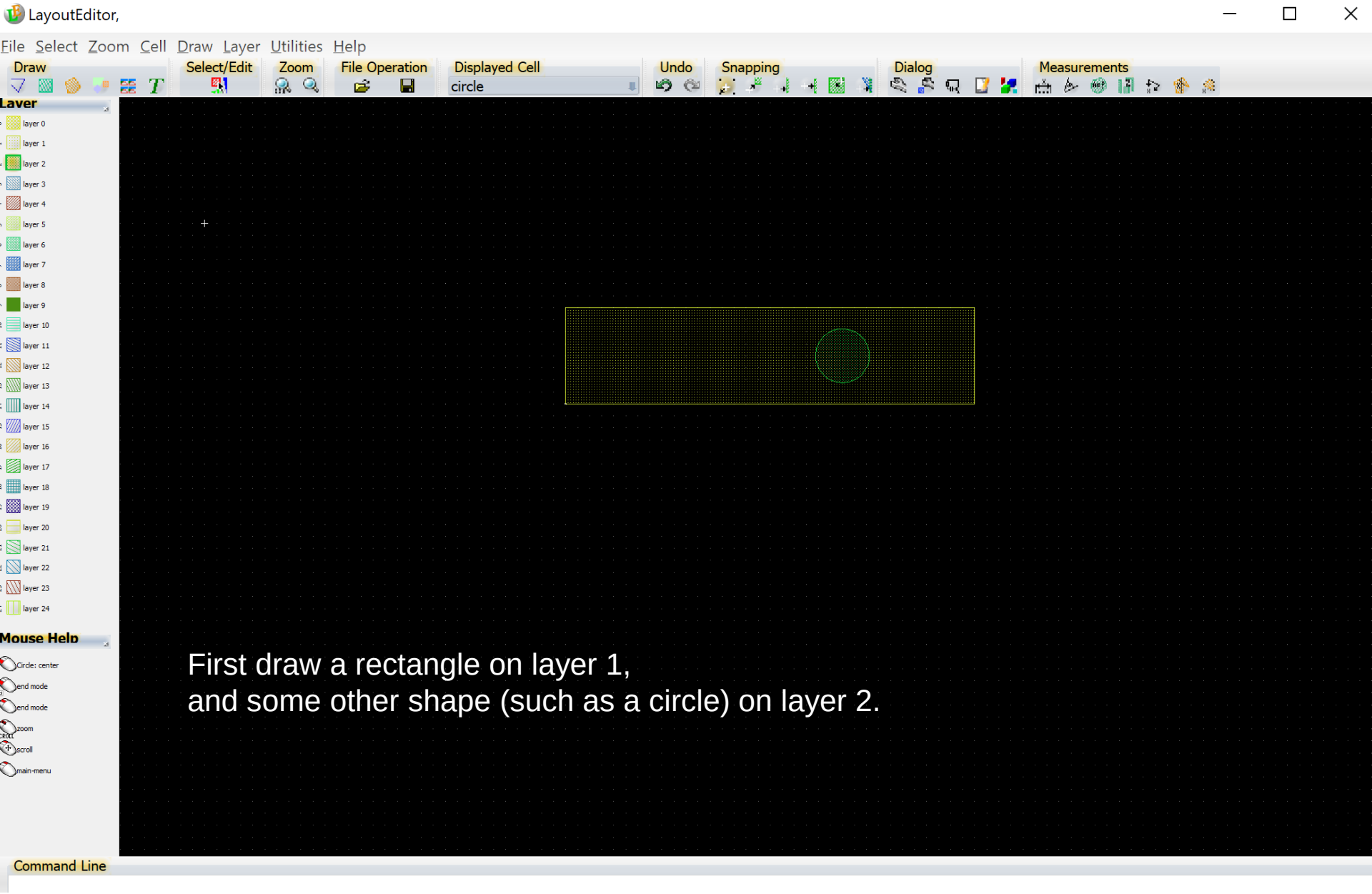
Draw → Merge or ‘V’ removes overlaps. The resulting polygon is on layer 1, and the new shape is now selected. Use Select → Invert Selection then type ‘d’ to delete the original shapes.

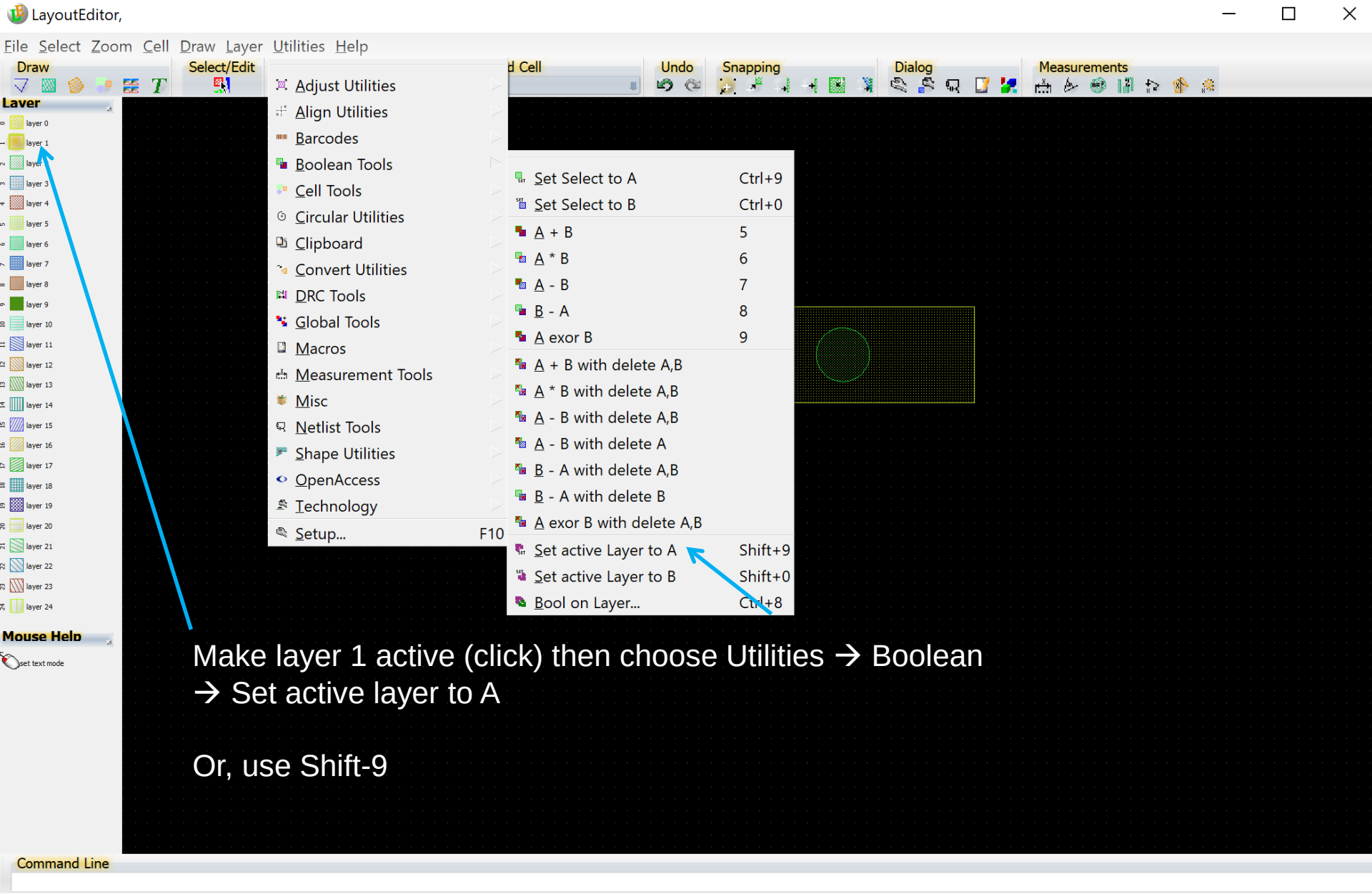
Boolean operations

Logical operations such as “and”, “or”, and “not”,
as well as +/-, are very useful for designing complex designs.

Layout will let you perform Boolean operations on individual shapes, but this example shows you how to do these operations on entire layers.

