A Short Introduction to PostScript

Peter Fischer, ZITI, Uni Heidelberg

What is PostScript ?

- Postscript is a *language* to describe graphic objects (& text)
- It is a *vector format*
  - Shapes, characters,.. are defined in an *exact*, mathematical way → objects / characters can be scaled, magnified, rotated... without loss of quality
  - Other vector formats are, for instance: *pdf* (portable data format) and *svg* (scalable vector graphics)
- Postscript is a *programming* language
  - Complex graphics can be described quickly and efficiently
  - They can be *parameterized* and changed *easily*
- Postscript devices (printers) must be intelligent, because they must *interpret* the language
  - Otherwise, the host computer must do the translation. Most often using the (free) tool 'ghostscript'

Why Use & Know About Postscript ?

- *Simple manual* generation of ***high quality*** graphics
- Graphics can be *parameterized*
- *Automatic* generation of graphics from within other programs
- Small files
- *Exact* dimensions

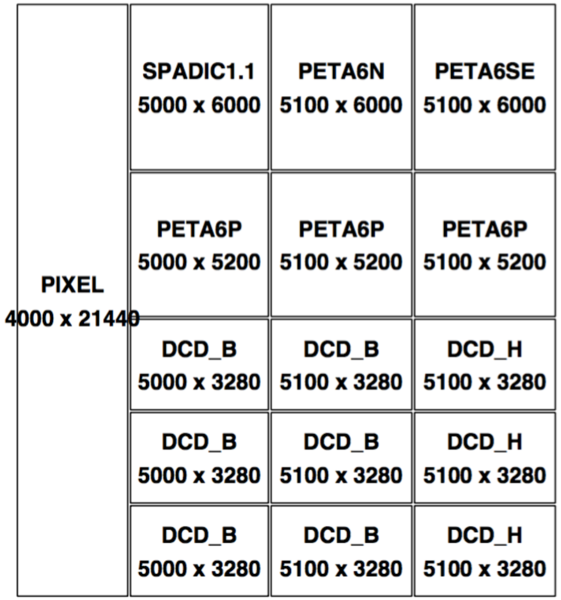
- Postscript is (still) common for LaTeX
- Sometimes, modification of available .ps or .eps files is required
  - Change a font
  - Modify colors or line width
  - Add water mark

- Many concepts are used in other languages (pdf, swift)

- Generating Graphics can be fun !

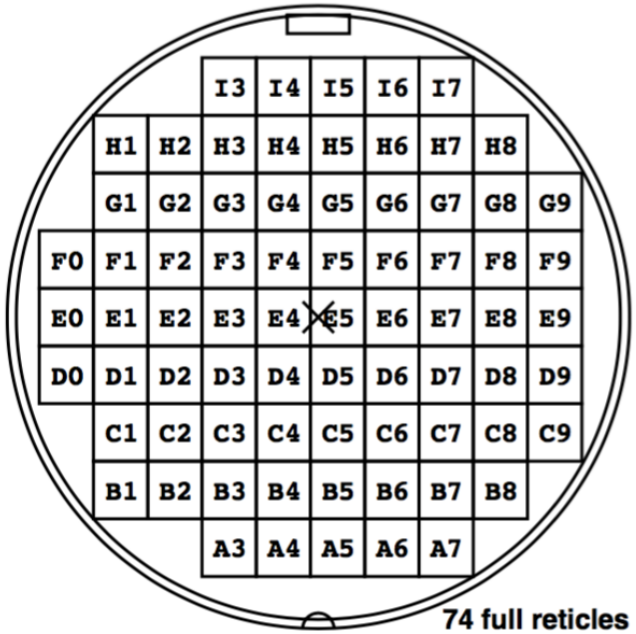
Examples

- Arrangement of chips in a 'reticle':

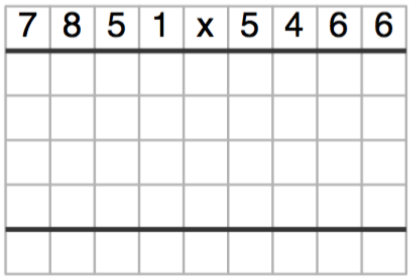


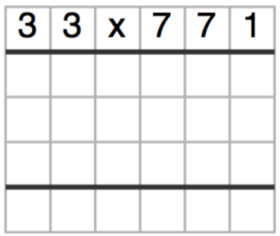
Reticle size is 19500 x 21440

Reticles on a wafer



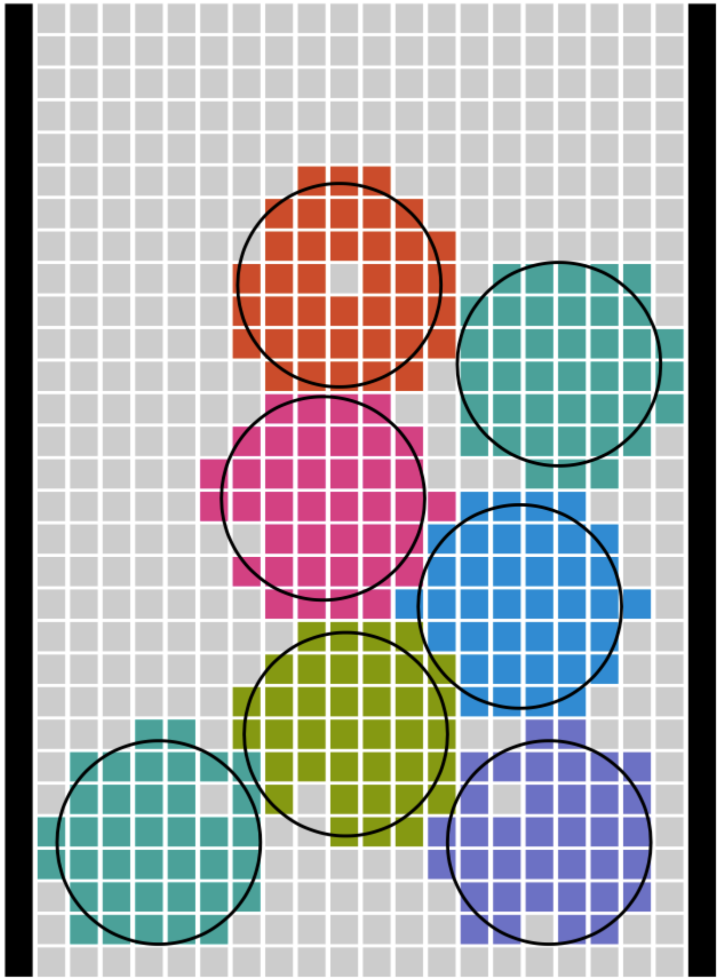
- Math exercises for your kids (with random generator):