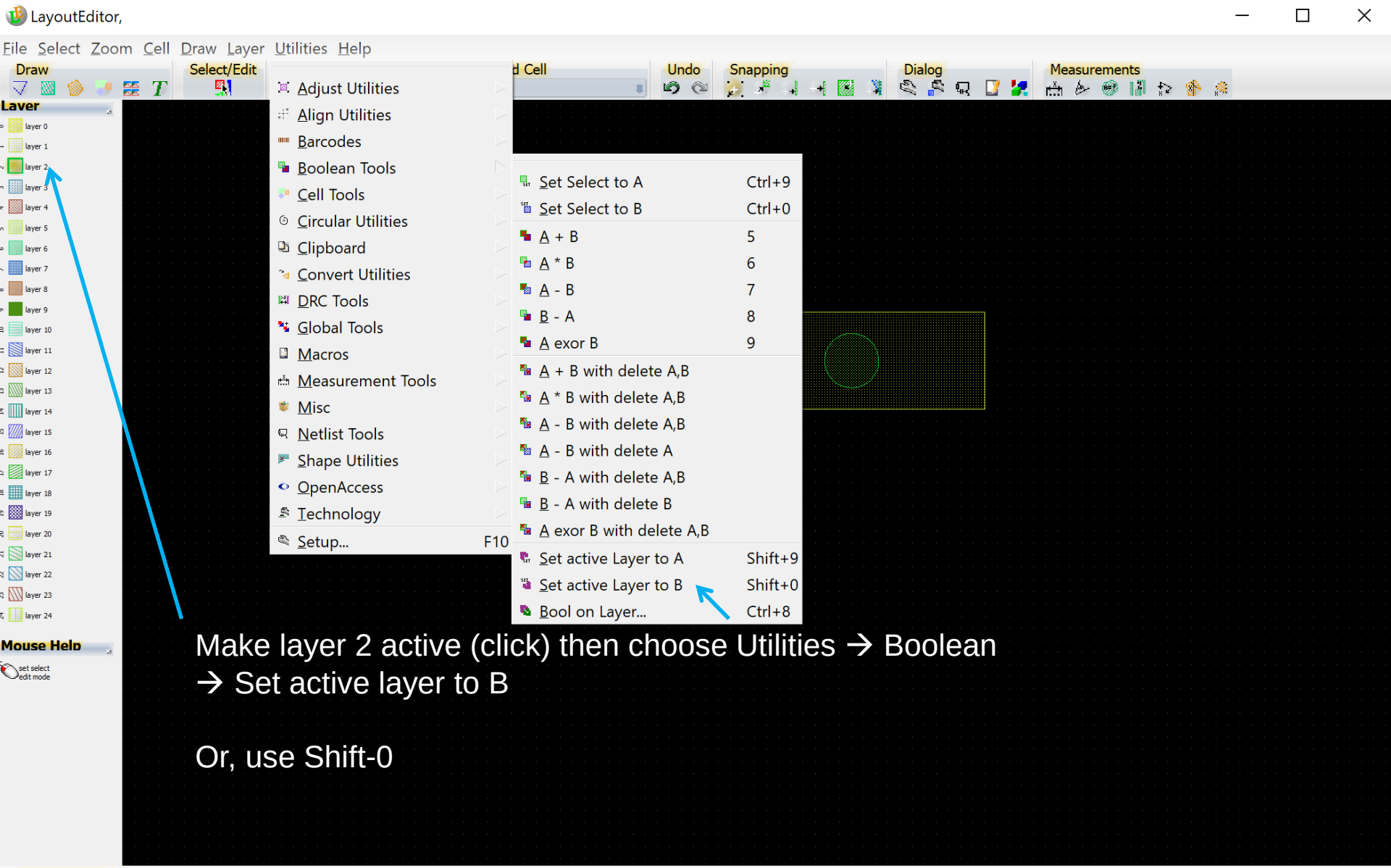
First we will assign the label “A” to one layer, and the label “B” to another layer. We will select a third layer to hold the results, and then we will perform an operation such as A – B.


LayoutEditor,
File Select Zoom Cell Draw Layer Utilities Help
Draw
Select/Edit
Zoom
File Operation
Displayed Cell
circle
Undo
Snapping
Dialog
Measurements
Layer
layer 0
layer 1
layer 2
layer 3
layer 4
layer 5
layer 6
layer 7
layer 8
layer 9
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15
layer 16
layer 17
layer 18
layer 19
layer 20
layer 21
layer 22
layer 23
layer 24
Mouse Help
Circle: center
end mode
end mode
zoom
scroll
main-menu
First draw a rectangle on layer 1,
and some other shape (such as a circle) on layer 2.
Command Line



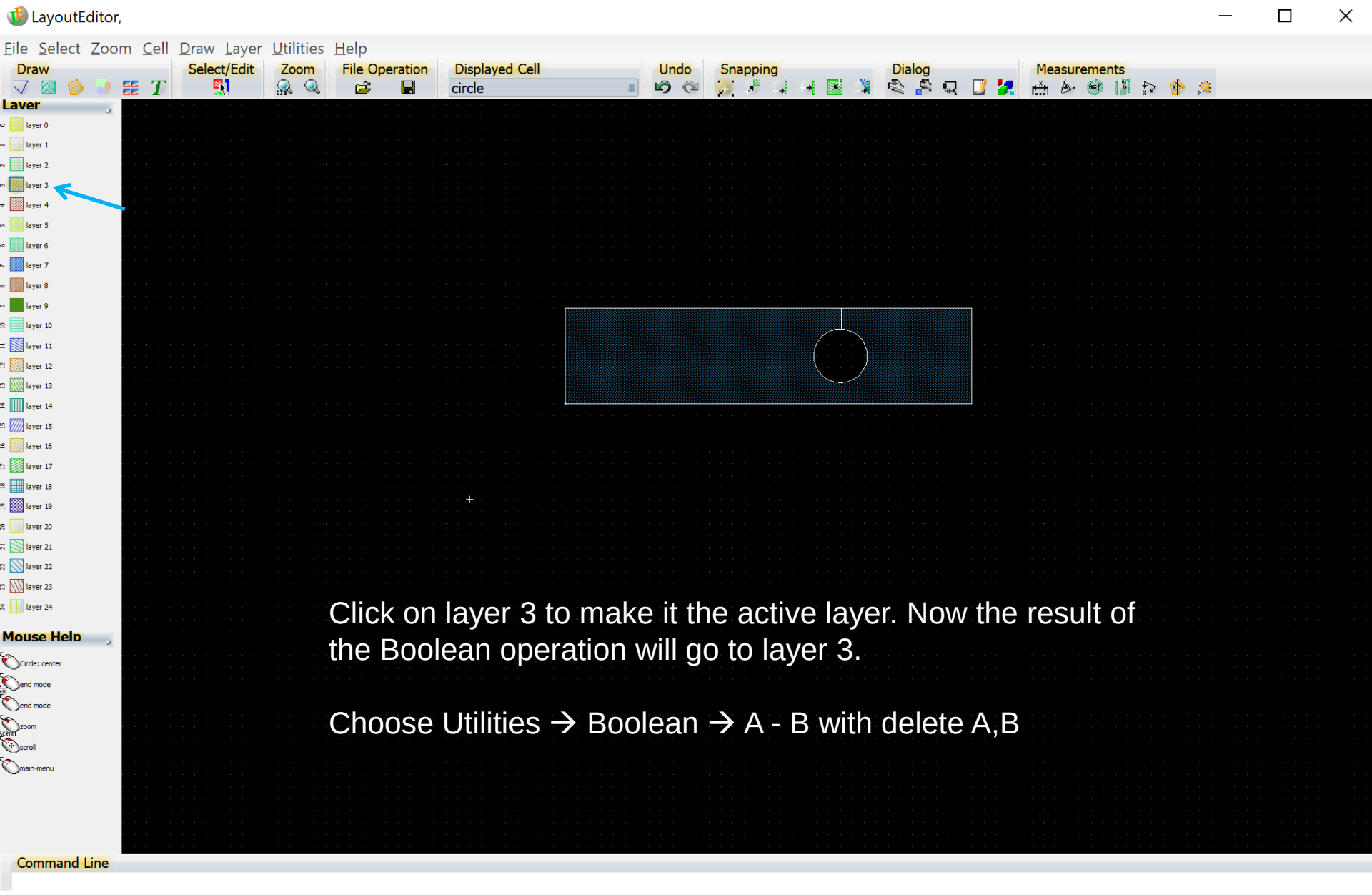
Make layer 1 active (click) then choose Utilities → Boolean → Set active layer to A

Or, use Shift-9



Make layer 2 active (click) then choose Utilities → Boolean → Set active layer to B

Or, use Shift-0



Click on layer 3 to make it the active layer. Now the result of the Boolean operation will go to layer 3.

Choose Utilities → Boolean → A - B with delete A,B

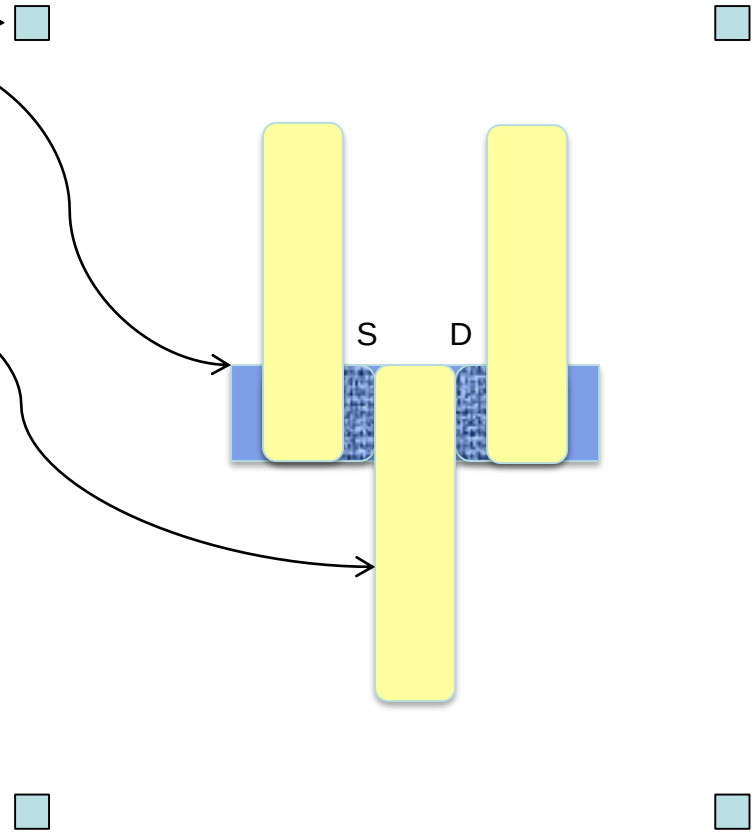
Homework: Design a simple transistor:

Put square alignment marks on layer 0.

Draw the mesa (silicon island) on layer 1.

Source and drain go on layer 2.

Metal pads go on layer 3.



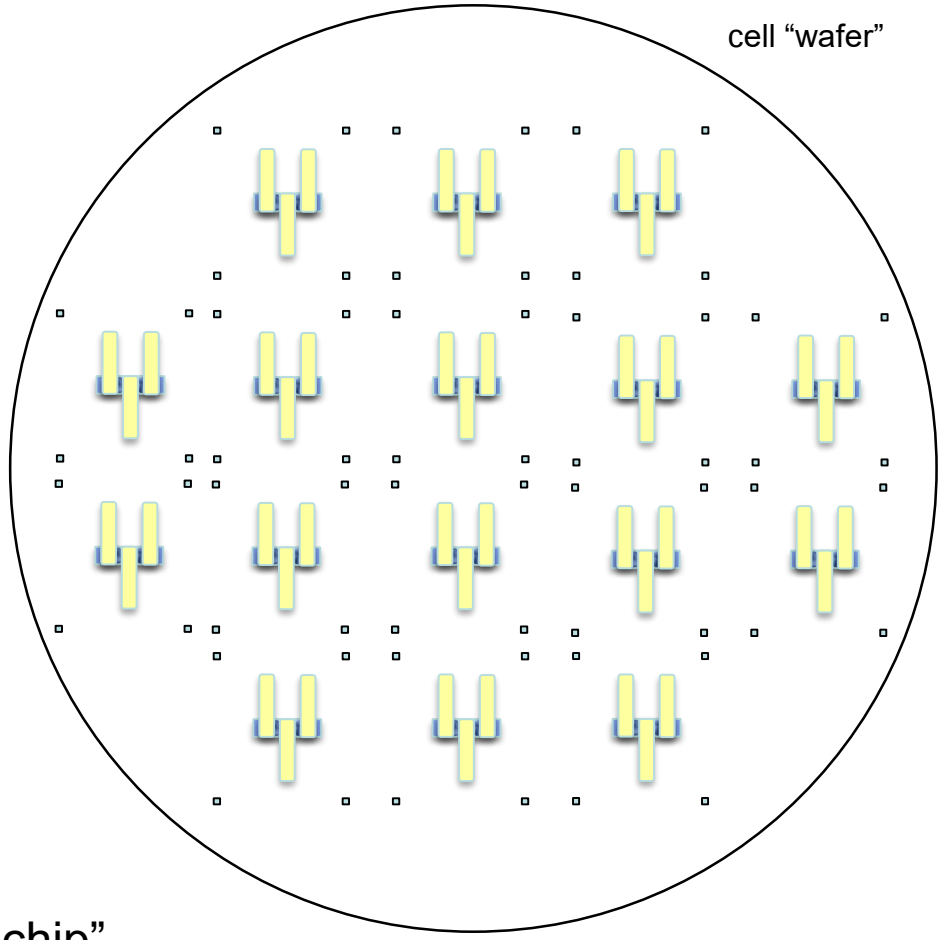
Alignment marks should be 20 um squares, in the corners. The center of each mark should fall on a 10 um grid; that is, the coordinate of each mark should be a multiple of 10 um.

Sometimes it is handy to mock up the full wafer by creating a higher-level cell.

But you would not print this version with the e-beam writer.

Instead, the e-beam writer will step out the unit cell.

Do not start thinking that you can simplify the job by creating one gigantic “chip” that covers the wafer. There are several reasons why this is not a good strategy.



Optional subjects:

Algorithmic pattern generation

Using photos in CAD

(you can stop here if you are not interested)

Algorithmic CAD

You will find an example C program on sizzlorr, in /public

The program

write_gds_examples.c

can be compiled by copying this along with /public/makefile, then

make write_gds_examples

```
$
$ ls /public
astronaut.jpg  class.gds     ls.gpf         makefile  silicon_psf.dat  write_gds_examples.c
cao.gds        gaas_psf.dat  macromacro.py  rings.c   wedge10.gpf
$
$
$
$ cp /public/write_gds_examples.c barf.c
$
$ cp /public/makefile .
$
$ gedit makefile
```

Copy the example to your directory (folder)

Copy the makefile to '.' meaning "here"

Edit the makefile

```
rings: rings.o
        gcc rings.o -lc -lm -o ring

rings.o: rings.c
        gcc -c rings.c

barf: barf.c
        gcc -g -o barf barf.c -lm -lc -lgds
```

We can delete these 5 lines

and replace "make_gds_examples" with "barf"

```
$
$ ls /public
astronaut.jpg  class.gds     ls.gpf
cao.gds        gaas_psf.dat  macromacro
$
$
$
$ cp /public/write_gds_examples.c barf.
$
$ cp /public/makefile .
$
$ gedit makefile
$
$
$
$ gedit barf.c
```

barf.c (~) - gedit

```
/*-----------------------------------------------------------------------------------------*/
/*-----------------------------------------------------------------------------------------*/


main( int argc, char *argv[] )
    {

    int fd,     // output gds file descriptor
        x[5],
        y[5];

    fd = open( "stuff.gds", O_CREAT | O_TRUNC | O_WRONLY, S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH );

    if( fd <= 0 ) BAILOUT( "UNABLE TO OPEN OUTPUT FILE" );

    // start the gds library with HEADER, BGNLIB, LIBNAME, and UNITS

    gds_create_lib( fd, "dogs", 0.001 /* um per bit */ );
```

Make whatever changes you like to the C program

```
    gds_write_bgnstr( fd );
    gds_write_strname( fd, "hotdogs" );

    //-----------------------------------------------------------------------------
    // create a polygon

    gds_write_boundary( fd );        // write just the token
    gds_write_layer( fd, 0 );        // layer 0, for example
    gds_write_datatype( fd, 1 );     // datatype 1, for example

    x[0] =    0;  y[0] =   0;        // signed four-byte integers
    x[1] =    0;  y[1] = 500;
    x[2] = 1000;  y[2] = 500;        // in this example 1 integer unit = 1 nm
    x[3] = 1000;  y[3] =   0;
    x[4] =    0;  y[4] =   0;        // required repetition of first point (yup, that's stupid)

    gds_write_xy( fd, x, y, 5 );     // polygon, four vertices, first vertex repeated => 5 points
    gds_write_endel( fd );           // end of element
```