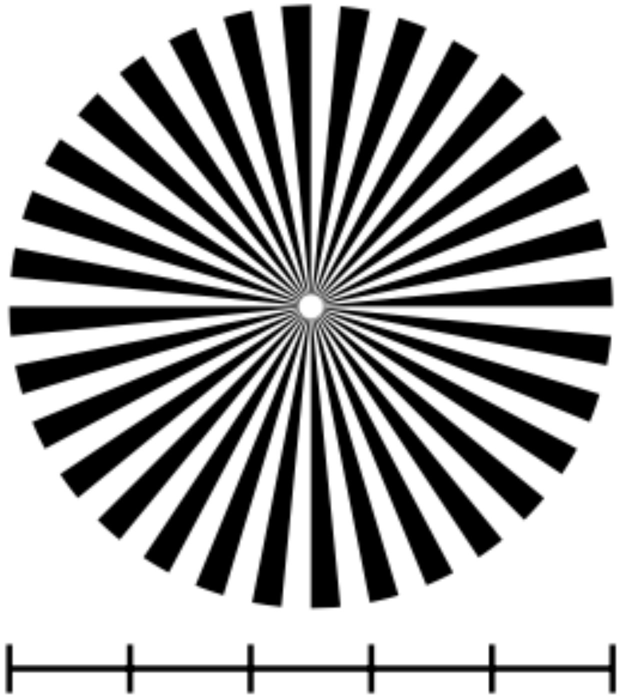


More Examples

- Illustration of a sensor readout

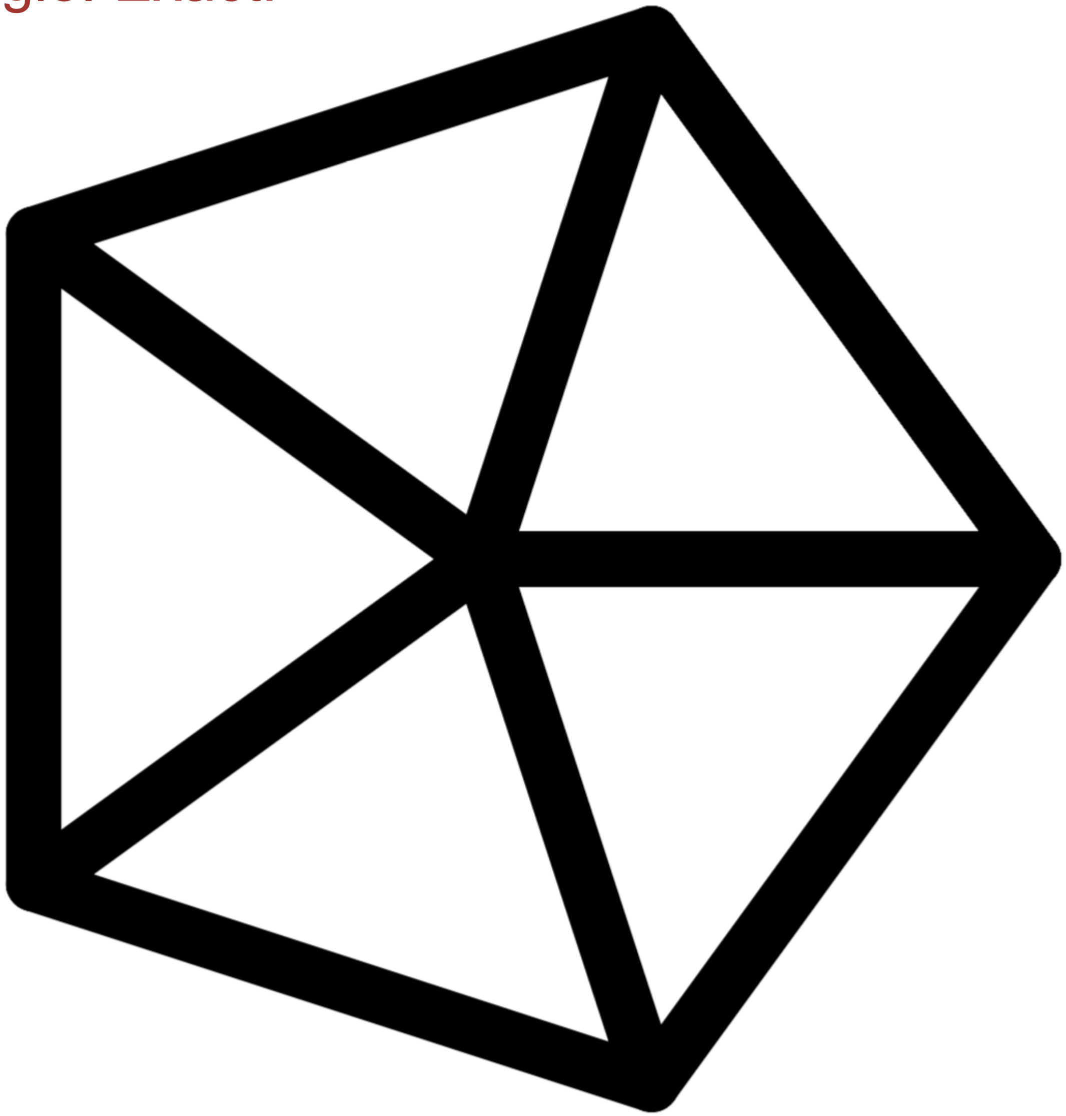


Siemensstern



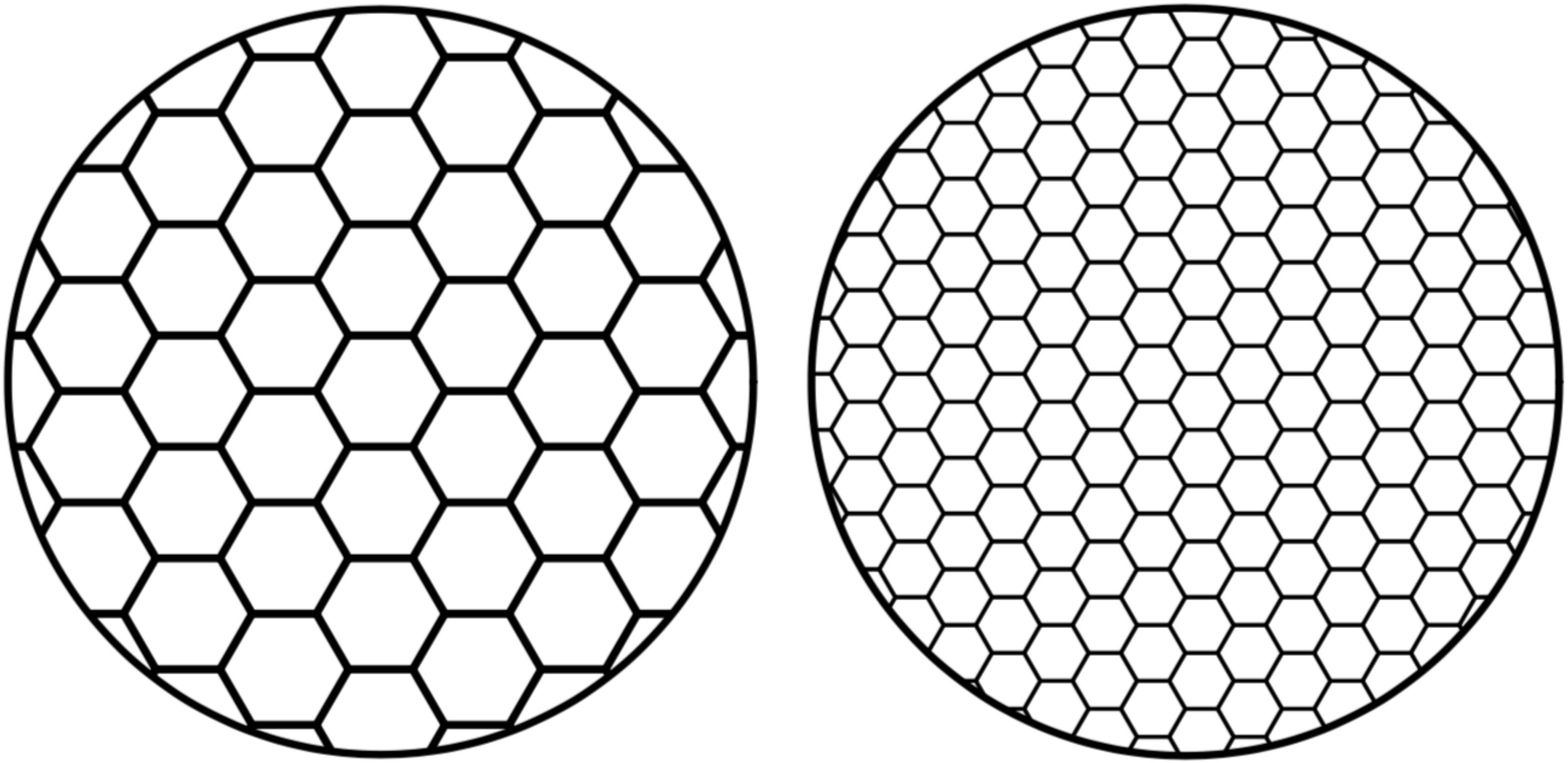
More Examples

- Any Angle. Exact:



More Examples

- Exact Dimensions, exact clipping:



What is the drawback ?

- Postscript is used less and less (replaced by pdf)
- Importing .eps in other documents is often difficult
  - It is simple in LaTeX (pdfLaTeX requires .pdf, but conversion from .eps → .pdf is simple and robust)
- Conversions often lead to quality loss.

- Why not pdf?
  - pdf is *much* more complicated!
  - A ‘minimal’ pdf file is already lengthy
  - Hard to do ‘by hand’ because bytes need to be counted!

  - See the (short) intro to pdf later in the lecture…

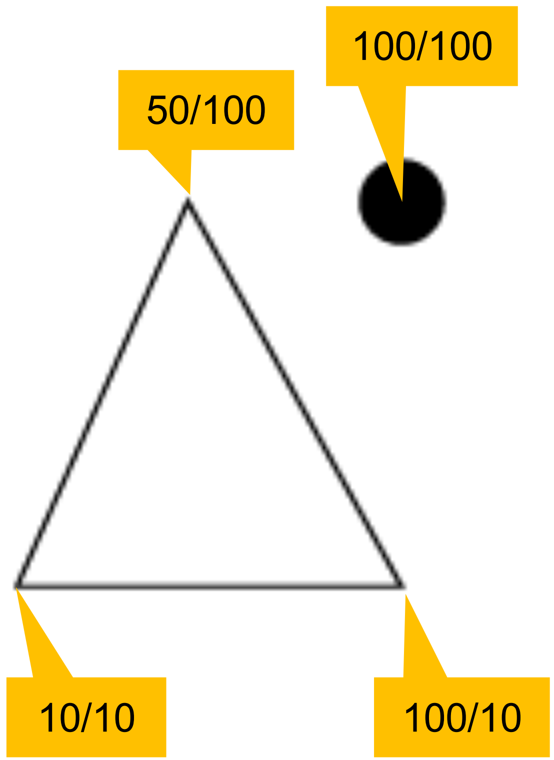
Getting Information

- Postscript Language Reference Manual (‘PLRM’)
  - https://www.adobe.com/content/dam/acom/en/devnet/actionscript/articles/PLRM.pdf
- Language Tutorial and Cookbook (the ‘Blue Book’)
  - https://www-cdf.fnal.gov/offline/PostScript/BLUEBOOK.PDF
- Language Program Design (the ‘Green Book’):
  - https://www-cdf.fnal.gov/offline/PostScript/GREENBK.PDF
- Many Web sites of good quality (see Lecture Page)

Simple Example 1: Triangle + Circle

```
%!PS
 newpath
  10  10 moveto
 100  10 lineto
  50 100 lineto
 closepath

stroke

 100 100
 10
 0 360 arc fill

showpage
```

- start a new shape
- start at (10/10)
- draw lines
- connect to start
- show outline
- x/y = 100/100
- radius = 10
- start/stop angle
- **fill** the arc
- print everything

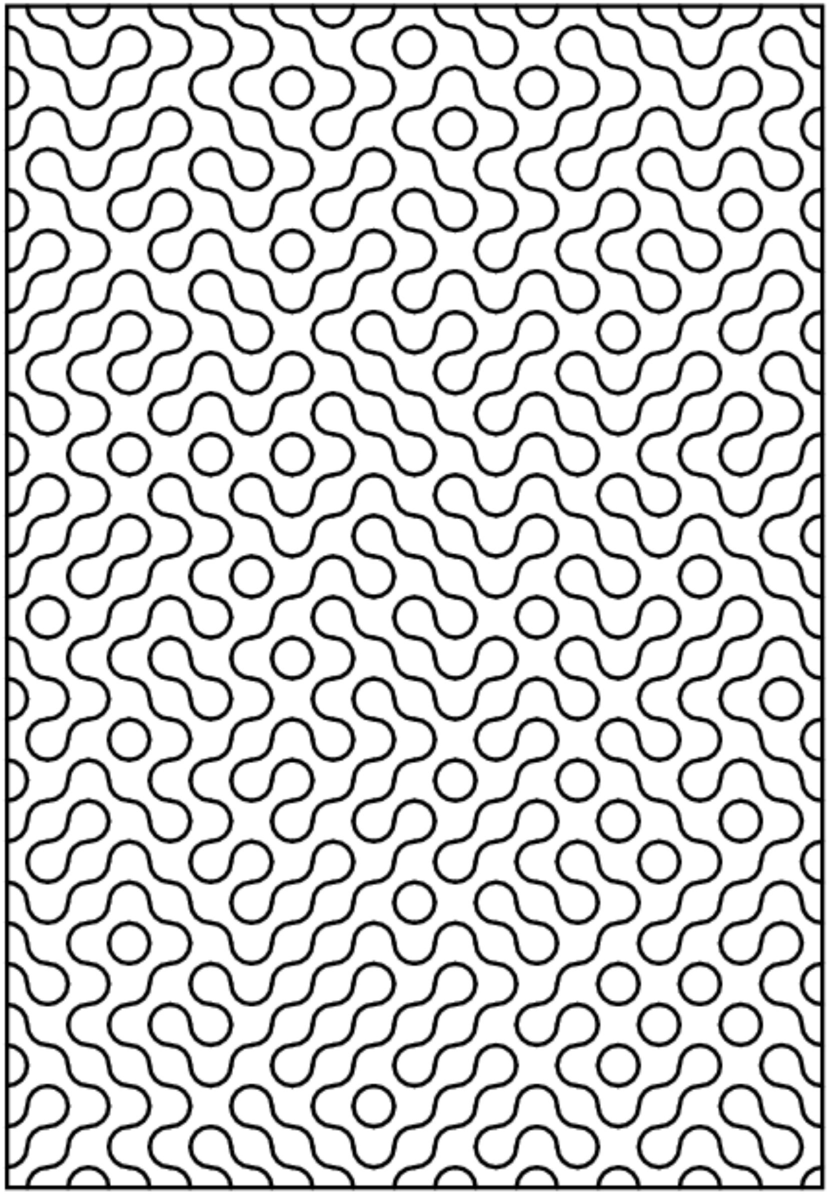


Viewing Postscript Files

- On Linux machines, files can be viewed with
  - gv (on the CIP Pool machines)
  - evince (on the CIP Pool machines)
  - ghostview, okkular, ShowView, GSView,…
  - ...there is always a viewer...
- On windows
  - Ghostview (must be installed, I do not know about new versions of Windows…)
- On MAC
  - Using Preview (for .eps).
  - ps files are converted to pdf automatically
- Always need GhostScript to interpret the language
  - GhostScript is also used to convert ps/eps → pdf, png, jpg…

Advanced Example 2: Truchet Pattern

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 595 842

2.835 dup scale
5 4 translate 1 setlinecap
0 0 200 290 rectstroke
100 145 translate

/W 10 def /W2 { W 2 div } bind def

/DRAWUNIT {
  gsave  translate rotate
 W2 neg W2 neg W2   0  90 arc stroke
 W2 W2 W2 180 270 arc stroke
  grestore
} def

-95 W 95 {
  /x exch def
  -140 W 140 {
    /y exch def
    rand 4 mod 90 mul  x y  DRAWUNIT
  } for
} for

showpage
```



File Structure

- File **MUST** start with `%!PS` (may add PS - version number)
  - If forgotten, (most) printers will output (a lot of) ASCII stuff…
- PostScript is *CaseSensitive*!
- Blanks and Line breaks are *irrelevant*

- Comments
  - In-Line comments start with

```
% … commented code here …
```

  - Larger code blocks can be commented with

```
false {
 … commented code here …
} if
```

- Files have extension *.ps*
- To actually *print*, the file ***must*** end with `showpage`

eps Files

- .eps files contains some *additional* meta-information
- These 'encapsulated postscript files' have extension **.eps**
- .eps type is announced in first line by EPSF text:

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 595 842
…
```

- All eps meta information is added as comment with '%%'

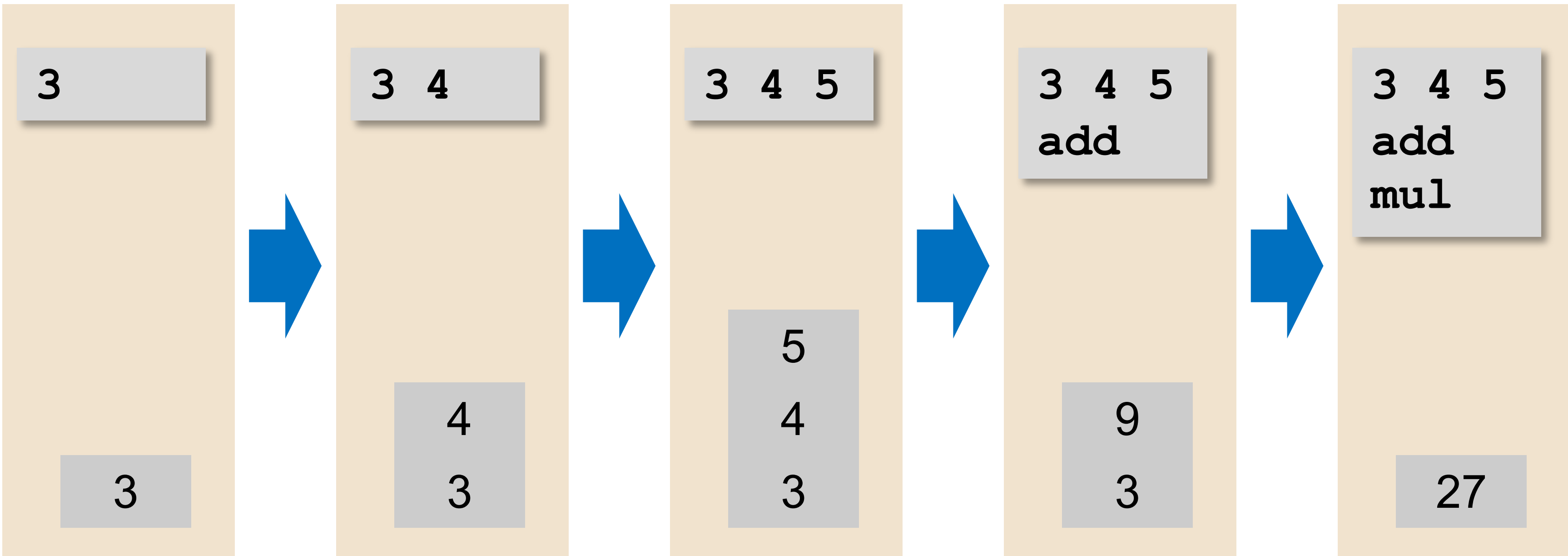
- Most important (and the only *required*) information:
  size of the viewing area = BoundingBox:
- parameters (in integer postscript units) are:

```
%%BoundingBox: x_botleft y_botleft x_topright y_topright
```

- **Best always use .eps !!!**

The Stack

- PostScript uses
  - a stack (Last In - First out)
  - RPN (Reverse Polish Notation) = UPN (Umgekehrt Poln. Notation): Operands are put to stack **first**, operator is **last**
- Example `3 4 5 add mul` → (4+5) × 3



- Operators can have *1 or more* arguments

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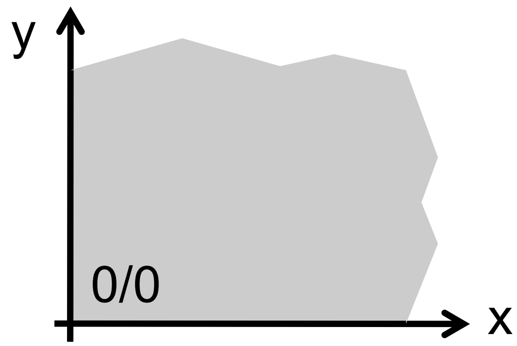
Coordinate System, Lengths and Points

- Origin (0/0) is ***BOTTOM LEFT***
- X is to the *RIGHT*
- Y is *UPWARD*



- 1 PostScript Unit = 1 Point = **1/72 inch = 0.353 mm**
  - (1 inch = 1 Zoll = 2.54 cm exactly)

- Convert *mm* to *point* by multiplying with 72 / 25.4 = 2.835..
- By defining the command (see later...)

```
/mm { 2.835 mul } def
```

  you can just write

```
15 mm
```

  in your code!

- Later we will use the `scale` command to change units...

The Page / Sheet Size

- ‘sheet’ size & orientation (in .ps) are undefined.
  - They depend on the ‘viewer’ or printer
  - (This is a drawback. This is better in .eps and .pdf!)

- The sheet size can be ‘fixed’ as a ‘bounding box’ using an eps command, see before…
  - `%!PS-Adobe-3.0 EPSF-3.0`
  - `%%BoundingBox: llx lly urx ury`

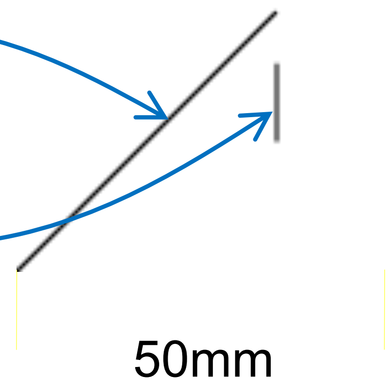
    (***llx*** = lower left x, … using *integer postscript* units)

- A4 (portrait) paper has
  - width = 210 mm = 595.28... points
  - height = 297 mm = 841.89... points
  - `%%BoundingBox: 0 0 595 842    % A4 portrait`

Hello World

- Shapes / Outlines are defined as *paths*.
  A *path* is a sequence of straight lines / bends / gaps / …
- `x y moveto` **moves** the ‚pen' to coordinate [x y]
- `x y lineto` **draws** a line **from the last point** to [x y]
- `stroke` executes the path drawing

```
%!PS
0 0 moveto
100 100 lineto
100 80 moveto
100 50 lineto
stroke
showpage
```



  - Remember: 100 Units = 100 × 0.353 mm = 35.3 mm
- `rmoveto` and `rlineto` are *relative* to the *last* point
- Note: You **MUST** first move to 0 0!

Drawing and Filling Paths

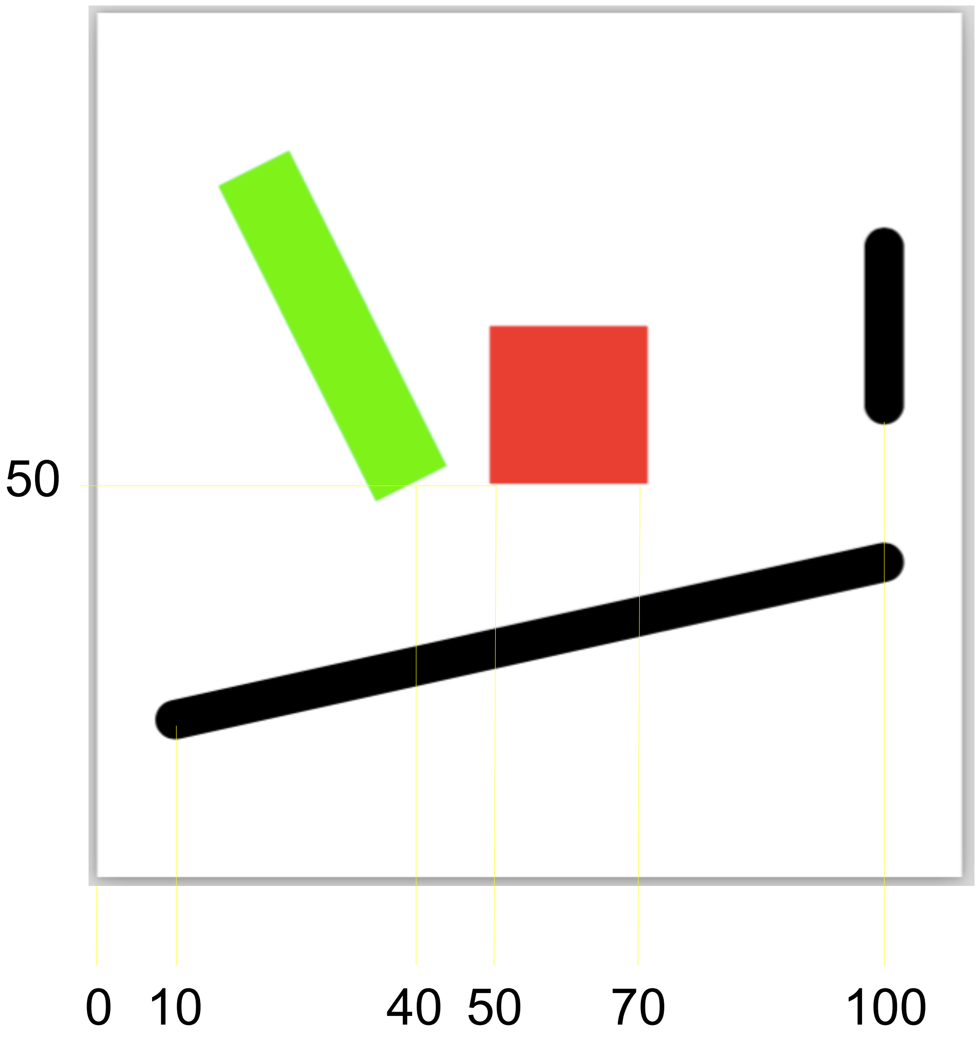
- A path *can* be started with **`newpath`**
- The command **`closepath`** connects the last active point to the starting point (see Example 1 on slide 10)
- A path can be used for further operations (e.g. clipping,…)
- Using a path is not always necessary

- To draw a path (or sequence of **`moveto`** / **`lineto`** commands)
  - **`stroke`** draws the **outline**
    - the *width* of the line can be set with **`value setlinewidth`**
    - the shape of the line *end* can be set with **`value setlinecap`**
    - the shape of corners is set with **`value setlinejoin`**.
  - **`fill`** fills the **inner part** with the presently selected color
- **`x y w h rectstroke`** is a shortcut to draw a rectangle

- Color can be set with **`r g b setrgbcolor`** (r,g,b = 0.0 … 1.0) or with **`g setgray`** (for gray values)

One More Example

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 110 110

10  20 moveto   100 40 lineto
100 60 moveto   100 80 lineto
5 setlinewidth  1 setlinecap
stroke

newpath
 50 50 moveto     20  0 rlineto
  0 20 rlineto  -20  0 rlineto
closepath
1 0 0 setrgbcolor
fill

40 50 moveto      20 90 lineto
0  setlinecap 10 setlinewidth
0 1 0 setrgbcolor
stroke
showpage
```



Working in Linux on the CIP Pool

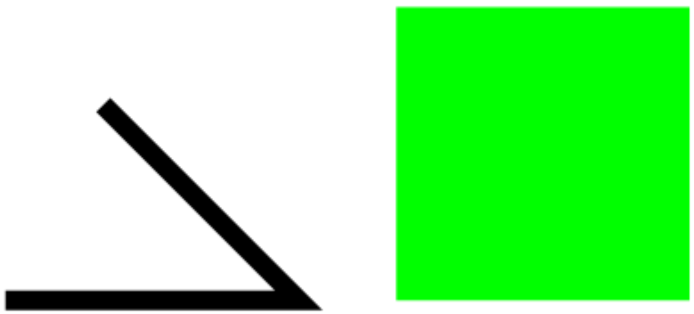
- Log in on one of the CIP Pools machines
  - chose a shell (I use Gnome)
- To work remote, use a browser and url **`https://physik1.kip.uni-heidelberg.de`** (or **`physik2`** or **`physik3`**)

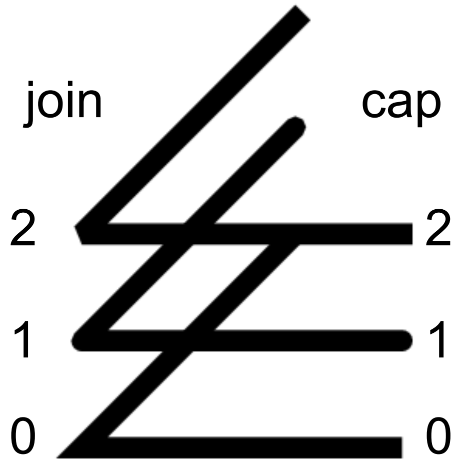
- Create a subdirectory with **`mkdir DIRNAME`**
- Move to the subdirectory with **`cd DIRNAME`**
- Edit files for instance with **`gedit filename.ps &`**

- View your file with **`evince filename.ps &`**

Exercise 1

- Draw a line from (10,10) to (40, 10) to (20,30)
  - Change the width of the line
  - Play with shape of the line ends and the shape of the corners (use values 0…2 and a ‘thick’ line).
  - Can you find out the difference between cap = 0 and 2?
- Draw a square of 30 units size with its lower left corner at (50,10)
  - Use **`moveto`** and **`lineto`**
  - Use also **`newpath`** and **`closepath`**
  - Fill the square with green color





Mathematics

- PostScript knows several mathematical functions.
- Remember RPN: first `operand(s)`, then `operator`
  - `x y sub` → x - y. Also: `add`, `mul`, `div`, `idiv`, `mod`
  - `x abs` → |x|. Also: `neg`, `round`, `floor`
  - `x sin` → sin(x). Also: `cos`, (no `tan`), `ln`, `log`, `sqrt`
  - `x y atan` → arctan(x/y) (in degrees)
- Angles are given (as floats) in *degrees* (i.e. 0…360)
- Examples:
  - (2 + 3) × 4 → `2 3 add 4 mul`
  - 2 + 3 × 4 → `2 3 4 mul add`
  - Sqrt (3 + 4) → `3 4 add sqrt`

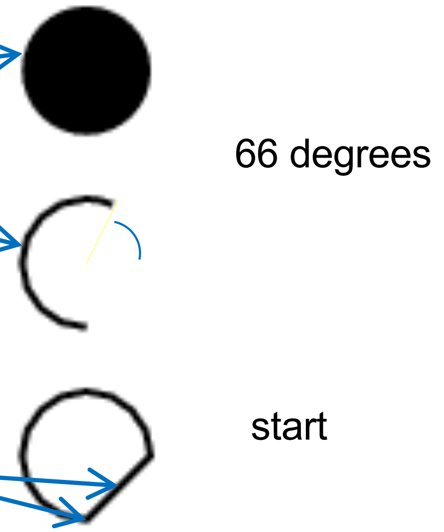
(Random Numbers)

- Random (integer) numbers can be obtained with
  - **`rand`** → random *integer* number
- A seed can be set with
  - **`value srand`**
- To obtain a different seed every time you 'run' (print) the postscript file, you can use a command that returns an integer time (in ms):
  - **`realtime`** → *integer* time value on stack
  - **`realtime srand`** → initialize with new value at each run

Drawing Arcs

- Arcs (parts of circles) are defined using
  `x y radius phistart phistop arc`
- Angles are in degrees, relative to *x-axis*
- **`arc`** turns *counter clock wise,* **`arcn`** turns *clock wise*
- They can be **`filled`** or **`stroked`**.
- Example:

```
%!PS
20  80  10  0  360   arc fill
20  50  10  66  270  arc stroke

newpath
20  20  10  0  270  arc
closepath
stroke

showpage
```



Defining Constants & Functions

- Defining a 'fix' constant:
  - `/name` ***`value`*** `def`
  - Example: `/PI 3.141 def`
- Defining a 'calculated' constant:
  - `/name` ***`commands`*** `def`
  - Example: `/TWO_PI  PI 2 mul  def`
- (*Constants* can be called more efficiently with a double slash: `//PI ... def`)
- Defining a *function*:
  - `/name { commands } def`
  - Example: `/ADDFIVE { 5 add } def`
    `3 ADDFIVE` → 8
- What happens?
  - The pair (name definition) is stored in a *dictionary* by **`def`**

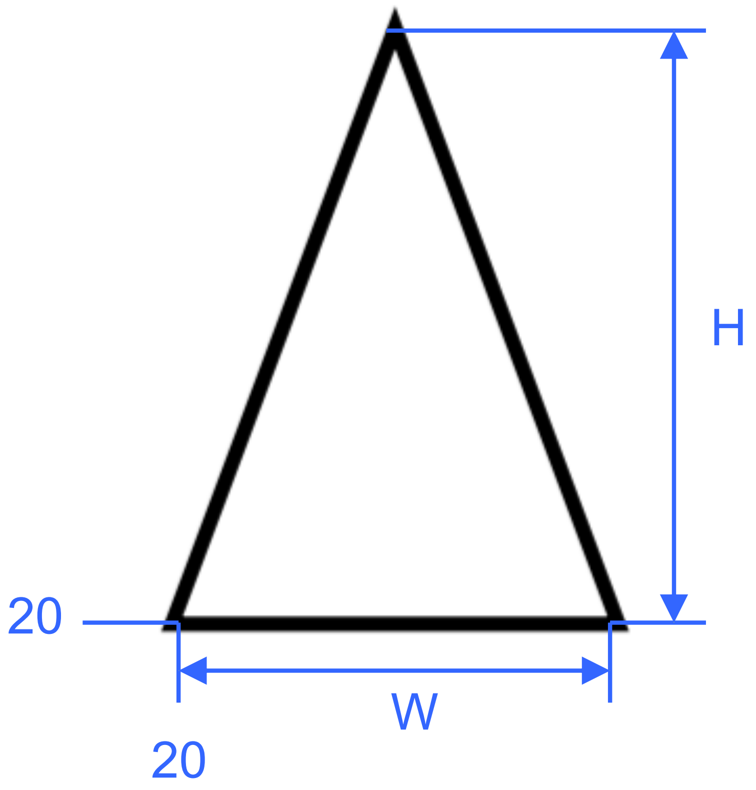
Example

- Understand in this example how the arguments of ‘lineto’ are constructed!
  - Note that the shift to (20,20) can be done more elegantly using the translate command, see later..

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 70 80

/W 30 def
/H 40 def

newpath
20 20 moveto
20 W add   20 lineto
20 W 2 div add   20 H add lineto
closepath
stroke

showpage
```

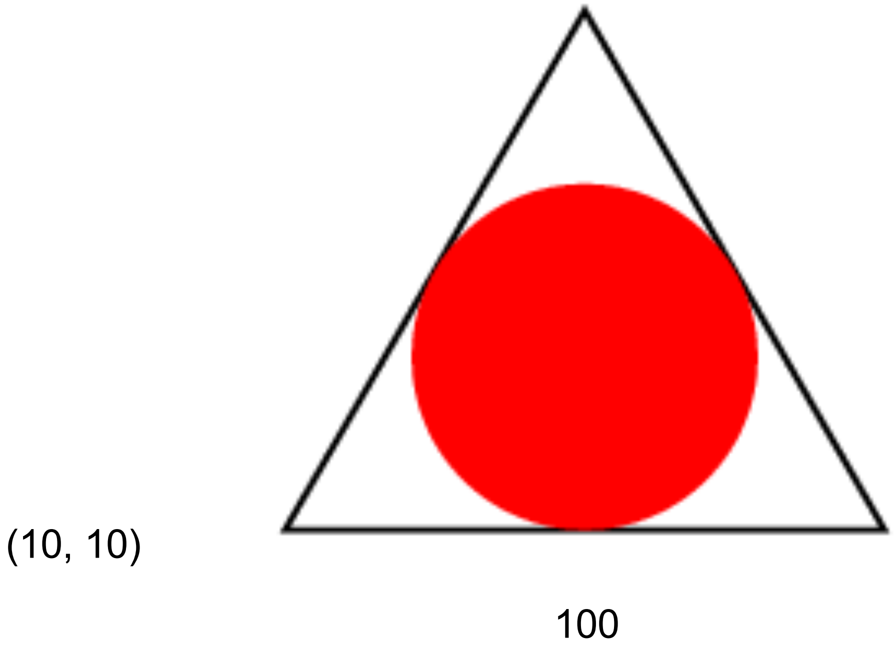
x coordinate of the top point

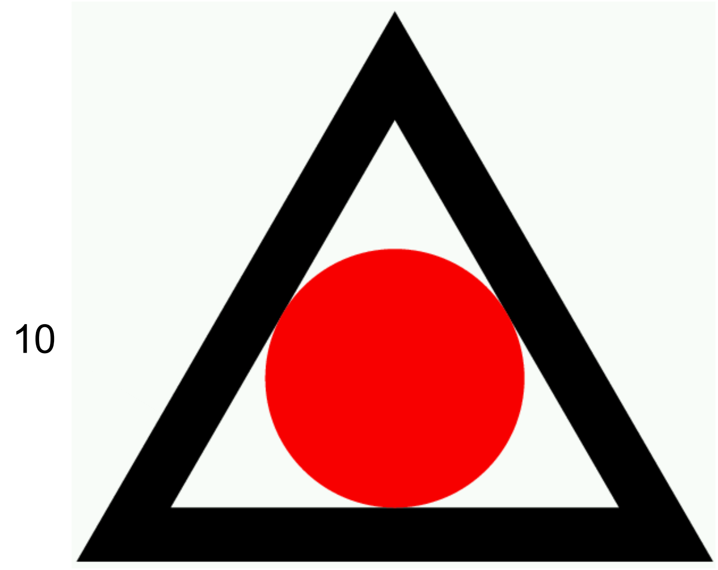
y coordinate of the top point



Exercise 2

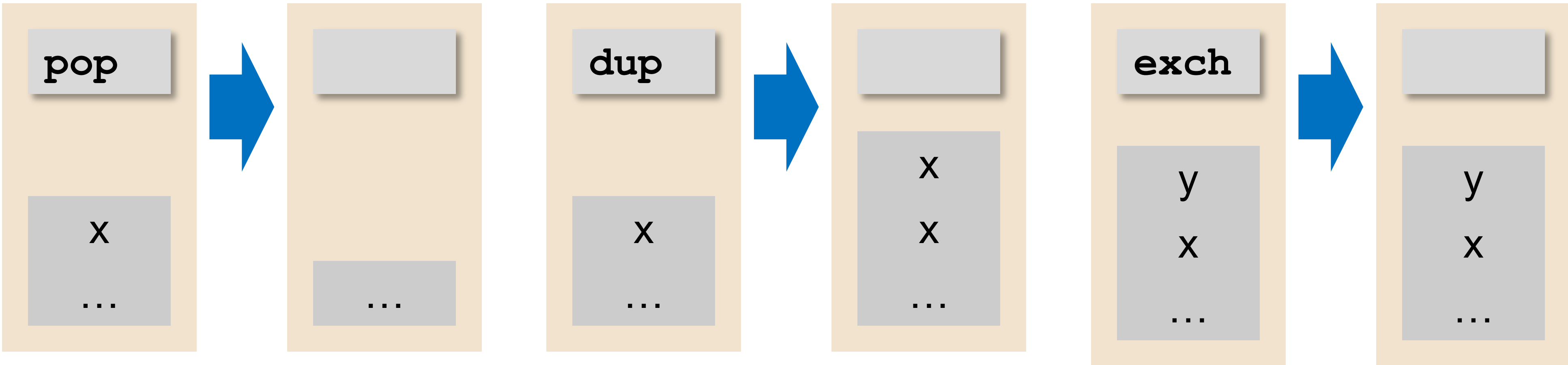
- Draw a triangle with *equal* sides
  - Start at (10,10), side length =100. Use a variable: /W 100 def
  - You have to do so some simple math for find the height H.
    Do it in postscript!
- Make the lines wide (for instance 10 points)
- Add a red, filled circle in the center which *just* touches the lines





Manipulating the Stack: pop, dup, exch

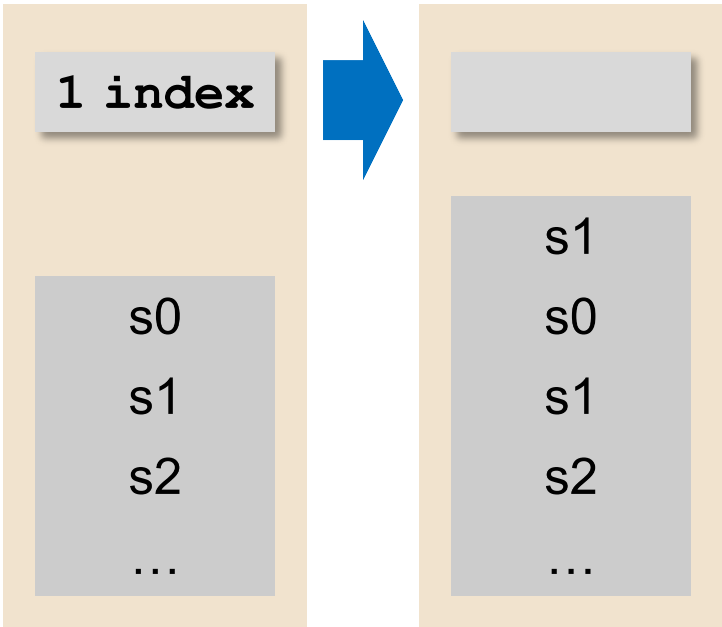
`pop`	`dup`	`exch`
drop top element:	duplicate top element:	swap topmost elements:



Manipulating the Stack: `index`, `copy`

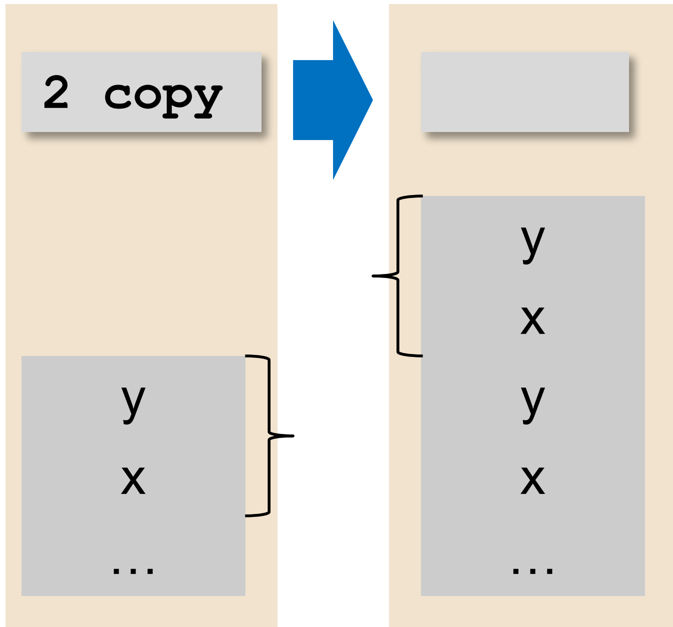
`n index`

copy t-th element (top index = 0):



`n copy`

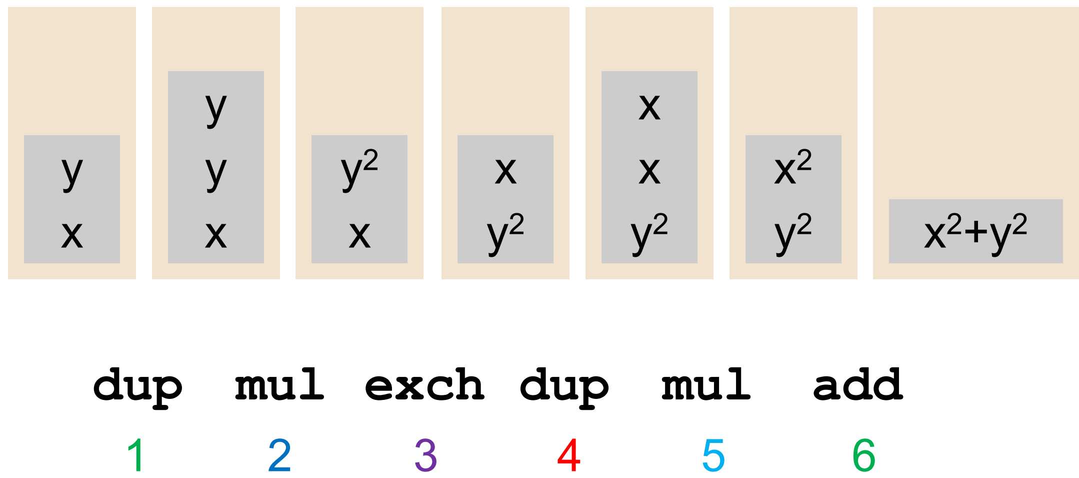
duplicate *n* elements:



Passing Values to Functions

- Parameters are passed *on the stack*
  - They can be used using stack manipulation commands
  - Example: Define DIST(x,y) = sqrt(x^2+y^2).
  - Assume x,y on stack:

```
/DIST {
   dup   %1
   mul   %2
   exch  %3
   dup   %4
   mul   %5
   add   %6
   sqrt
} def
```



- Usage: `3.2 1.7 DIST` → 3.6235
- Note: Functions can remove parameters or leave the stack intact. Stack over- / under-flows are very common mistakes!