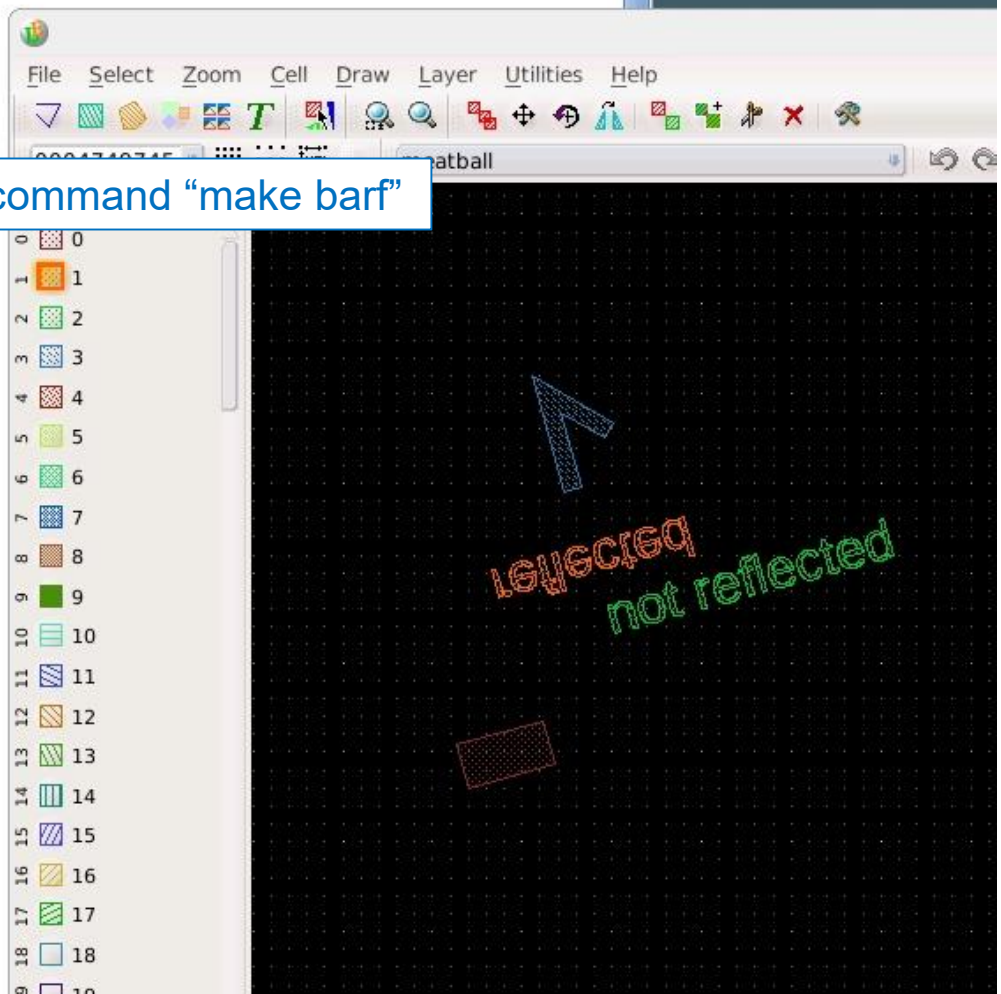
C Tab Width: 8 Ln 1, Col 1 INS

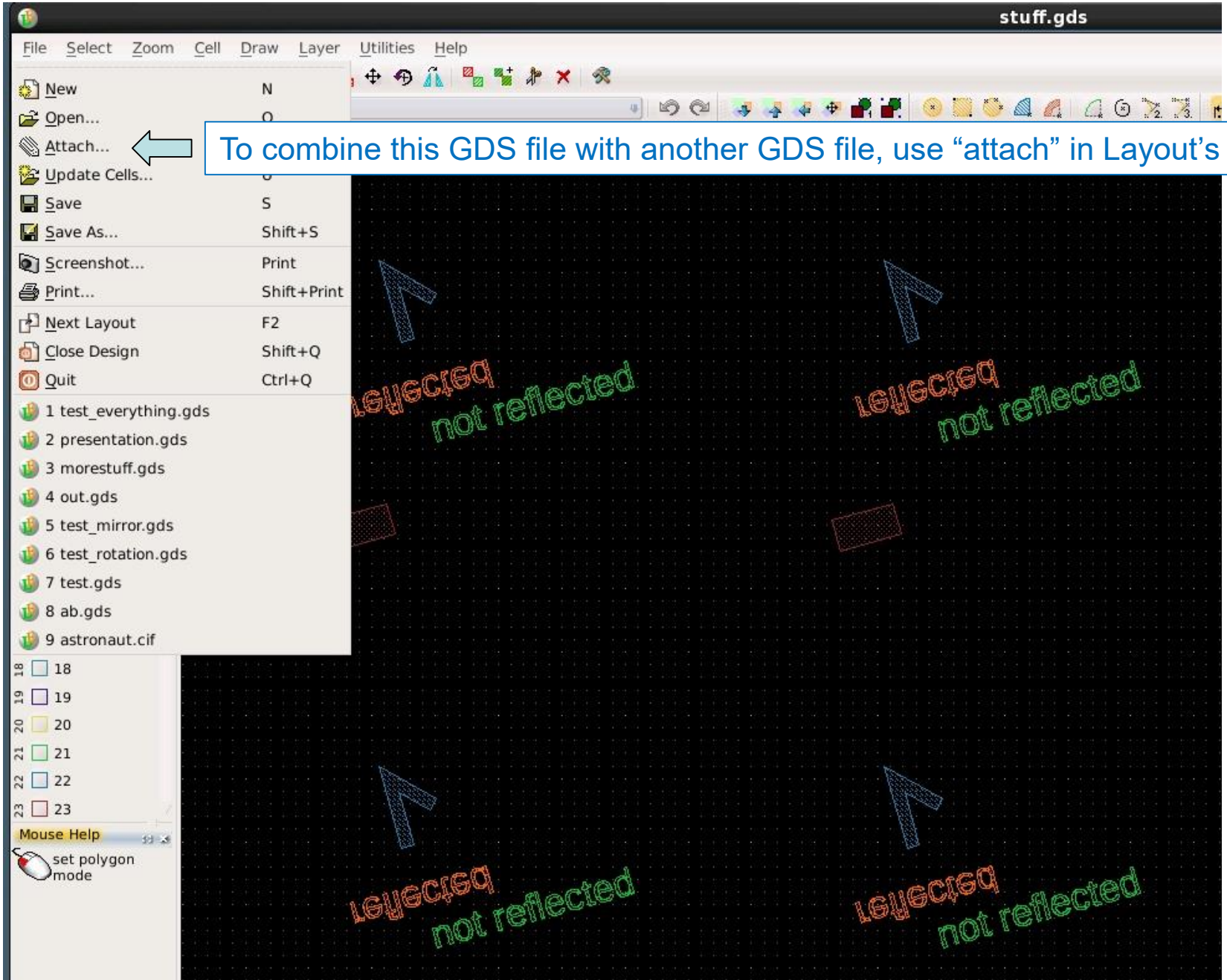
```
$
$ ls /public
astronaut.jpg  class.gds     ls.gpf         makefile  silicon_psf.dat  write_gds_examples.c
cao.gds        gaas_psf.dat  macromacro.py  rings.c   wedge10.gpf
$
$
$
$ cp /public/write_gds_examples.c barf.c
$
$ cp /public/makefile .
$
$ gedit makefile
$
$
$
$ gedit barf.c
$
$
$ make barf
gcc -g -o barf barf.c -lm -lc -lgds
$
$
$ ./barf

Done. Look at stuff.gds

$ layout stuff.gds
```

Compile barf.c with the command “make barf”

Run it by typing “barf”

Look at the result with Layout or any other CAD program





To combine this GDS file with another GDS file, use “attach” in Layout’s File menu

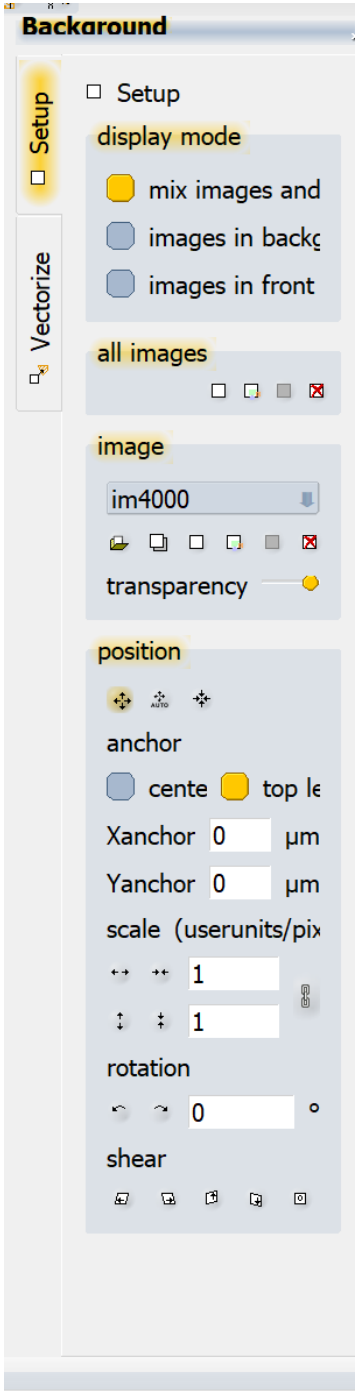
Using microscope images in CAD

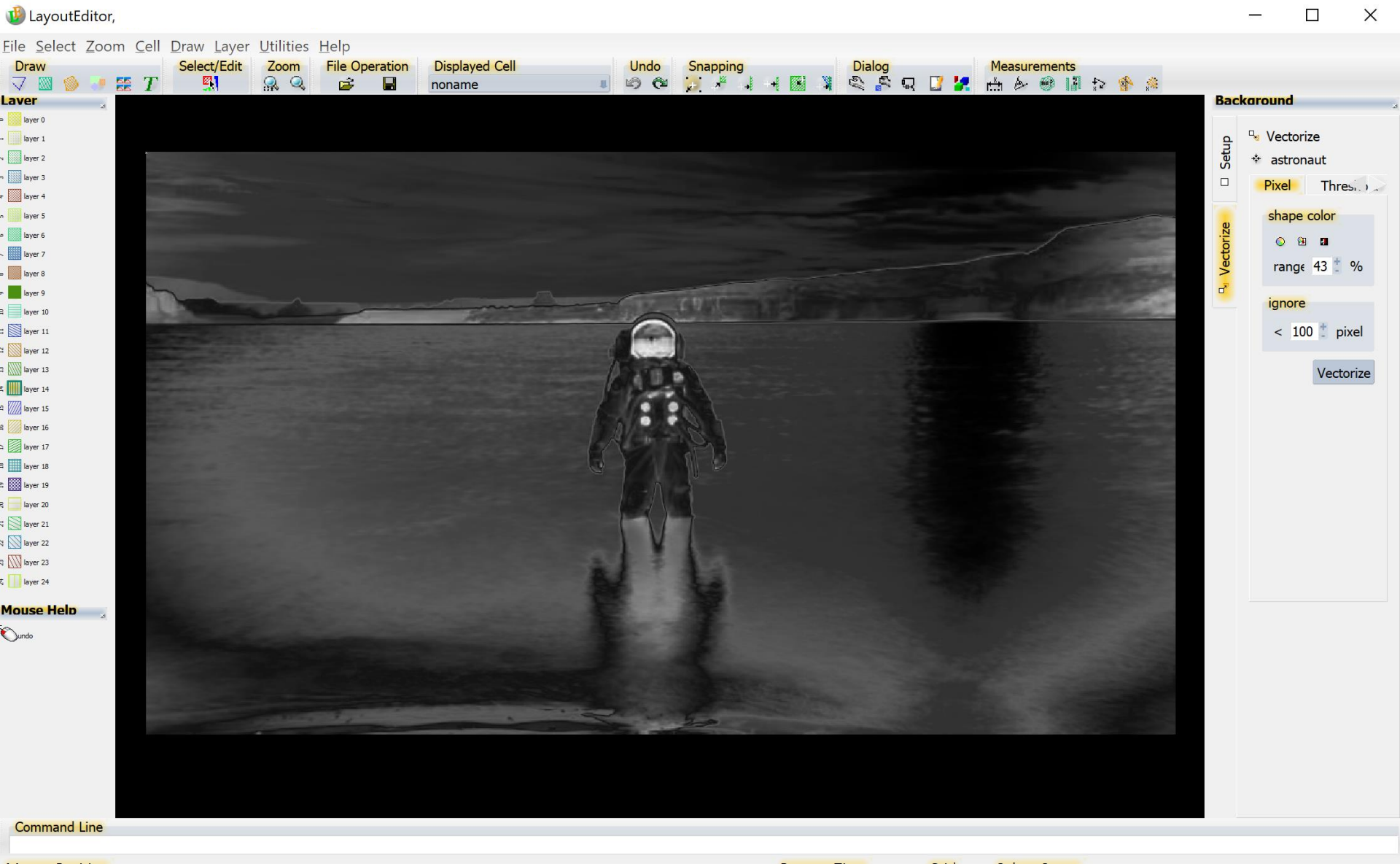
If you do not see the “background” panel on the right side, use the menu:

Utilities → Misc → Set background image

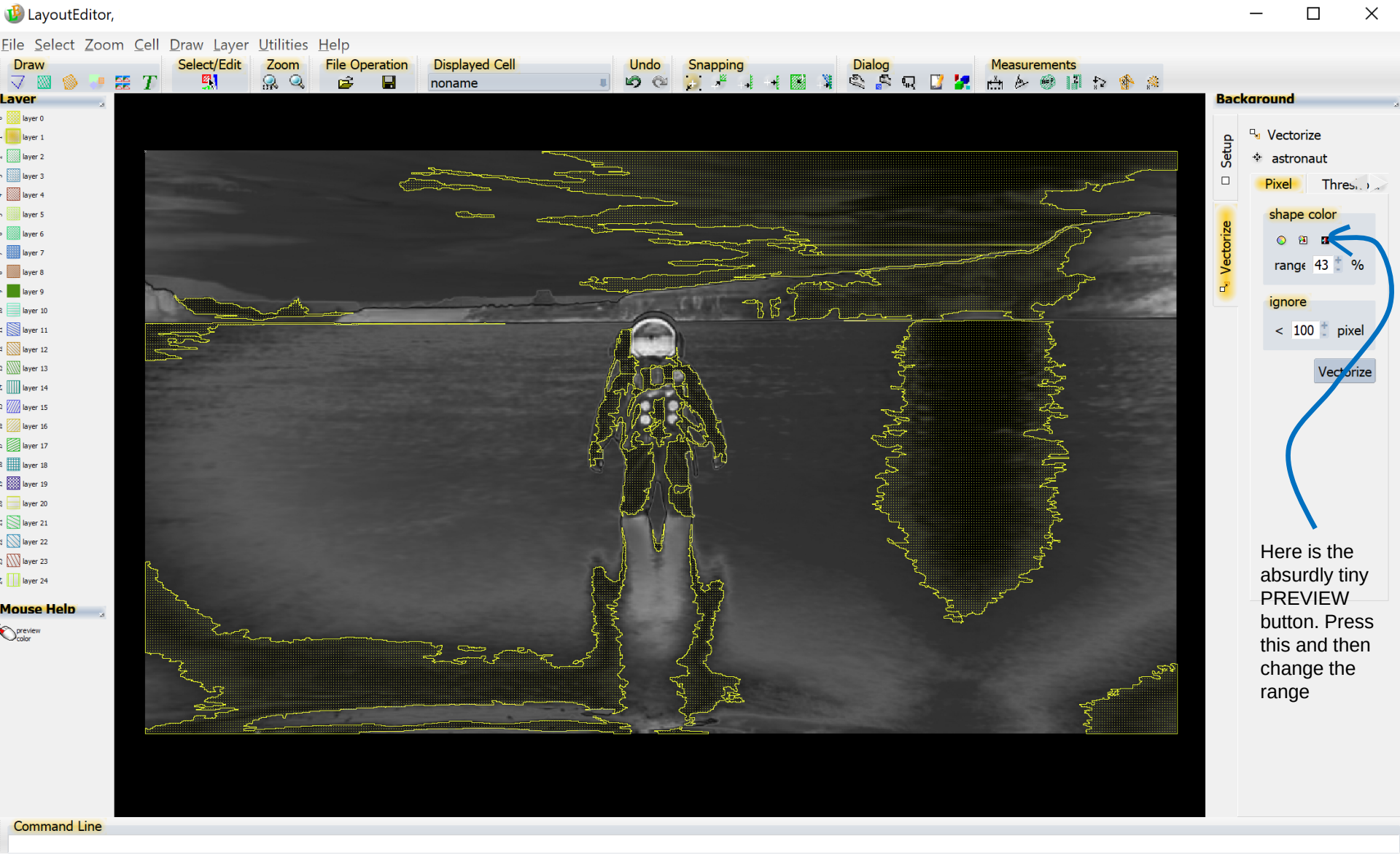
Start by adding an image to the background. Look in /public for an image.

At this step X and Y can be scaled independently, and you can rotate the image.



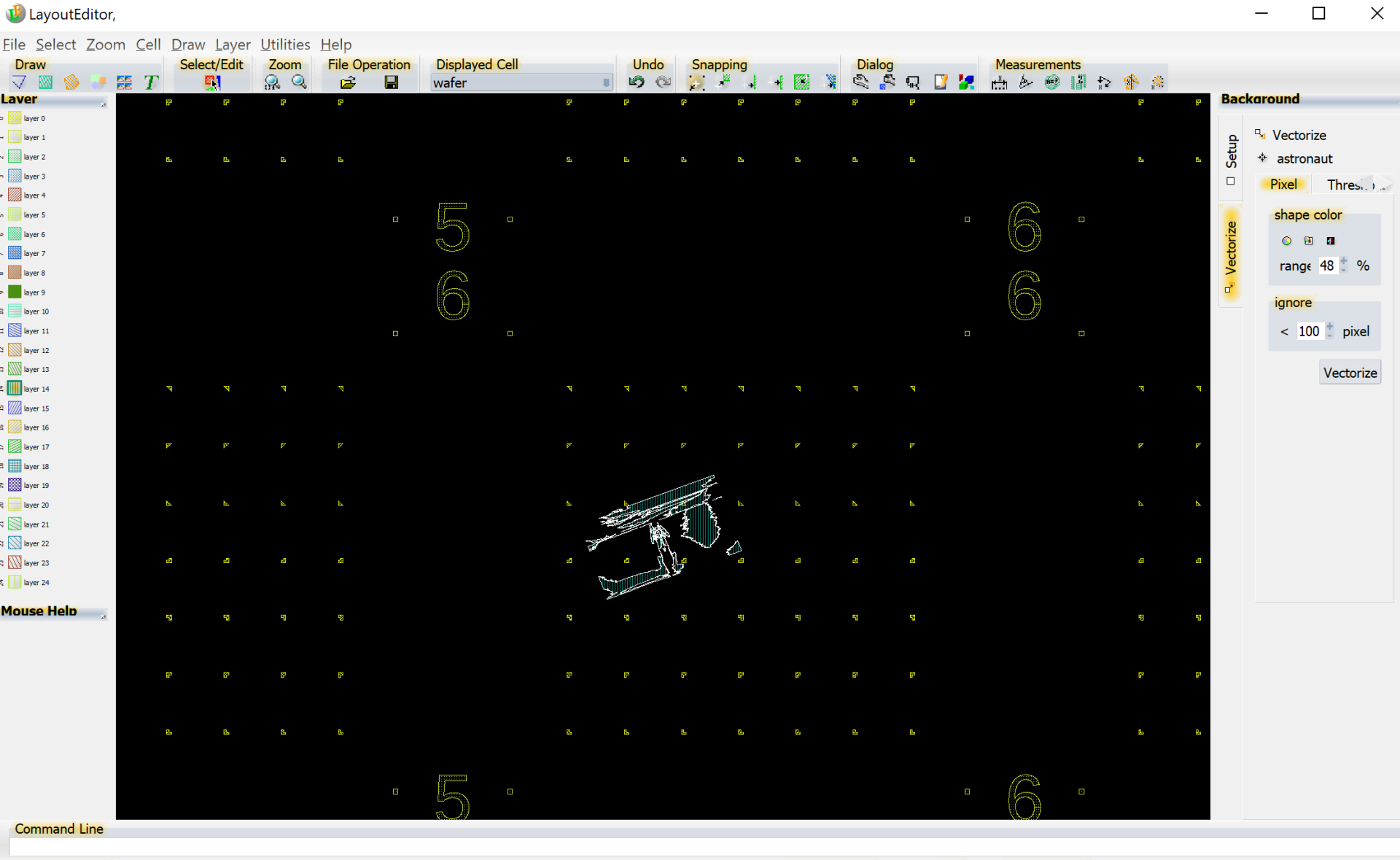


The image can be moved around in the background, but it is not part of the design and it is not inside any particular cell. Use “vectorize” to turn this image into polygons.



Here is the absurdly tiny PREVIEW button. Press this and then change the range

In the “vectorize” tab, click on the tiny “preview” button and then adjust the parameters. The chosen threshold (or the chosen color etc) will be used to turn the image into polygons. Click on “vectorize” to make it happen. Rename the cell, and the original image disappears.



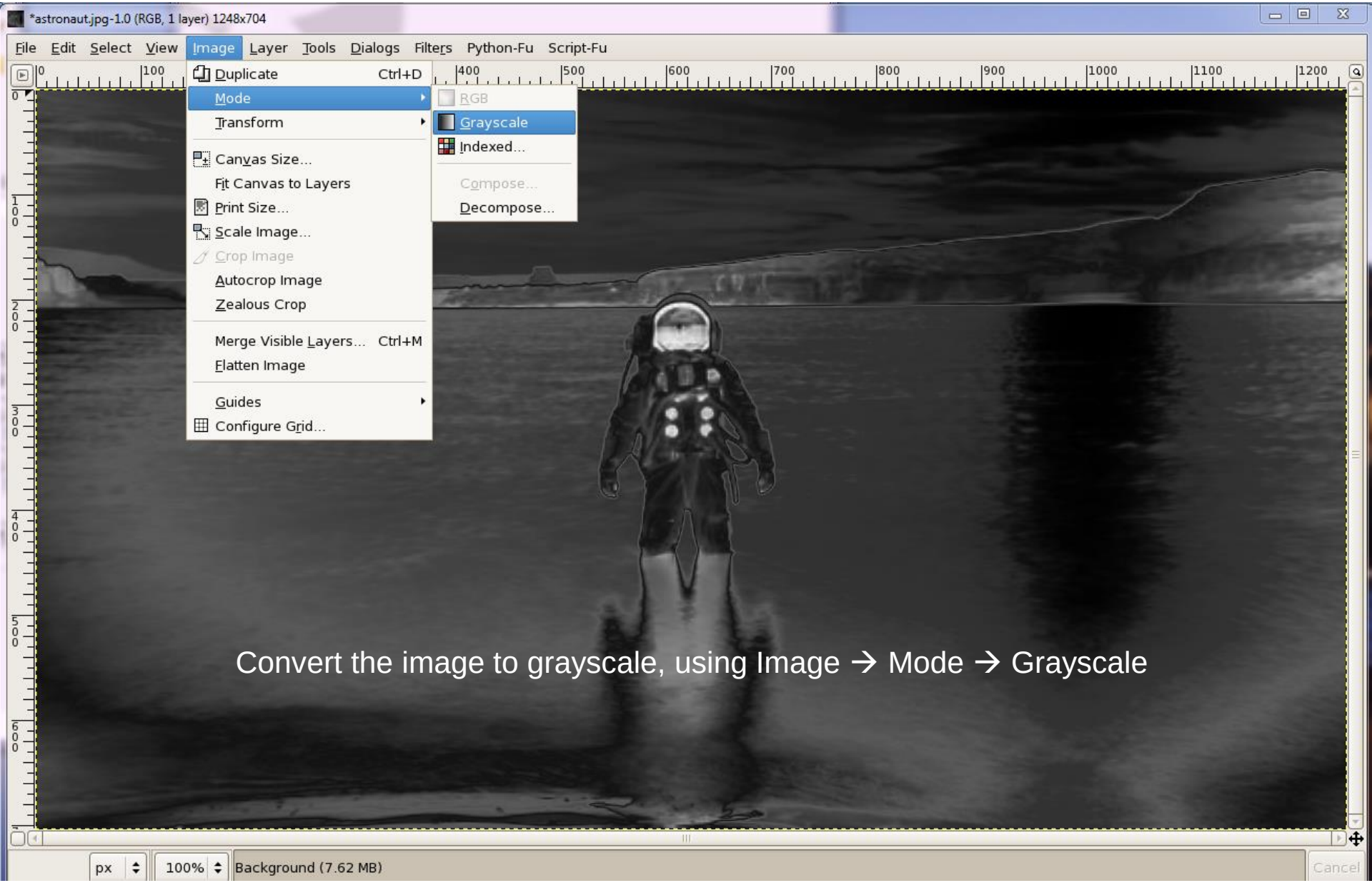
Here we show the image cell placed inside a cell of fiducial marks. We selected the image cell, then right-clicked to change scaling and rotation. We put the image on an unused layer, so we could design contact pads around it.

Converting images to exposable shapes

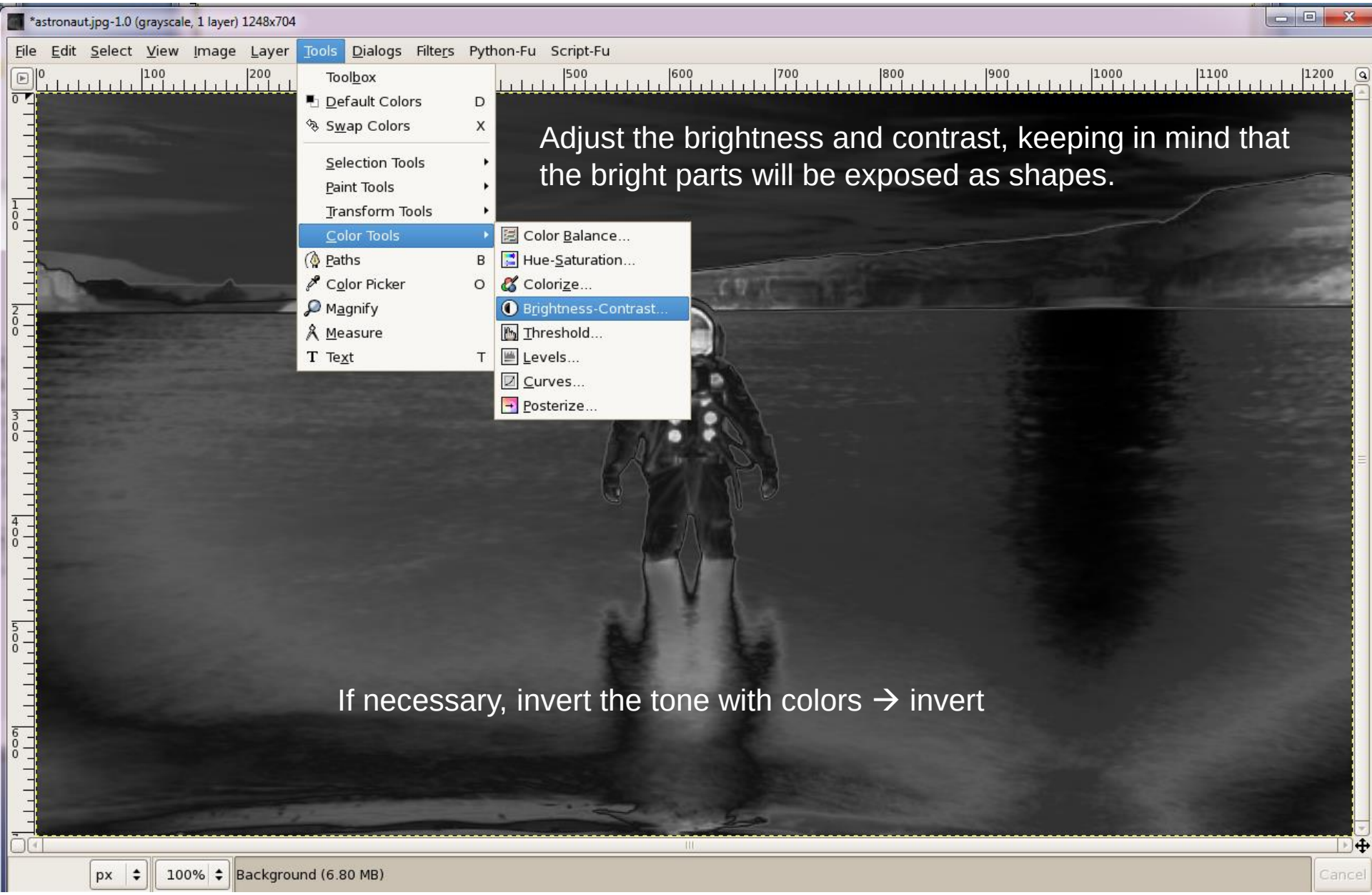
Simple thresholding, as shown above, is not a good way to prepare images for printing with e-beam or photo-lithography.

Since you are using a binary tone printing process, the image should be converted to grey-scale, and then the grey scales should be represented by different densities of dots. This dot representation is called “half tone” or “newsprint”.

Start by opening an image in gimp. (You could instead use Photoshop, but this tutorial uses gimp, which is free and runs on any operating system.)

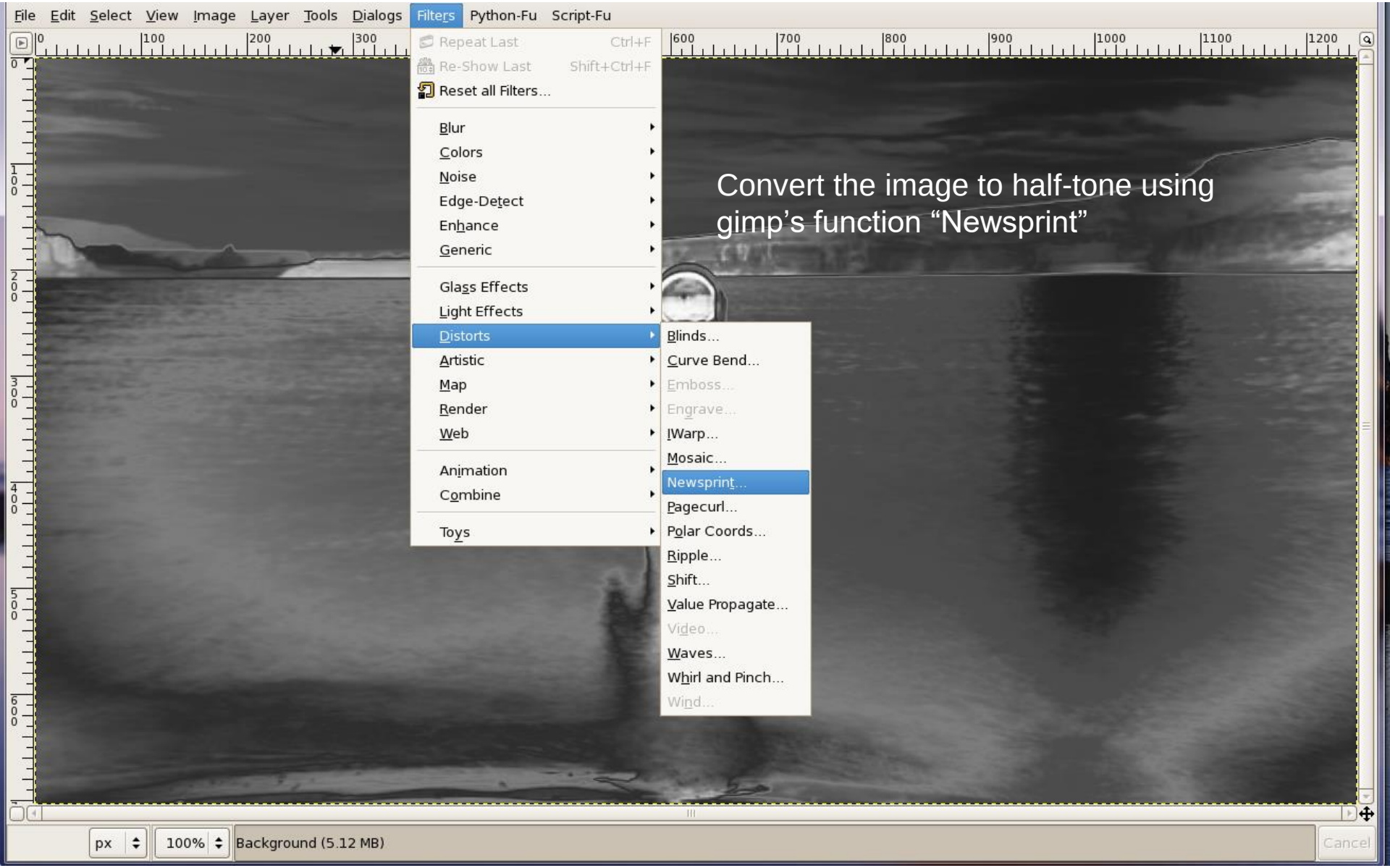


Convert the image to grayscale, using Image → Mode → Grayscale

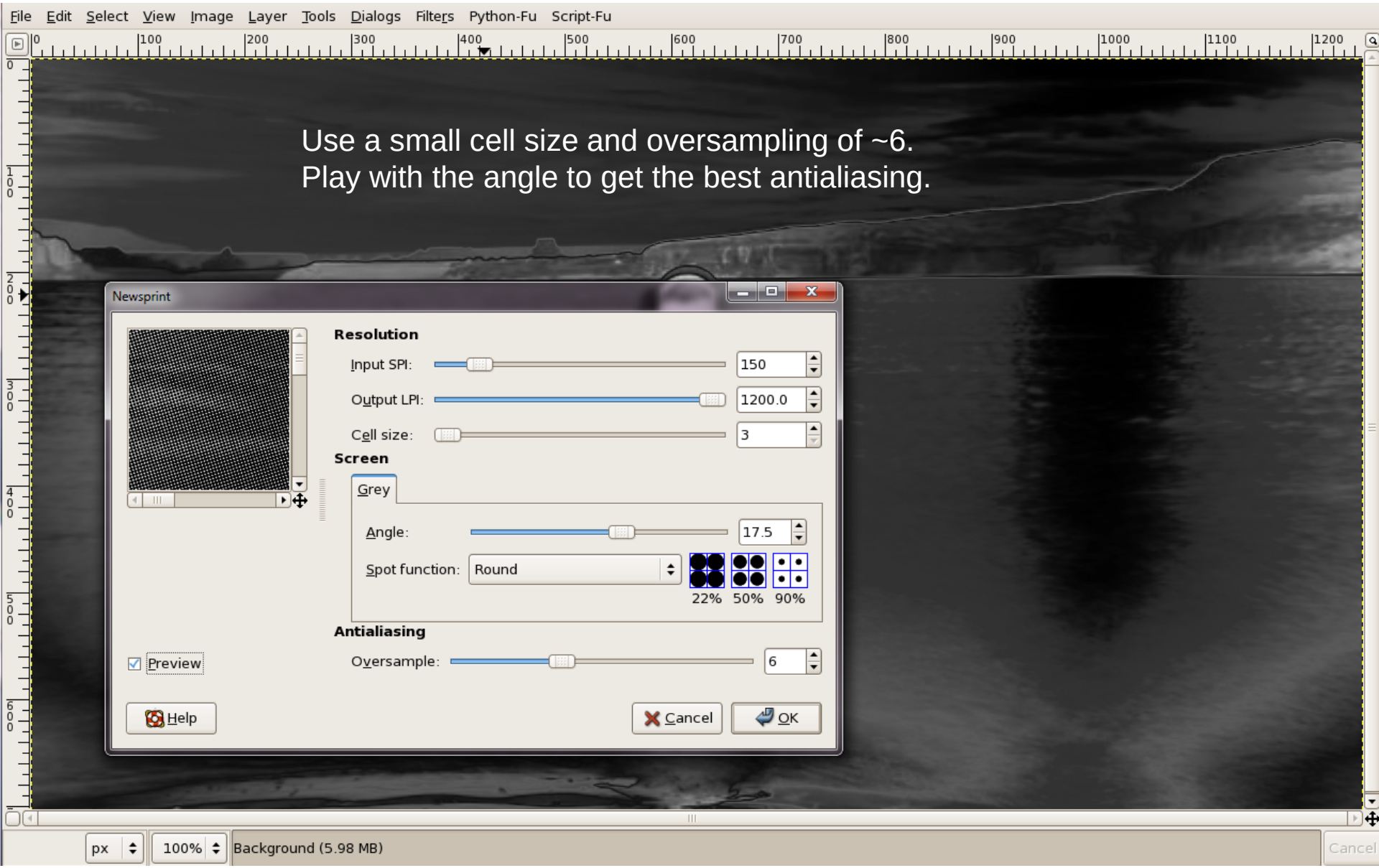


Adjust the brightness and contrast, keeping in mind that the bright parts will be exposed as shapes.

If necessary, invert the tone with colors → invert



Convert the image to half-tone using gimp's function "Newsprint"


File Edit Select View Image Layer Tools Dialogs Filters Python-Fu Script-Fu
Use a small cell size and oversampling of ~6.
Play with the angle to get the best antialiasing.
Newsprint
Resolution
Input SPI: 150
Output LPI: 1200.0
Cell size: 3
Screen
Grey
Angle: 17.5
Spot function: Round
22% 50% 90%
Antialiasing
Oversample: 6
Preview
Help
Cancel
OK
px
100%
Background (5.98 MB)
Cancel


File Edit Select View Image Layer Tools Dialogs Filters Python-Fu Script-Fu
px
100%
Background (5.98 MB)
Cancel

Save the image in TIFF format (filename.tif)
then convert the bright pixels to polygons
in CIF format.

From a terminal window, use

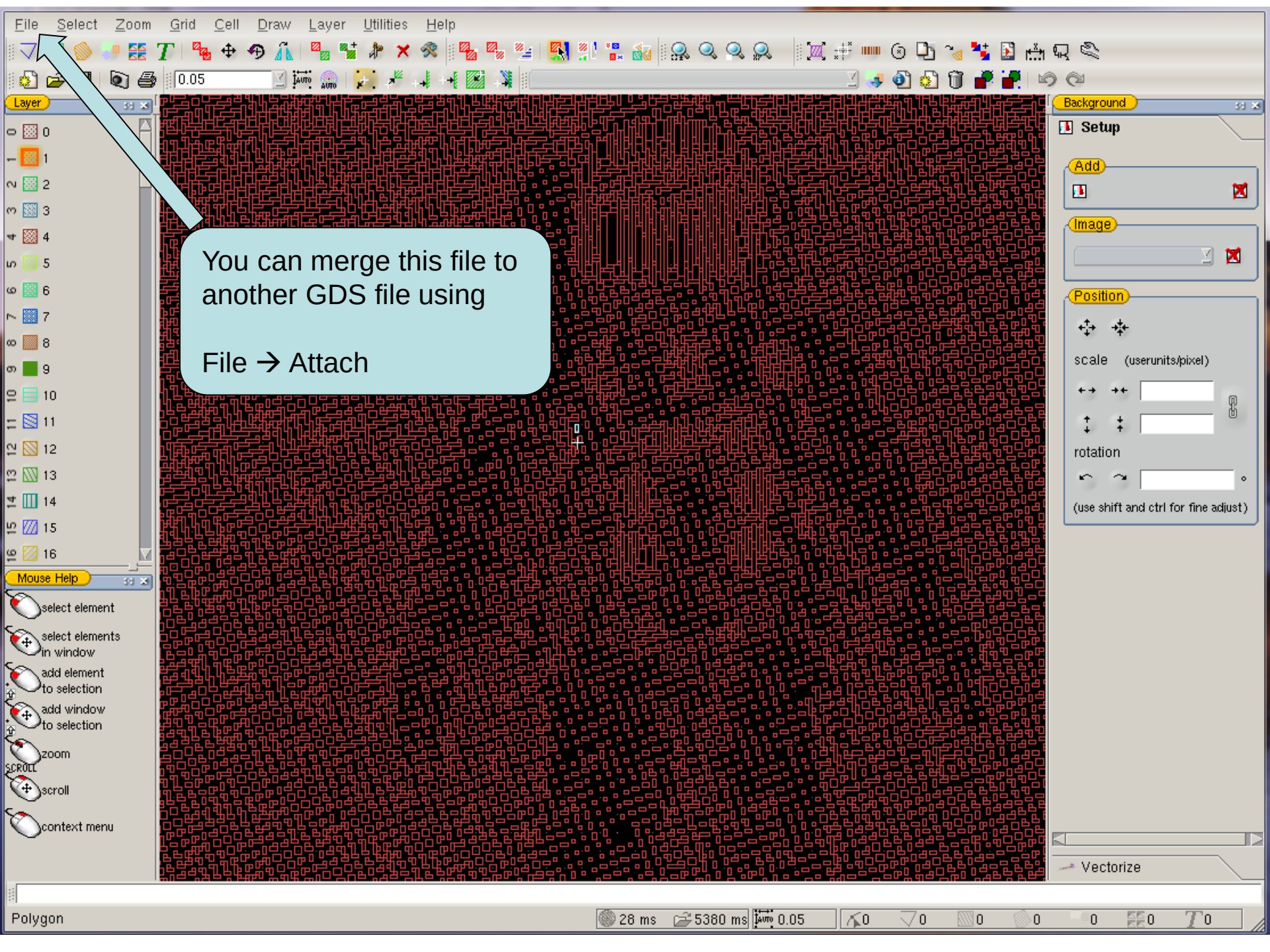
```
tif2gds filename
```

to convert filename.tif to filename.gds

Start the CAD program with the command

```
layout
```

then open the file filename.gds


File Select Zoom Grid Cell Draw Layer Utilities Help
0.05
Layer
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Mouse Help
select element
select elements in window
add element to selection
add window to selection
zoom
SCROLL
scroll
context menu
You can merge this file to another GDS file using
File → Attach
Background
Setup
Add
Image
Position
scale (userunits/pixel)
rotation
(use shift and ctrl for fine adjust)
Vectorize
Polygon
28 ms
5380 ms
0.05

End of Layout CAD tutorial

Go forth and design something cool.