Defining and Assigning Local Variables

- Values on the stack can be assigned to local variables:
  - **`/NAME exch def`**
  - (assume **`x`** is on the stack, then **`x /NAME exch`** leads to **`/NAME x`**, so that the **`def`** works normally)

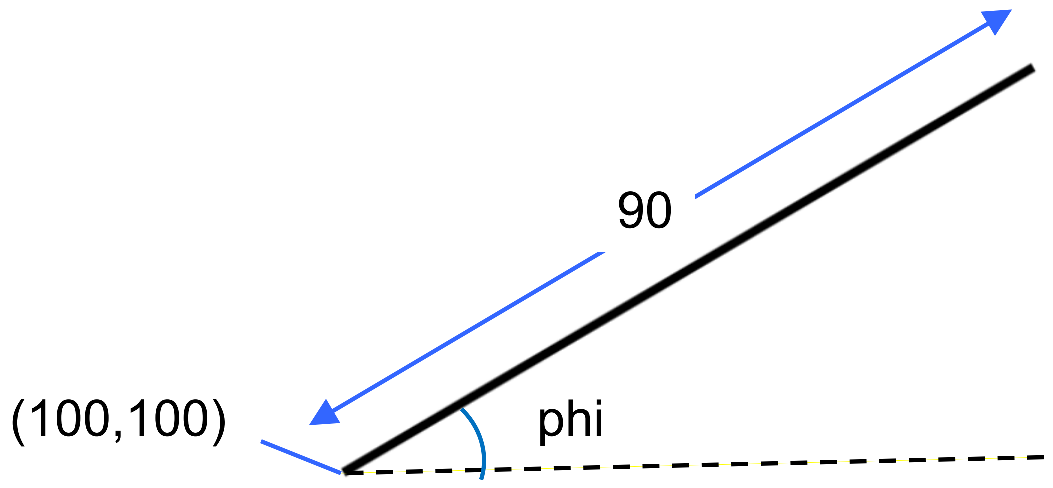
- Example: Define DIST(x,y) = sqrt(x^2+y^2)

```
/DIST {
  /y exch def   % topmost argument first!
  /x exch def   % now the stack is empty!
  x x mul       % on stack: x²
  y y mul       % on stack: x² y²
  add
  sqrt
} def
```

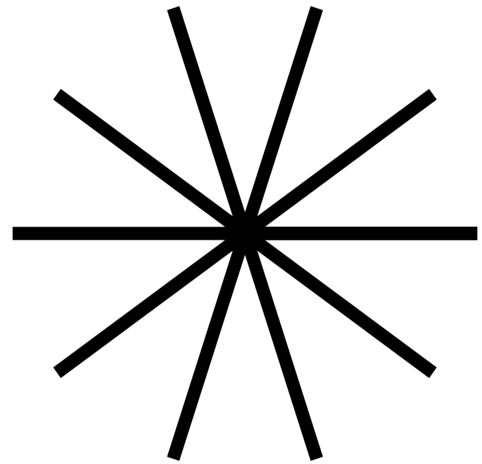
- This is much less efficient, because names must be looked up in a 'Dictionary'. (Furthermore, the variables are global!)

Exercise 3a

- Define a function **`LINE`** which draws a line of length 90 in an angle phi (on stack), starting at 100/100:

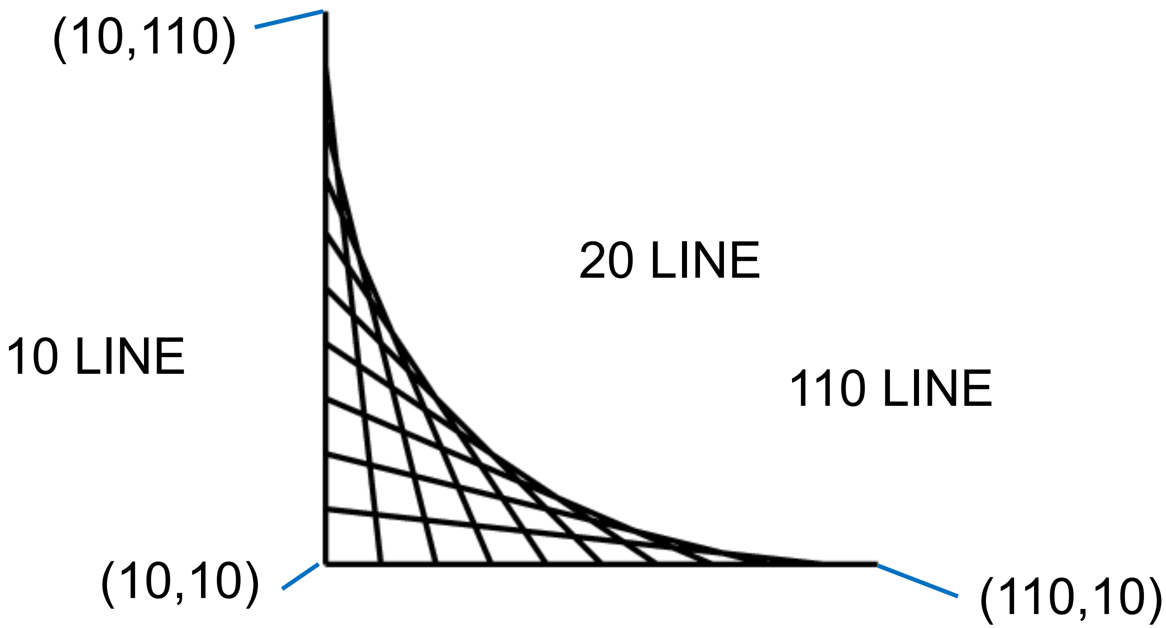


- Make a star by calling **`LINE`** several times



Exercise 3b

- Draw the following picture:



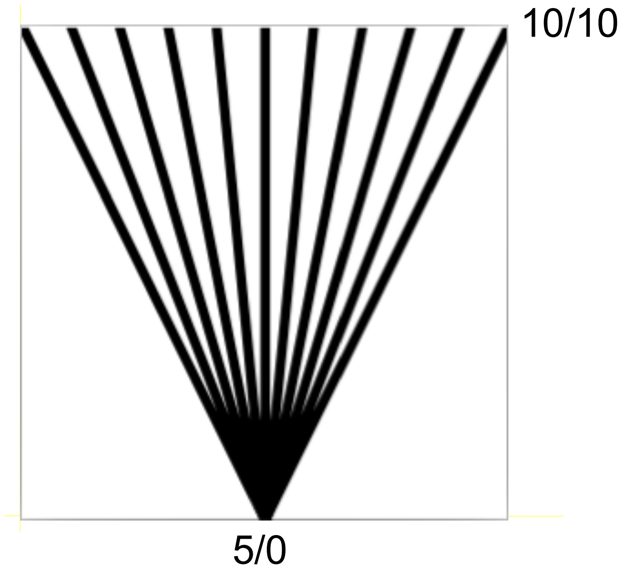
- First draw (a few) individual lines
- Next, define a function **`LINE`** which gets *one* value from the stack which indicates the *start of the line on the x-axis*.
- The drawing is then done by a sequence of **`LINE`** commands:
  `10 LINE   20 LINE   30 LINE` …

Loops

- There are several possibilities for repeating code
- We only treat 'for' - loops here:
  `istart istep imax { …commands… } for`
  - The loop value is put on the stack in each iteration (istart, istart+istep, istart+2 istep, …, *including* imax)
  - Then the commands are called
    They MUST consume (remove) the value from the stack
  - The loop variable can be assigned with **`/i exch def`**
- Example:

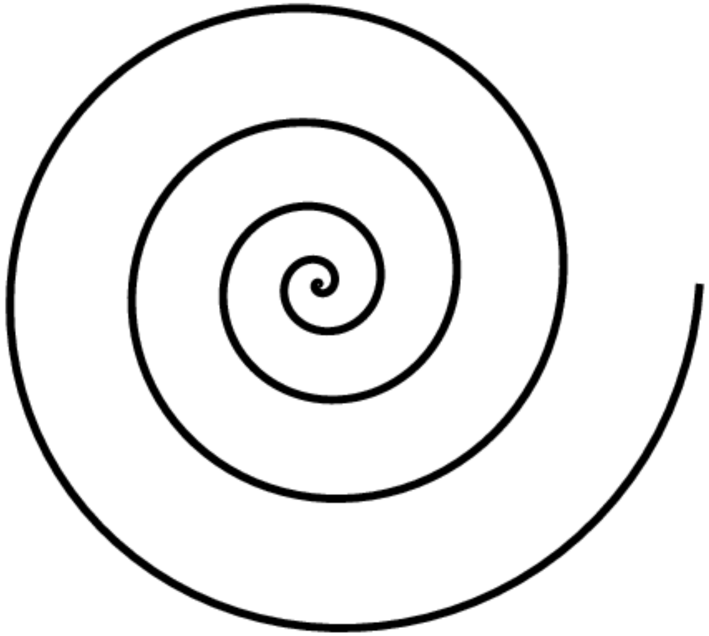
```
%!PS
0.2 setlinewidth
0 1 10 {
  5  0 moveto
     10 lineto
} for
stroke
showpage
```

Here we use the sweep variable which is still on the stack!!!



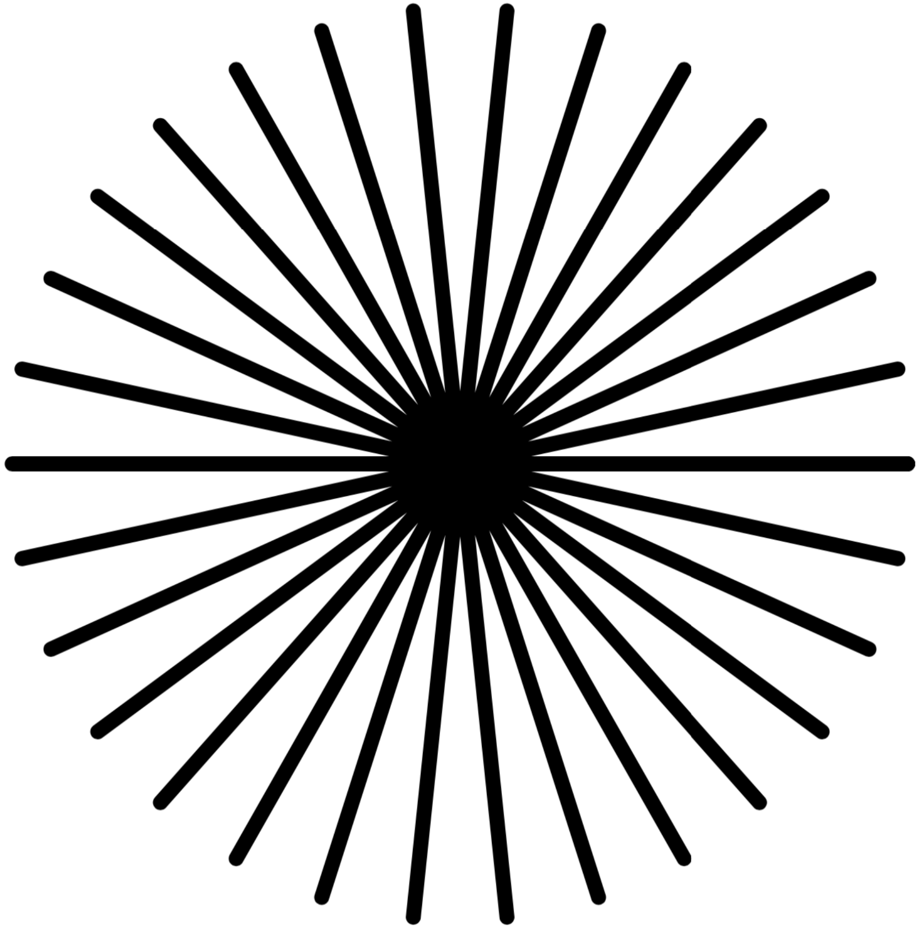
Loops: Another Example

```
%!PS
/X0    50 def           % center position
/Y0    50 def
/RMAX 48 def            % outer radius
/NTURN 5 def            % number of turns

/PHIMAX 360 NTURN mul def % maximal angle

X0 Y0 moveto            % start in center
0 10 PHIMAX {
  /phi exch def         % keep loop var.
                        % (drop from stack!)
  phi PHIMAX div        % get a value from 0 to 1
  dup mul RMAX mul      % square and scale
  dup                   % we need this for x and y
  phi cos mul X0 add % this is x
  exch                  % get radius on top of stack
  phi sin mul Y0 add % this is y
  lineto                % draw a line
} for
stroke
showpage
```



Exercise 4a

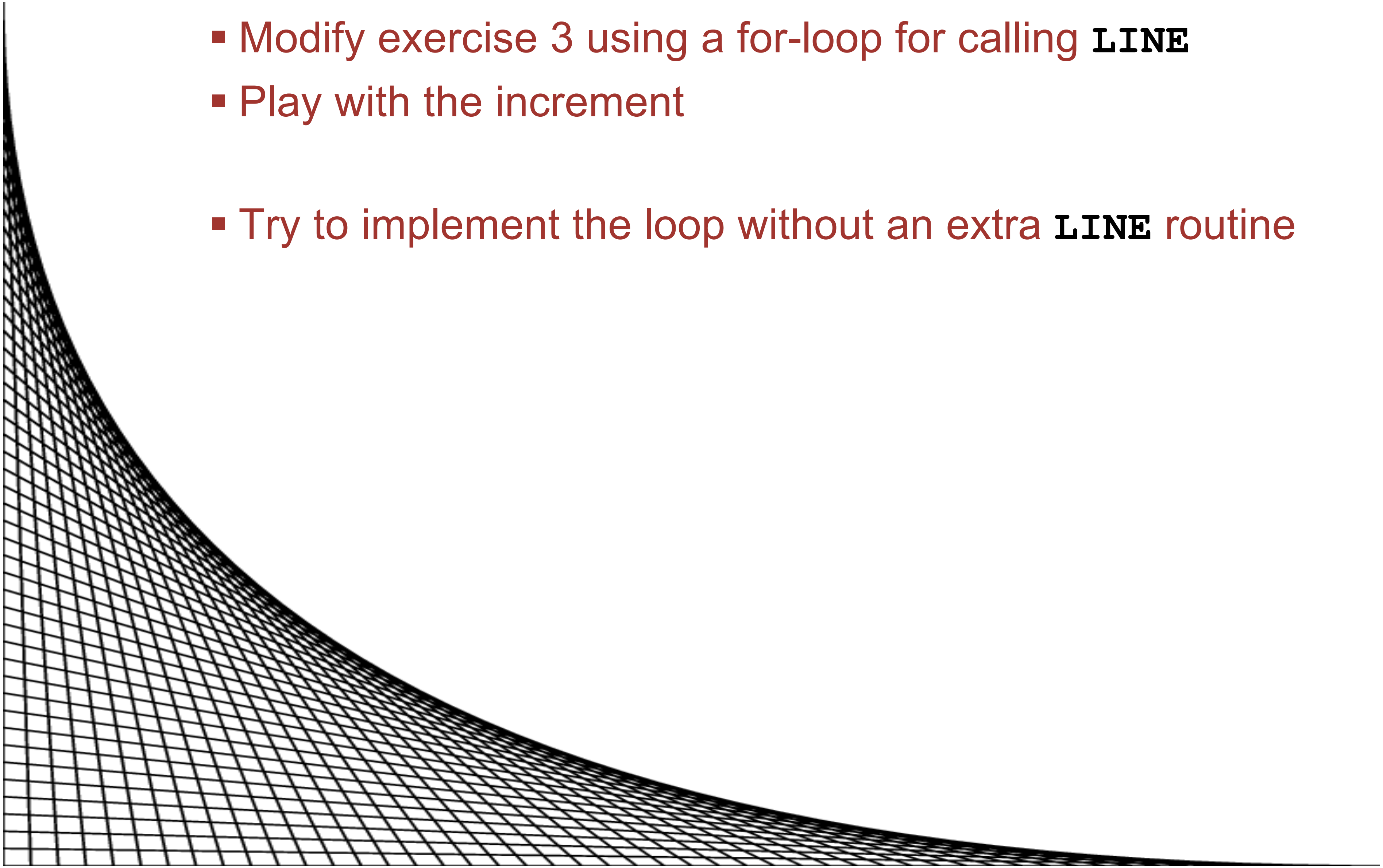
- Modify exercise 3a using a for-loop for calling `LINE`
- Play with the increment



- Try to implement the loop without an extra `LINE` routine

Exercise 4b

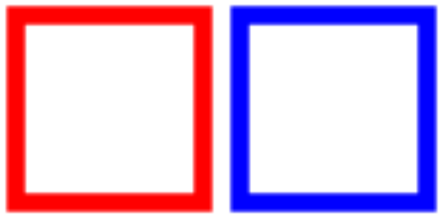
- Modify exercise 3 using a for-loop for calling **`LINE`**
- Play with the increment
- Try to implement the loop without an extra **`LINE`** routine



Conditionals

- Conditional expression are possible
  - ***boolval* {…*commands*…} if**
  - ***boolval* {…*cmds (true)*…} {…*cmds (false)*…} ifelse**
- Boolean values can be
  - **true**
  - **false**
  - **x y eq**
  - **x y gt**
  - **bool1 bool2 or**
  - **bool not**
  - …

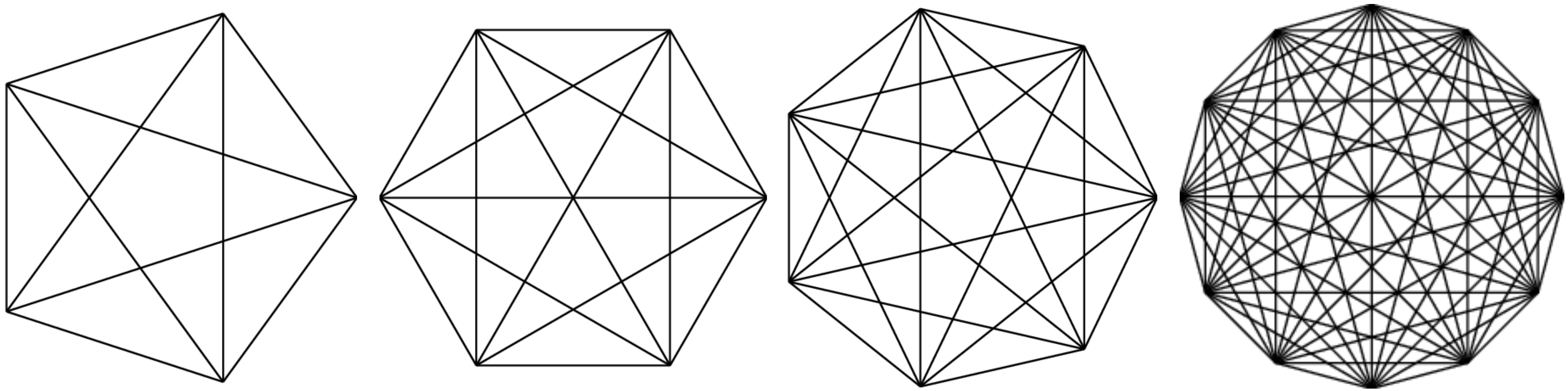
```
%!PS
/BOX { % Assume bool value on stack
 {1 0 0} {0 0 1} ifelse setrgbcolor
 0 0 10 10 rectstroke
} def

1  1 translate true  BOX
12 0 translate false BOX

showpage
```



- Can be used to comment out larger parts of code

Exercise 5

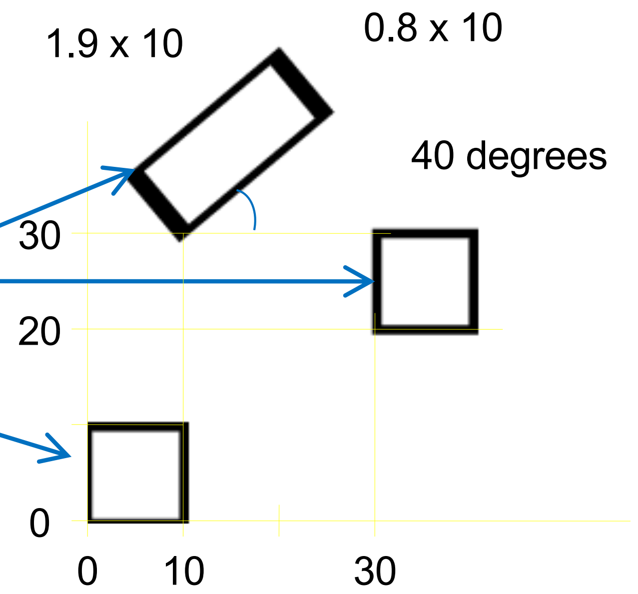
- This exercise is inspired by a problem in the 'Mathekalender' 2011 which offers a mathematics competition every year at http://www.mathekalender.de
- Draw an N-fold polygon with all inner connections…
  - Use two a double loop with 2 indices for the corners
  - Use a function to convert corner index to x/y (using trigonometry)



Translating and Scaling Things

- The coordinate system can be *translated*, *scaled* and *rotated* at any time.
- New transformations are 'added on top'
  - **x y translate**
  - **x y scale** % negative arguments are allowed → flip
  - **phi rotate** % angle in degree, as always

```
%!PS
/BOX {
  0 0 10 10 rectstroke
} def

BOX
30 20 translate BOX
-20 10 translate
40 rotate
1.9 0.8 scale
BOX
showpage
```



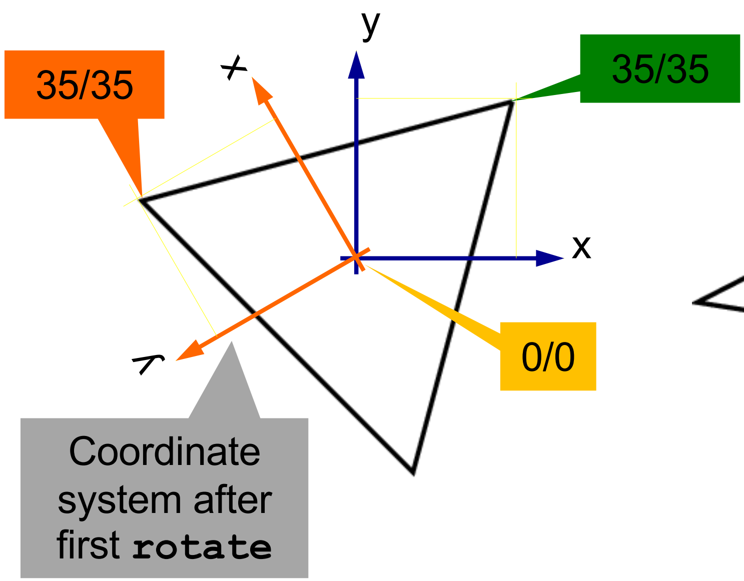
Applications of Coordinate Transformations

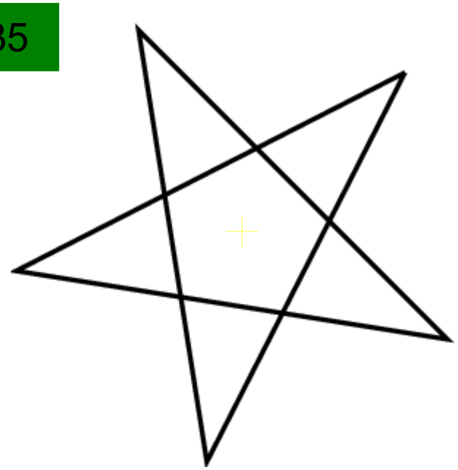
- Coordinate Transformations can simplify code *a lot*:

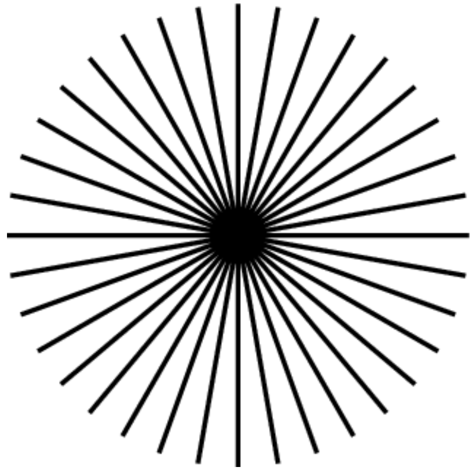
```
35 35 moveto
1 1 3 {
  pop
  120 rotate
  35 35 lineto
} for
stroke
```

```
35 35 moveto
1 1 5 {
  pop
  144 rotate
  35 35 lineto
} for
stroke
```

```
0 0 moveto
1 1 36 { pop
    50 0 lineto
     0 0 moveto
   10 rotate
} for
stroke
```







Converting Orientation and Units

- With

```
%!PS
2.835 dup scale         % now one unit is 1 mm
5 dup translate         % shift by 5/5 mm to center
0.1 setlinewidth        % line width is 0.1mm
newpath                 % draw a frame around A4
  0   0 moveto          % (in portait format)
  0 287 lineto
200 287 lineto
200   0 lineto
closepath
stroke
100 143.5 translate     % move origin to the center
```

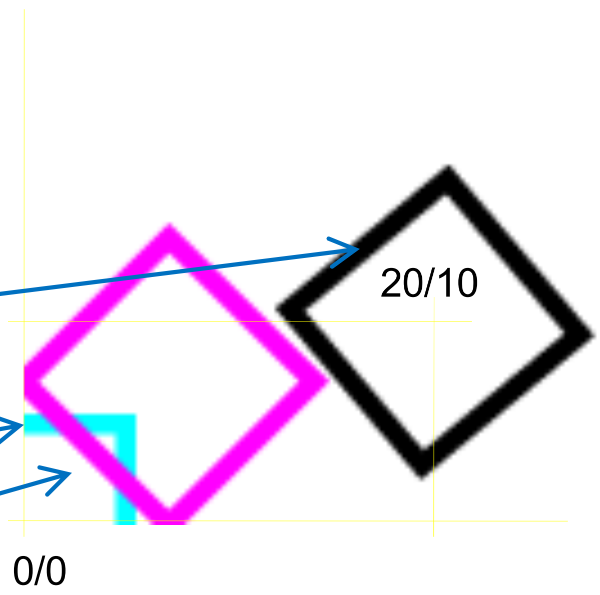
drawing can start in the center, in mm units.

- A frame is drawn around a A4 sheet.

Saving the Graphic State

- Temporary scaling / translating… operations often lead to 'corrupt' coordinate systems
- The graphics state can be remembered with **`gsave`** and restored with **`grestore`**
- Example:

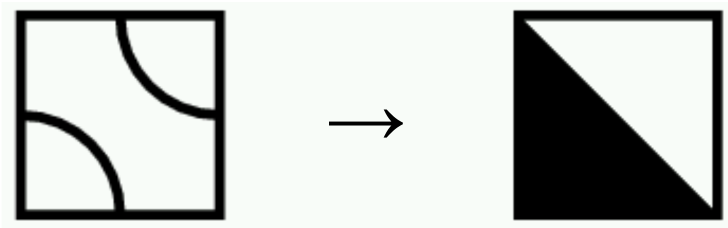
```
%!PS

/BOX { -5 -5 10 10 rectstroke } def
gsave
20 10 translate
40 rotate
0 0 0 setrgbcolor BOX % black

grestore
0 1 1 setrgbcolor BOX % magenta

45 rotate
10 0 translate
1 0 1 setrgbcolor BOX % pink
```



Exercise 6

- Understand how the Truchet Pattern on page 9 works
- Copy the code and play around
  - Change the number of tiles
  - Change the size of the tiles

- Replace the rounded tile by a triangle



Drawing Text

- Strings are delimited by `()`. Example: `(text)`
- Before drawing a **font** must be selected:
  - `/name findfont` (or `currentfont`) — put font '*name*' to stack (height is 1 unit)
    Some font names:
    - `Times-Roman`
    - `Helvetica-Bold`
    - `Courier`
  - `value scalefont` — resize (multiply) font (leave on stack)
  - `setfont` — use it from now on (remove from stack)

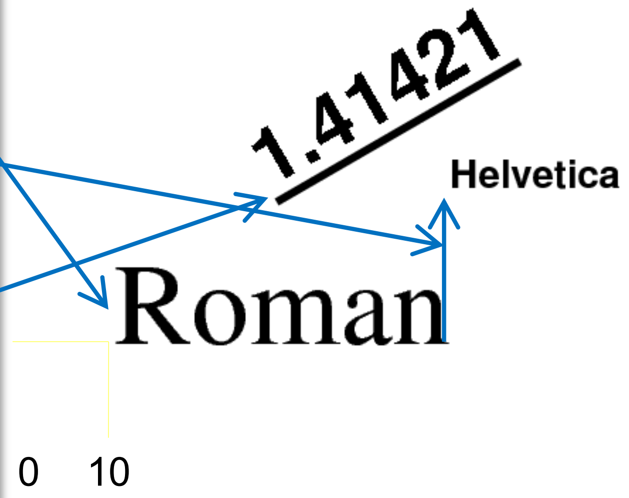
Also: selectfont

- Show a string (which is on the stack): `show`
  - start at current point
  - current point moves to end of string!
- Convert a number to a string: `value 10 string cvs`
- Get width of a string: `strval stringwidth` (get x *and* y)
  - Note: y is always zero and must often be `pop`ed

Drawing Text: Example

- Example:

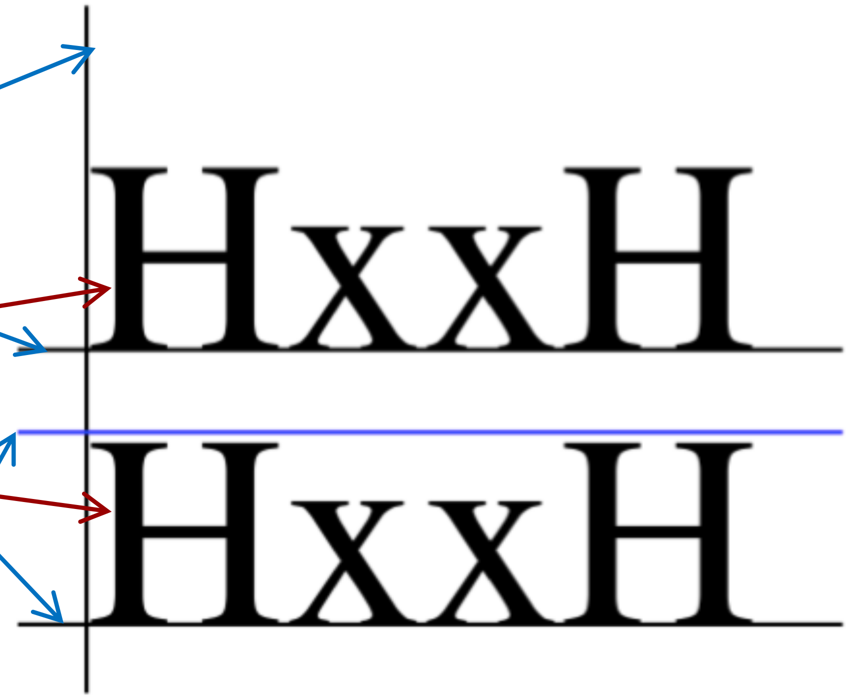
```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 80 70

10 10 translate 0 0 moveto
/Times-Roman findfont
15 scalefont setfont (Roman) show

0 20 rmoveto
/Helvetica-Bold findfont
5 scalefont setfont (Helvetica) show

/x 2 sqrt 10 string cvs def

20 20 translate 30 rotate
0 0 moveto
currentfont 2 scalefont setfont
x show
0 -2 moveto
x stringwidth rlineto stroke

showpage
```



(A Detail: Font Size)

- Font height is from baseline to baseline
- **Character height** is ~ 0.7 x font height (depending on font)

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 70 60

10 10 translate

/FF 20 def
/Times-Roman findfont
FF scalefont setfont

0.3 setlinewidth
 0  -5 moveto 0 50 rlineto stroke
-5  FF moveto 60 0 rlineto stroke
-5   0 moveto 60 0 rlineto stroke

0 FF moveto (HxxH) show
0  0 moveto (HxxH) show

0 0 1 setrgbcolor
-5  FF 0.7 mul moveto 60 0 rlineto stroke

showpage
```



Exercise 7

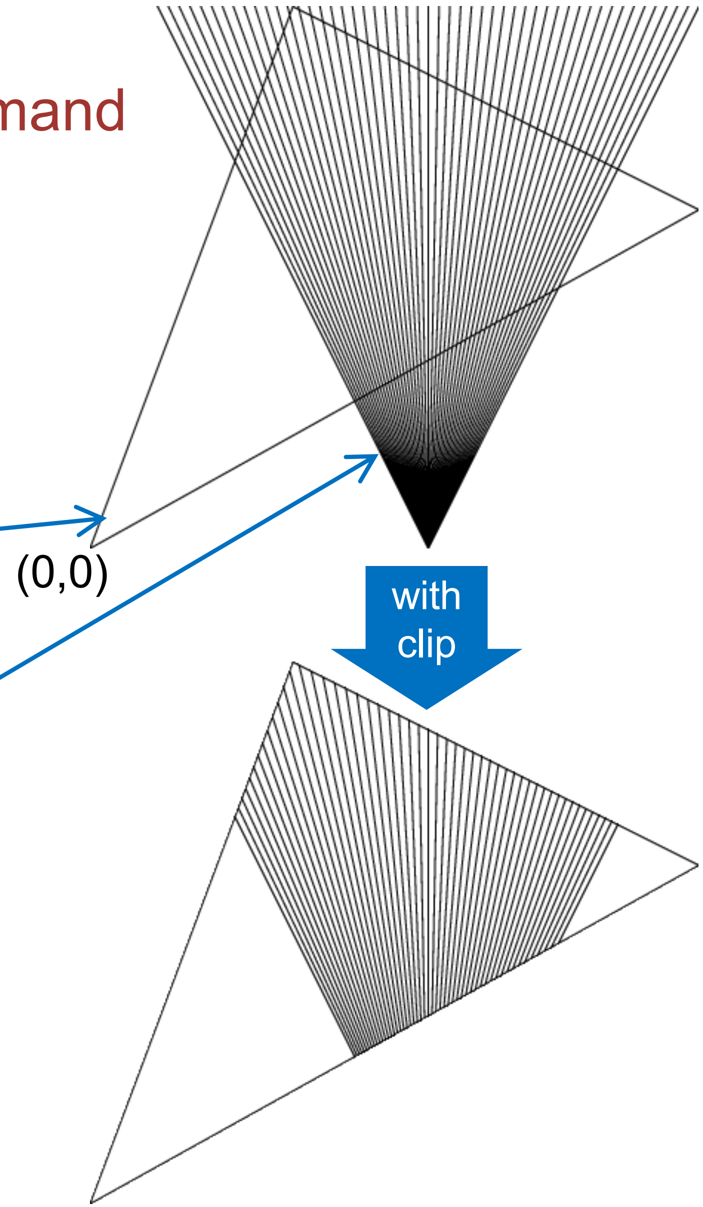
- Draw a box from (10,10) to (50,30)
- Print some text *centered* in the box
  - Use **`stringwidth`** to get the x- and y size of the text
  - Unfortunately, the y size is zero and cannot be used! Use the font height you have chosen instead.

Advanced Topic: Clipping

- A path can be used to restrict the drawing area using the **`clip`** command
- **`initclip`** clears the clipping path

construct clipping path

```
%!PS
0.2 setlinewidth

newpath 0 0 moveto
30 80 lineto 90 50 lineto
closepath
clip

0 2 100 {
  50 0 moveto 100 lineto
} for
stroke

showpage
```



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(For fun: charpath)

- The outline of characters can be converted to a path using the **`charpath`** command.
- Example using **`clip`**:

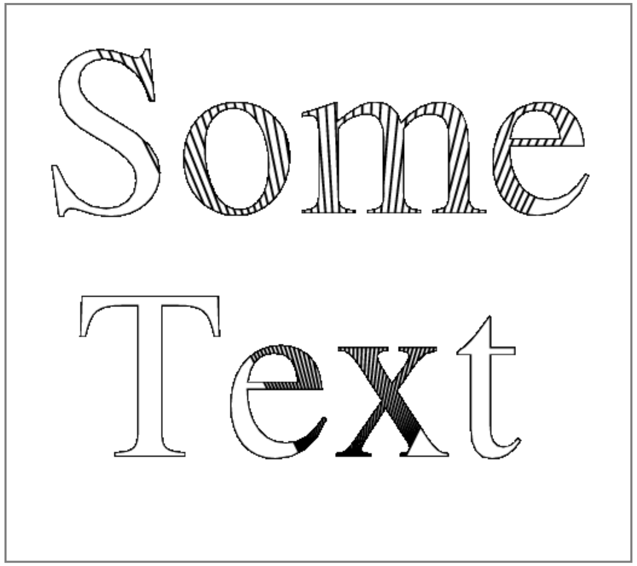
```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 90 80
0.3 setlinewidth

/Times-Roman findfont
35 scalefont setfont
 5 50 moveto (Some) false charpath
10 15 moveto (Text) false charpath

clip

0 2 100 {
  50  0 moveto
    100 lineto
} for
stroke

showpage
```



Advanced: Bit Maps

- The command **`image`** draws a bit map in a *unit square*
  - To change size: scale before in x- and y
- Parameters are:
  - Number of pixels in x
  - Number of pixels in y
  - Bits per pixel
  - A rotation matrix (not explained here..)
  - A function to get the values. Simplest case is a list of values
- Similar command is **`colorimage`**
  - It has some more parameters…

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 100 100

10 10 translate % move image to middle of page
80 80 scale      % make image one inch on a side
4 4 2 [4 0 0 4 0 0] {<fc1be400>} image
showpage
```

We need
4 x 4 x 2 = 32 bit

(Example for colorimage)

```
%!PS-Adobe-3.0 EPSF-3.0
%%BoundingBox: 0 0 102 102

1 1 translate
100 100 scale

/picstr 6 string def

2 2 4 [2 0 0 -2 0 2]
{ currentfile picstr readhexstring pop}
false 3
colorimage
f00080f0088

showpage
```

NX NY bits_per_col

colors separate ?

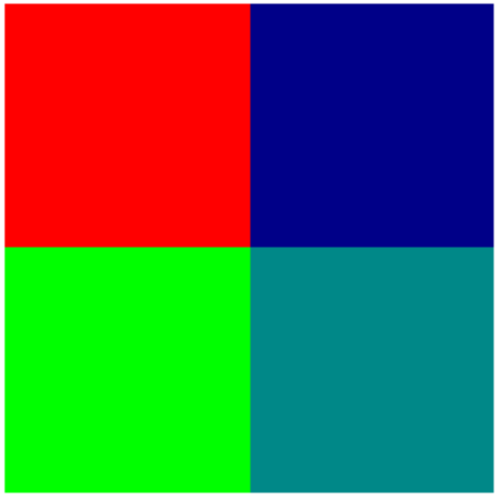
Function to create a string of NX x NCOL characters

matrix

NCOL

Function to retrieve data from file

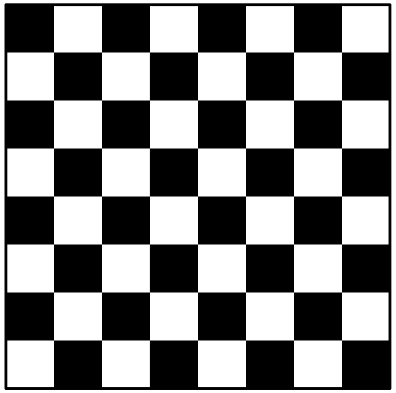
data

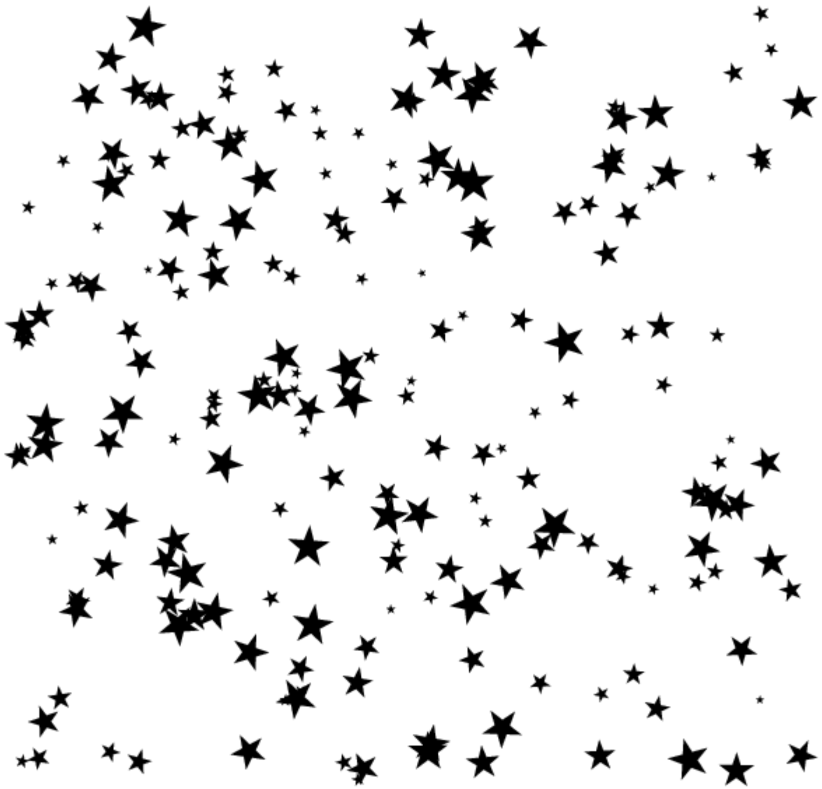


Homework

- Generate a Postscript Drawing with at least the following ingredients:
  - eps file with 10 x 10 cm^2 drawing size
  - Your name printed centered at the bottom
  - Several graphics elements
  - Several colors or gray levels
  - At least one loop
    (as a minimum, repeat some element multiple times)

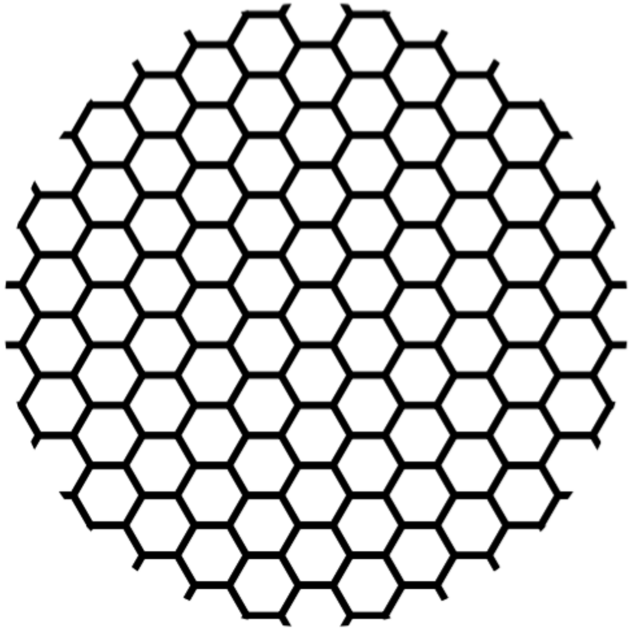
Inspirations

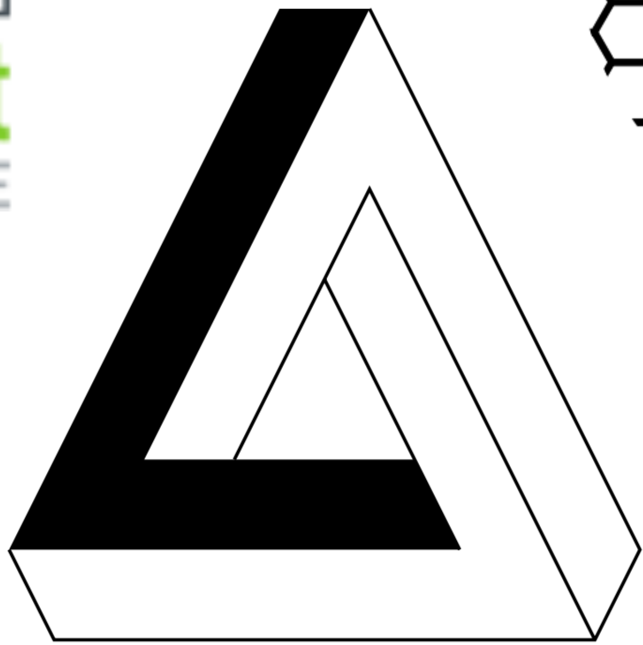




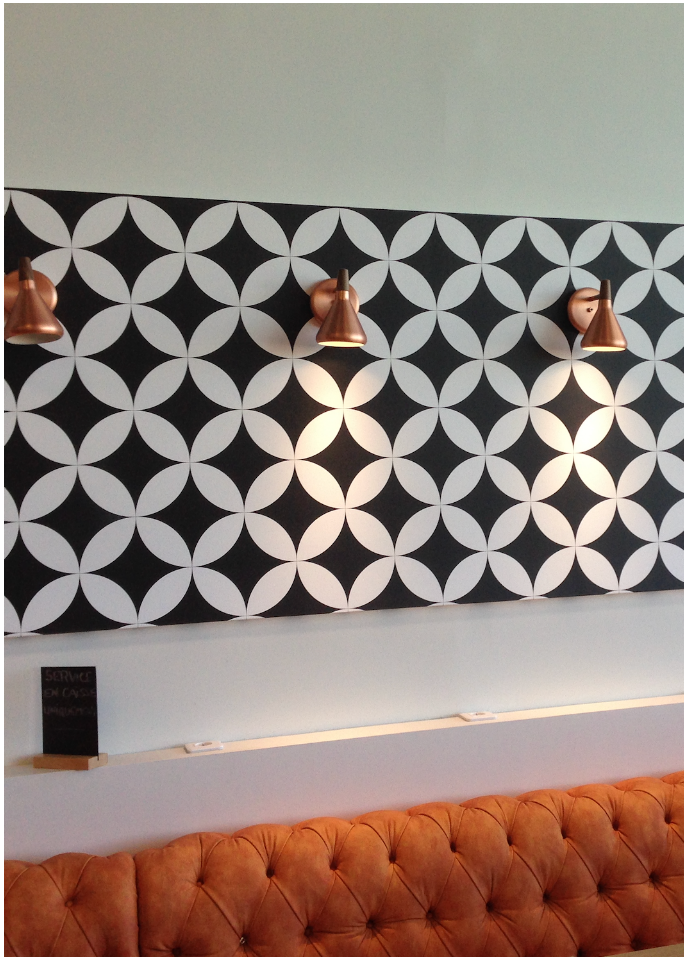
Inspirations

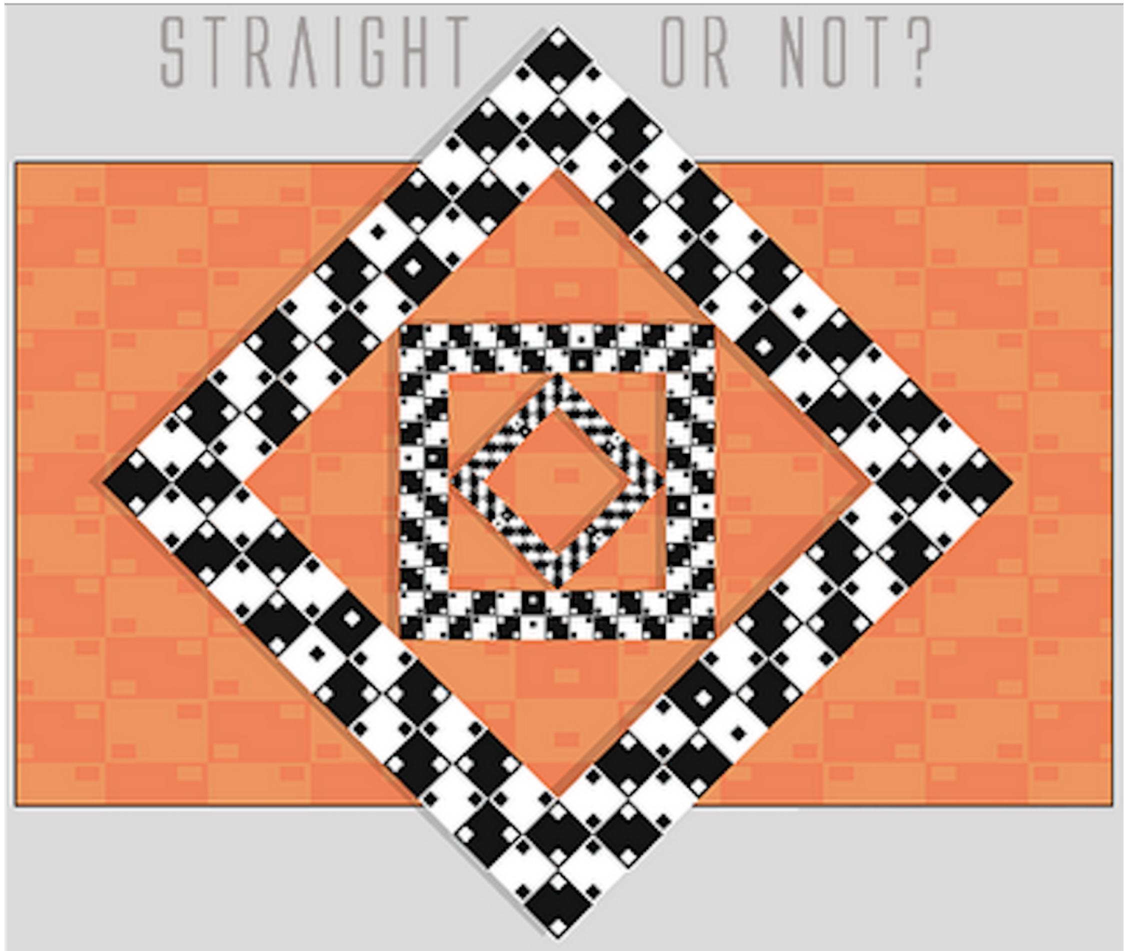
BioQuant
MODEL base of LIFE





More Inspirations





More Inspirations

- Draw Pascal‘s Triangle (https://de.wikipedia.org/wiki/Pascalsches_Dreieck)
- Put a marker (circle, triangle,..) at the position of on all numbers which are multiples of some modulus K
- Examples: