# Ti*k*Z & PGF

TikZ 3.0.1a 中文手册

```
\begin{tikzpicture}
  \coordinate (front) at (0,0);
  \coordinate (horizon) at (0,.31\paperheight);
  \coordinate (bottom) at (0,-.6\paperheight);
  \coordinate (sky) at (0,.57\paperheight);
  \coordinate (left) at (-.51\paperwidth,0);
  \coordinate (right) at (.51\paperwidth,0);

  \shade [bottom color=white,
          top color=blue!30!black!50]
              ([yshift=-5mm]horizon -|  left)
    rectangle (sky -| right);

  \shade [bottom color=black!70!green!25,
          top color=black!70!green!10]
    (front -| left) -- (horizon -| left)
    decorate [decoration=random steps] {
      -- (horizon -| right)  }
    -- (front -| right) -- cycle;

  \shade [top color=black!70!green!25,
         bottom color=black!25]
              ([yshift=-5mm-1pt]front -| left)
    rectangle ([yshift=1pt]front -| right);

  \fill [black!25]
              (bottom -| left)
    rectangle ([yshift=-5mm]front -| right);

  \def\nodeshadowed[#1]#2;{
    \node[scale=2,above,#1]{
      \global\setbox\mybox=\hbox{#2}
      \copy\mybox};
    \node[scale=2,above,#1,yscale=-1,
          scope fading=south,opacity=0.4]{\box\mybox};
  }

  \nodeshadowed [at={(-5,8  )},yslant=0.05]
    {\Huge Ti\textcolor{orange}{\emph{k}}Z};
  \nodeshadowed [at={( 0,8.3)}]
    {\huge \textcolor{green!50!black!50}{\&}};
  \nodeshadowed [at={( 5,8  )},yslant=-0.05]
    {\Huge \textsc{PGF}};
  \nodeshadowed [at={( 0,5  )}]
    {Manual for Version \pgftypesetversion};

  \foreach \where in {-9cm,9cm} {
    \nodeshadowed [at={(\where,5cm)}] { \tikz
      \draw [green!20!black, rotate=90,
             l-system={rule set={F -> FF-[-F+F]+[+F-F]},
               axiom=F, order=4,step=2pt,
               randomize step percent=50, angle=30,
               randomize angle percent=5}] l-system; }}

  \foreach \i in {0.5,0.6,...,2}
    \fill
      [white,opacity=\i/2,
       decoration=Koch snowflake,
       shift=(horizon),shift={(rand*11,rnd*7)},
       scale=\i,double copy shadow={
         opacity=0.2,shadow xshift=0pt,
         shadow yshift=3*\i pt,fill=white,draw=none}]
      decorate {
        decorate {
          decorate {
            (0,0)- ++(60:1) -- ++(-60:1) -- cycle
          } } };

   \node (left text) ...
   \node (right text) ...

   \fill [decorate,decoration={footprints,foot of=gnome},
          opacity=.5,brown]          (rand*8,-rnd*10)
     to [out=rand*180,in=rand*180] (rand*8,-rnd*10);
\end{tikzpicture}
```

Für meinen Vater, damit er noch viele schöne TEX-Graphiken erschaffen kann.

*Till*

# TikZ 和 PGF 宏包

**TikZ 3.0.1a 中文手册**[*][†]

`http://sourceforge.net/projects/pgf`

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August 29, 2015 [§]

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[*] 翻译者：Hansimov。此项目开源在 GitHub，欢迎提出建议或参与翻译：https://github.com/Hansimov/pgfmanual-zh
[†] 本手册中译者所加注释均为蓝色，与本来的注释区分开来。
[‡] 该手册的编者。手册的部分内容由另外一些作者写成，详见 1.5 小节。
[§] 本中文手册更新时间：2018 年 7 月 3 日

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# 1 引言

欢迎阅读 Ti*k*Z 和底层 pgf 系统的文档。一开始这只是一个小小的 LaTeX 样式，用来在我（Till Tantau）的博士论文里画图，如今它已经变成了飞速发展的图形语言，手册有一千多页。Ti*k*Z 的大量选项常常吓到新手，不过好消息是，这个文档还有一些慢节奏的教程，你不必看其他部分，就能学到几乎所有你需要知道的关于 Ti*k*Z 的内容。

我想从“什么是 Ti*k*Z?”这个问题开始。大体上，它只是定义一些 TeX 中的绘图命令。比如说，代码 `\tikz \draw (0pt,0pt) --(20pt,6pt);` 会生成一条线段 ⁄，代码 `\tikz \fill[orange] (1ex,1ex) circle (1ex);` 会生成一个橙色实心圆 ●。从某种意义上说，当你用 Ti*k*Z 的时候，你是在**编写**图形**程序**，就像你用 TeX **编写**文档**程序**一样。这也解释了 Ti*k*Z 这个名字的由来：它是一个递归缩写，追随了“gnu is not unix”的传统。它的德文含义是“Ti*k*Z ist *kein* Zeichenprogramm”，翻译成英文就是“Ti*k*Z is not a drawing program”，中文意思是“Ti*k*Z 不是一个绘图程序”，它在提醒读者注意这个宏包的真正意图。Ti*k*Z 采用“TeX 式的排版”，因此在绘图时沿袭了这样一些优点：迅速创建简单图形，精准定位，可以使用宏，以及一流的排版。同样，它也继承了 TeX 系统的缺点：学习曲线陡峭，不是“所见即所得”（wysiwyg，What You See Is What You Get），微小的改变就需要长时间的重新编译，并且代码并不能真正 “展示出” 事物将有的样子。

现在我们知道什么是 Ti*k*Z 了，那么 pgf 呢？我们之前提过，Ti*k*Z 一开始是 TeX 中一些绘图的宏，并且能同时用在 pdfLaTeX 和传统的（基于 PostScript 的）LaTeX。换句话说，我当时想的是为 TeX 实现一个“可移植的图形格式”（**p**ortable **g**raphics **f**ormat），这也是为什么叫 pgf。这些早期的宏仍然在用，并且组成了该手册所述的“基本层”（basic layer）。不过，如今一名写作者几乎都在和 Ti*k*Z 打交道——它已经自成一套完整的语言了。

## 1.1 Ti*k*Z 底下的图层

事实上，在 Ti*k*Z 底下有两个图层（layer）：

**系统层：** 这一层提供了对**驱动**的完整抽象。驱动就是一个程序，比如 `dvips` 或者 `dvipdfm`，输入 `.dvi` 文件，输出 `.ps` 或者 `.pdf` 文件。（`pdftex` 也可以算作是驱动，尽管它的输入并不是 `.dvi` 文件。这没有影响。）每个驱动都有一套自己的生成图形的语法，每个想用统一语法绘图的人，都对此感到很头疼。而 pgf 的系统层则将这些差异抽象掉了。比如，系统命令 `\pgfsys@lineto{10pt}{10pt}` 延伸了从当前图片 `{pgfpicture}` 到相对坐标 $(10pt, 10pt)$ 的路径。对于不同的驱动，比如 `dvips`、`dvipdfm` 或者是 `pdftex`，系统命令会将其转换成不同的 `\special` 命令。系统层尽可能做到简约，毕竟每加一个额外的命令，都意味着将 pgf 对接到新驱动时，要做更多的工作。

作为一个使用者，你不会直接接触系统层。

**基本层：** 基本层提供了一套基本的命令，在创建复杂图形时，用基本层要比系统层简单的多。比如说，系统层没有画圆的命令，因为圆形几乎可以由更加基础的贝塞尔曲线（Bézier curves）组成。然而作为一个使用者，在画圆时，你只想用一条简单的命令（至少我是这样），而不是写上半页纸的贝塞尔曲线的控制点坐标。因此，基本层有一个 `\pgfpathcircle` 的命令，帮你生成必要的曲线坐标。

基本层拥有一个**核心**(**core**)，它包含了几个相互依赖的包，并且只能一起导入，而其它的**模块**(**modules**)则用于扩展核心，提供更多特定用途的命令，比如操纵节点（node）或者作图。例如，beamer 宏包只用了基本层的核心，而没有用到 `shapes` 这样的模块。

理论上，Ti*k*Z 本身只是几个可能的“前端”之一，集成了一些命令或者特定的语法，使基本层更容易使用。直接使用基本层有一个问题，就是代码通常都很“冗长”。比如要画一个简单的三角形，用基本层你可能需要多达 5 条命令：第 1 条命令从三角形的一个角开始一条路径，第 2 条命令将这条路径延伸到第二个角，第 3 条命令连接第三个角，第 4 条命令闭合路径，第 5 条命令将三角形“绘制”出来（而非“填充”）。如果用 Ti*k*Z 这个前端，这些可以归为一句 metafont 式的简单命令：

```
\draw (0,0) -- (1,0) -- (1,1) -- cycle;
```

实际上，Ti*k*Z 是 PGF 唯一“正式”的前端。Ti*k*Z 可以访问 PGF 的所有特性，不过更容易使用。它的语法结合了 METAFONT 和 PSTRICKS，外加一些我自己的想法。除了 Ti*k*Z ，还有一些其他的前端，但它们大多更倾向于“技术研究”，并且没有 Ti*k*Z 正式。特别是 `pgfpict2e` 这个前端，使用 PGF 的基本层，重新实现了标准的 LaTeX `{picture}` 环境，以及 `\line` 和 `\vector` 这样的命令。这一层其实并没有必要，因为 `pict2e.sty` 宏包在重新实现 `{picture}` 环境上同样出色。当然，`pgfpict2e` 宏包背后的出发点是，简单展示一下如何实现一个前端。

由于大多数使用者只会用到 Ti*k*Z ，几乎不会有人直接用到系统层，因此这个手册的前面部分主要涉及 Ti*k*Z，基本层和系统层将在最后介绍。

## 1.2 和其他图形宏包的对比

Ti*k*Z 并不是 TeX 中唯一的图形宏包。接下来，我会将 Ti*k*Z 和其他宏包作一个非常合理的对比。

1. 标准的 LaTeX `{picture}` 环境可以创建基本图形，但只是一点点。这并不是 LaTeX 的设计者缺乏知识或者想象力，相反，这是 `{picture}` 环境的可移植性带来的代价：它在所有后端驱动上都能用。

2. `pstricks` 宏包

   Compared to Ti*k*Z, `pstricks` has a similar support base. There are many nice extra packages for special purpose situations that have been contributed by users over the last decade. The Ti*k*Z syntax is more consistent than the `pstricks` syntax as Ti*k*Z was developed “in a more centralized manner” and also “with the shortcomings on `pstricks` in mind.”

3. The `xypic` package is an older package for creating graphics. However, it is more difficult to use and to learn because the syntax and the documentation are a bit cryptic.

4. The `dratex` package is a small graphic package for creating a graphics. Compared to the other package, including Ti*k*Z, it is very small, which may or may not be an advantage.

5. The `metapost` program is a powerful alternative to Ti*k*Z. It used to be an external program, which entailed a bunch of problems, but in LuaTeX it is now build in. An obstacle with `metapost` is the inclusion of labels. This is *much* easier to achieve using PGF.

6. The `xfig` program is an important alternative to Ti*k*Z for users who do not wish to “program” their graphics as is necessary with Ti*k*Z and the other packages above. There is a conversion program that will convert `xfig` graphics to Ti*k*Z.

## 1.3 Utility Packages

The PGF package comes along with a number of utility package that are not really about creating graphics and which can be used independently of PGF. However, they are bundled with PGF, partly out of convenience, partly because their functionality is closely intertwined with PGF. These utility packages are:

1. The `pgfkeys` package defines a powerful key management facility. It can be used completely independently of PGF.

2. The `pgffor` package defines a useful `\foreach` statement.

3. The `pgfcalendar` package defines macros for creating calendars. Typically, these calendars will be rendered using PGF’s graphic engine, but you can use `pgfcalendar` also typeset calendars using normal text. The package also defines commands for “working” with dates.

4. The `pgfpages` package is used to assemble several pages into a single page. It provides commands for assembling several “virtual pages” into a single “physical page.” The idea is that whenever TeX has a page ready for “shipout,” `pgfpages` interrupts this shipout and instead stores the page to be shipped out in a special box. When enough “virtual pages” have been accumulated in this way, they are scaled down and arranged on a “physical page,” which then *really* shipped out. This mechanism allows you

to create “two page on one page” versions of a document directly inside LaTeX without the use of any external programs. However, `pgfpages` can do quite a lot more than that. You can use it to put logos and watermark on pages, print up to 16 pages on one page, add borders to pages, and more.

## 1.4 How to Read This Manual

This manual describes both the design of Ti*k*Z and its usage. The organization is very roughly according to “user-friendliness.” The commands and subpackages that are easiest and most frequently used are described first, more low-level and esoteric features are discussed later.

If you have not yet installed Ti*k*Z, please read the installation first. Second, it might be a good idea to read the tutorial. Finally, you might wish to skim through the description of Ti*k*Z. Typically, you will not need to read the sections on the basic layer. You will only need to read the part on the system layer if you intend to write your own frontend or if you wish to port PGF to a new driver.

The “public” commands and environments provided by the system are described throughout the text. In each such description, the described command, environment or option is printed in red. Text shown in green is optional and can be left out.

## 1.5 Authors and Acknowledgements

The bulk of the PGF system and its documentation was written by Till Tantau. A further member of the main team is Mark Wibrow, who is responsible, for example, for the PGF mathematical engine, many shapes, the decoration engine, and matrices. The third member is Christian Feuersänger who contributed the floating point library, image externalization, extended key processing, and automatic hyperlinks in the manual.

Furthermore, occasional contributions have been made by Christophe Jorssen, Jin-Hwan Cho, Olivier Binda, Matthias Schulz, Renée Ahrens, Stephan Schuster, and Thomas Neumann.

Additionally, numerous people have contributed to the PGF system by writing emails, spotting bugs, or sending libraries and patches. Many thanks to all these people, who are too numerous to name them all!

## 1.6 Getting Help

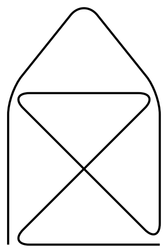
When you need help with PGF and Ti*k*Z, please do the following:

1. Read the manual, at least the part that has to do with your problem.
2. If that does not solve the problem, try having a look at the sourceforge development page for PGF and Ti*k*Z (see the title of this document). Perhaps someone has already reported a similar problem and someone has found a solution.
3. On the website you will find numerous forums for getting help. There, you can write to help forums, file bug reports, join mailing lists, and so on.
4. Before you file a bug report, especially a bug report concerning the installation, make sure that this is really a bug. In particular, have a look at the `.log` file that results when you TeX your files. This `.log` file should show that all the right files are loaded from the right directories. Nearly all installation problems can be resolved by looking at the `.log` file.
5. *As a last resort* you can try to email me (Till Tantau) or, if the problem concerns the mathematical engine, Mark Wibrow. I do not mind getting emails, I simply get way too many of them. Because of this, I cannot guarantee that your emails will be answered timely or even at all. Your chances that your problem will be fixed are somewhat higher if you mail to the PGF mailing list (naturally, I read this list and answer questions when I have the time).

# Part I
# 教程和指导

*by Till Tantau*

为了帮你入门 Ti*k*Z，本手册没有立刻给出长长的安装和配置过程，而是直接从教程开始。这些教程解释了该系统所有基本特性和部分高级特性，并不深入所有细节。这部分还指导你在用 Ti*k*Z 绘图时，如何继续前进。

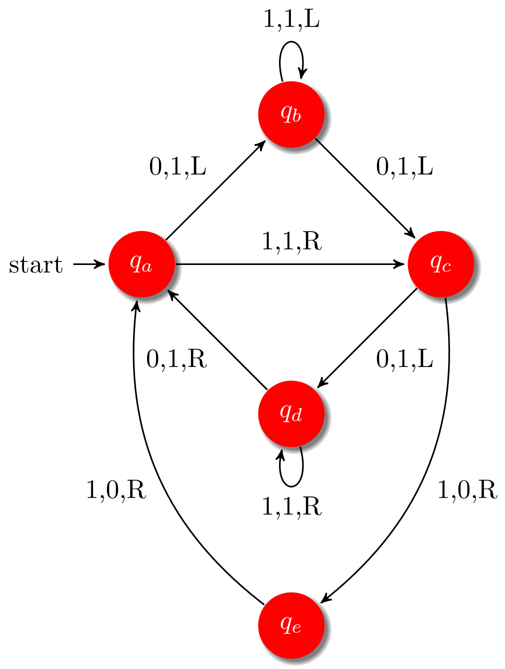


```
\tikz \draw[thick,rounded corners=8pt]
  (0,0) -- (0,2) -- (1,3.25) -- (2,2) -- (2,0) -- (0,2) -- (2,2) -- (0,0) -- (2,0);
```

# Part II
# 安装和配置

*by Till Tantau*

这部分介绍如何安装该系统。通常已经有人帮你装好了，所以你可以跳过这部分；但是如果事与愿违，你是那个不得不自己安装的可怜的家伙，那么请阅读这一部分。



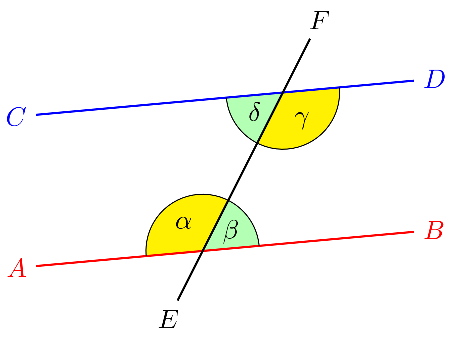
The current candidate for the busy beaver for five states. It is presumed that this Turing machine writes a maximum number of 1's before halting among all Turing machines with five states and the tape alphabet $\{0, 1\}$. Proving this conjecture is an open research problem. 中文测试

```
\begin{tikzpicture}[->,>=stealth',shorten >=1pt,auto,node distance=2.8cm,on grid,semithick,
                    every state/.style={fill=red,draw=none,circular drop shadow,text=white}]

  \node[initial,state] (A)                    {$q_a$};
  \node[state]         (B) [above right=of A] {$q_b$};
  \node[state]         (D) [below right=of A] {$q_d$};
  \node[state]         (C) [below right=of B] {$q_c$};
  \node[state]         (E) [below=of D]       {$q_e$};

  \path (A) edge              node {0,1,L} (B)
            edge              node {1,1,R} (C)
        (B) edge [loop above] node {1,1,L} (B)
            edge              node {0,1,L} (C)
        (C) edge              node {0,1,L} (D)
            edge [bend left]  node {1,0,R} (E)
        (D) edge [loop below] node {1,1,R} (D)
            edge              node {0,1,R} (A)
        (E) edge [bend left]  node {1,0,R} (A);

   \node [right=1cm,text width=8cm] at (C)
   {
     The current candidate for the busy beaver for five states. It is
     presumed that this Turing machine writes a maximum number of
     $1$'s before halting among all Turing machines with five states
     and the tape alphabet $\{0, 1\}$. Proving this conjecture is an
     open research problem. 中文测试
   };
\end{tikzpicture}
```

Part III

# Ti*k*Z ist *kein* Zeichenprogramm

*by Till Tantau*



When we assume that $AB$ and $CD$ are parallel, i. e., $AB \parallel CD$, then $\alpha = \delta$ and $\beta = \gamma$.

```
\begin{tikzpicture}[angle radius=.75cm]

  \node (A) at (-2,0)    [red,left]   {$A$};
  \node (B) at ( 3,.5)    [red,right]  {$B$};
  \node (C) at (-2,2)  [blue,left]  {$C$};
  \node (D) at ( 3,2.5)  [blue,right] {$D$};
  \node (E) at (60:-5mm) [below]      {$E$};
  \node (F) at (60:3.5cm)  [above]      {$F$};

  \coordinate (X) at (intersection cs:first line={(A)--(B)}, second line={(E)--(F)});
  \coordinate (Y) at (intersection cs:first line={(C)--(D)}, second line={(E)--(F)});

  \path
    (A) edge [red, thick]  (B)
    (C) edge [blue, thick] (D)
    (E) edge [thick]       (F)
      pic ["$\alpha$",  draw, fill=yellow]   {angle = F--X--A}
      pic ["$\beta$",   draw, fill=green!30] {angle = B--X--F}
      pic ["$\gamma$",  draw, fill=yellow]   {angle = E--Y--D}
      pic ["$\delta$",  draw, fill=green!30] {angle = C--Y--E};

  \node at ($ (D)!.5!(B) $) [right=1cm,text width=6cm,rounded corners,fill=red!20,inner sep=1ex]
    {
      When we assume that $\color{red}AB$ and $\color{blue}CD$ are
      parallel, i.\,e., ${\color{red}AB} \mathbin{\|} \color{blue}CD$,
      then $\alpha = \delta$ and $\beta = \gamma$.
    };
\end{tikzpicture}
```

## Part IV

# Graph Drawing

*by Till Tantau et al.*

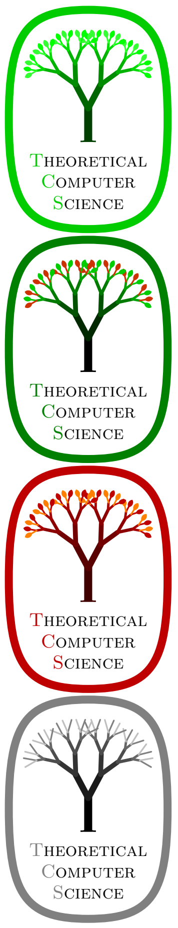
*Graph drawing algorithms* do the tough work of computing a layout of a graph for you. Ti*k*Z comes with powerful such algorithms, but you can also implement new algorithms in the Lua programming language.

You need to use LuaTeX to typeset this part of the manual (and, also, to use algorithmic graph drawing).

## Part V
# Libraries

*by Till Tantau*

In this part the library packages are documented. They provide additional predefined graphic objects like new arrow heads or new plot marks, but sometimes also extensions of the basic PGF or Ti*k*Z system. The libraries are not loaded by default since many users will not need them.

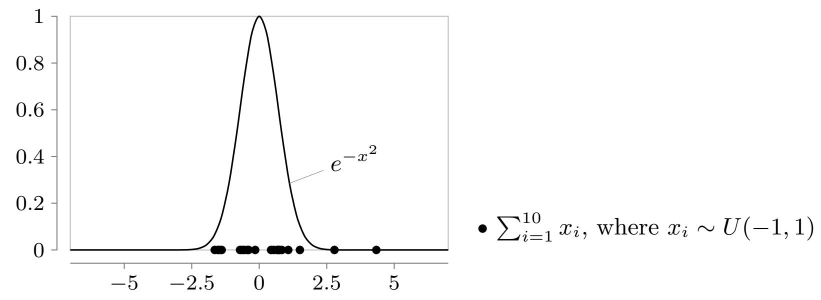


```
\tikzset{
  ld/.style={level distance=#1},lw/.style={line width=#1},
  level 1/.style={ld=4.5mm, trunk,          lw=1ex ,sibling angle=60},
  level 2/.style={ld=3.5mm, trunk!80!leaf a,lw=.8ex,sibling angle=56},
  level 3/.style={ld=2.75mm,trunk!60!leaf a,lw=.6ex,sibling angle=52},
  level 4/.style={ld=2mm,   trunk!40!leaf a,lw=.4ex,sibling angle=48},
  level 5/.style={ld=1mm,   trunk!20!leaf a,lw=.3ex,sibling angle=44},
  level 6/.style={ld=1.75mm,leaf a,         lw=.2ex,sibling angle=40},
}
\pgfarrowsdeclare{leaf}{leaf}
  {\pgfarrowsleftextend{-2pt} \pgfarrowsrightextend{1pt}}
{
  \pgfpathmoveto{\pgfpoint{-2pt}{0pt}}
  \pgfpatharc{150}{30}{1.8pt}
  \pgfpatharc{-30}{-150}{1.8pt}
  \pgfusepathqfill
}

\newcommand{\logo}[5]
{
  \colorlet{border}{#1}
  \colorlet{trunk}{#2}
  \colorlet{leaf a}{#3}
  \colorlet{leaf b}{#4}
  \begin{tikzpicture}
    \scriptsize\scshape
    \draw[border,line width=1ex,yshift=.3cm,
          yscale=1.45,xscale=1.05,looseness=1.42]
      (1,0) to [out=90, in=0]     (0,1)  to [out=180,in=90]  (-1,0)
            to [out=-90,in=-180] (0,-1) to [out=0,  in=-90] (1,0) -- cycle;

    \coordinate (root) [grow cyclic,rotate=90]
    child {
      child [line cap=round] foreach \a in {0,1} {
        child foreach \b in {0,1} {
          child foreach \c in {0,1} {
            child foreach \d in {0,1} {
              child foreach \leafcolor in {leaf a,leaf b}
                { edge from parent [color=\leafcolor,-#5] }
        } } }
      } edge from parent [shorten >=-1pt,serif cm-,line cap=butt]
    };

    \node [align=center,below] at (0pt,-.5ex)
    { \textcolor{border}{T}heoretical \\ \textcolor{border}{C}omputer \\
      \textcolor{border}{S}cience };
  \end{tikzpicture}
}
\begin{minipage}{3cm}
  \logo{green!80!black}{green!25!black}{green}{green!80}{leaf}\\
  \logo{green!50!black}{black}{green!80!black}{red!80!green}{leaf}\\
  \logo{red!75!black}{red!25!black}{red!75!black}{orange}{leaf}\\
  \logo{black!50}{black}{black!50}{black!25}{}
\end{minipage}
```

Part VI

# Data Visualization

*by Till Tantau*

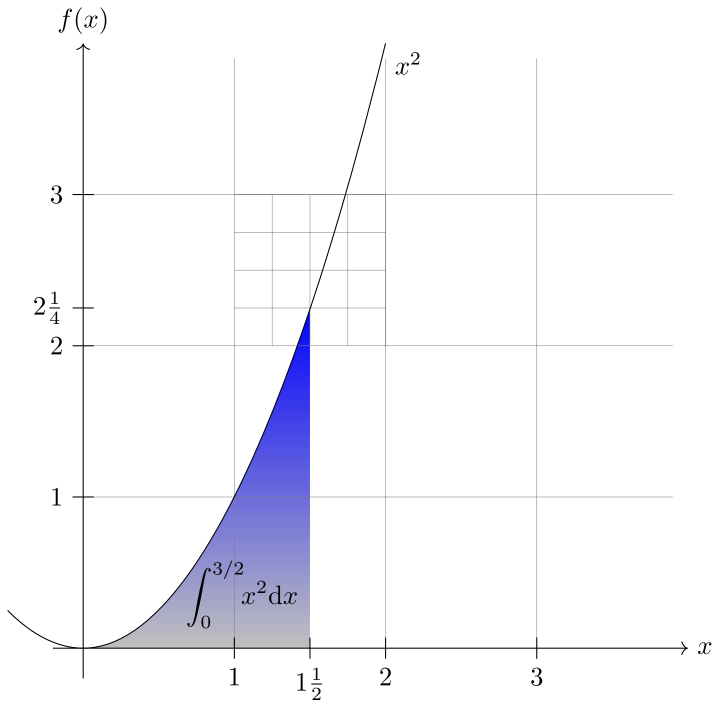


```
\tikz \datavisualization [scientific axes=clean]
[
  visualize as smooth line=Gaussian,
  Gaussian={pin in data={text={$e^{-x^2}$},when=x is 1}}
]
data [format=function] {
  var x : interval [-7:7] samples 51;
  func y = exp(-\value x*\value x);
}
[
  visualize as scatter,
  legend={south east outside},
  scatter={
    style={mark=*,mark size=1.4pt},
    label in legend={text={
        $\sum_{i=1}^{10} x_i$, where $x_i \sim U(-1,1) $}}}
]
data [format=function] {
  var i : interval [0:1] samples 20;
  func y = 0;
  func x = (rand + rand + rand + rand + rand +
            rand + rand + rand + rand + rand);
};
```

## Part VII
# Utilities

*by Till Tantau*

The utility packages are not directly involved in creating graphics, but you may find them useful nonetheless. All of them either directly depend on PGF or they are designed to work well together with PGF even though they can be used in a stand-alone way.



```
\begin{tikzpicture}[scale=2]
  \shade[top color=blue,bottom color=gray!50] (0,0) parabola (1.5,2.25) |- (0,0);
  \draw (1.05cm,2pt) node[above] {$\displaystyle\int_0^{3/2} \!\!x^2\mathrm{d}x$};

  \draw[help lines] (0,0) grid (3.9,3.9)
       [step=0.25cm]      (1,2) grid +(1,1);

  \draw[->] (-0.2,0) -- (4,0) node[right] {$x$};
  \draw[->] (0,-0.2) -- (0,4) node[above] {$f(x)$};

  \foreach \x/\xtext in {1/1, 1.5/1\frac{1}{2}, 2/2, 3/3}
    \draw[shift={(\x,0)}] (0pt,2pt) -- (0pt,-2pt) node[below] {$\xtext$};

  \foreach \y/\ytext in {1/1, 2/2, 2.25/2\frac{1}{4}, 3/3}
    \draw[shift={(0,\y)}] (2pt,0pt) -- (-2pt,0pt) node[left] {$\ytext$};

  \draw (-.5,.25) parabola bend (0,0) (2,4) node[below right] {$x^2$};
\end{tikzpicture}
```

Part VIII

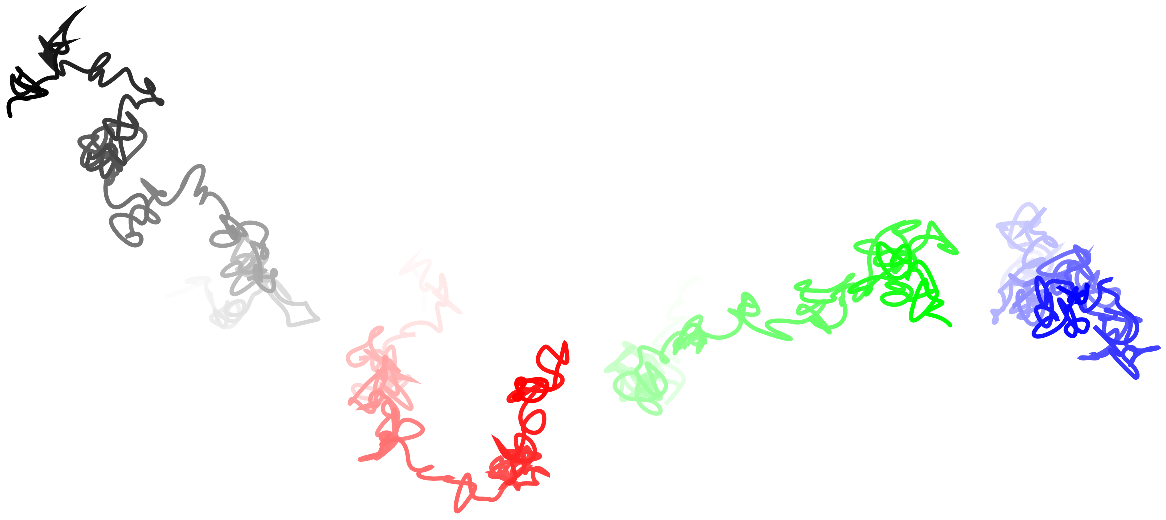
# Mathematical and Object-Oriented Engines

*by Mark Wibrow and Till Tantau*

PGF comes with two useful engines: One for doing mathematics, one for doing object-oriented programming. Both engines can be used independently of the main PGF.

The job of the mathematical engine is to support mathematical operations like addition, subtraction, multiplication and division, using both integers and non-integers, but also functions such as square-roots, sine, cosine, and generate pseudo-random numbers. Mostly, you will use the mathematical facilities of PGF indirectly, namely when you write a coordinate like `(5cm*3,6cm/4)`, but the mathematical engine can also be used independently of PGF and Ti*k*Z.

The job of the object-oriented engine is to support simple object-oriented programming in TeX. It allows the definition of *classes* (without inheritance), *methods*, *attributes* and *objects*.

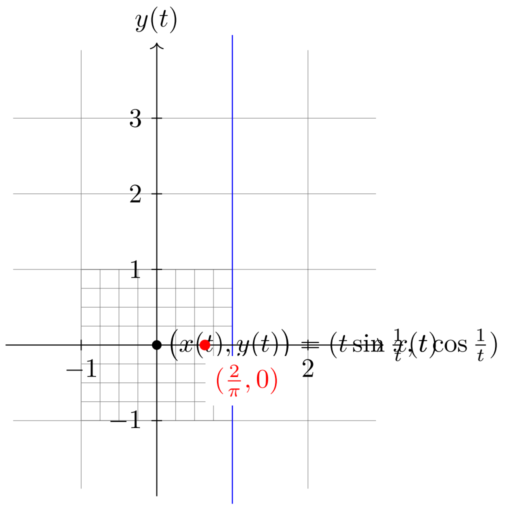


```
\pgfmathsetseed{1}
\foreach \col in {black,red,green,blue}
{
  \begin{tikzpicture}[x=10pt,y=10pt,ultra thick,baseline,line cap=round]
    \coordinate (current point) at (0,0);
    \coordinate (old velocity) at (0,0);
    \coordinate (new velocity) at (rand,rand);

    \foreach \i in {0,1,...,100}
    {
      \draw[\col!\i] (current point)
      .. controls ++([scale=-1]old velocity) and
                  ++(new velocity) .. ++(rand,rand)
         coordinate (current point);
      \coordinate (old velocity) at (new velocity);
      \coordinate (new velocity) at (rand,rand);
    }
  \end{tikzpicture}
}
```

Part IX

# The Basic Layer

*by Till Tantau*



```
\begin{tikzpicture}
  \draw[gray,very thin] (-1.9,-1.9) grid (2.9,3.9)
          [step=0.25cm] (-1,-1) grid (1,1);
  \draw[blue] (1,-2.1) -- (1,4.1); % asymptote

  \draw[->] (-2,0) -- (3,0) node[right] {$x(t)$};
  \draw[->] (0,-2) -- (0,4) node[above] {$y(t)$};

  \foreach \pos in {-1,2}
    \draw[shift={(\pos,0)}] (0pt,2pt) -- (0pt,-2pt) node[below] {$\pos$};

  \foreach \pos in {-1,1,2,3}
    \draw[shift={(0,\pos)}] (2pt,0pt) -- (-2pt,0pt) node[left] {$\pos$};

  \fill (0,0) circle (0.064cm);
  \draw[thick,parametric,domain=0.4:1.5,samples=200]
    % The plot is reparameterised such that there are more samples
    % near the center.
    plot[id=asymptotic-example] function{(t*t*t)*sin(1/(t*t*t)),(t*t*t)*cos(1/(t*t*t))}
    node[right] {$\bigl(x(t),y(t)\bigr) = (t\sin \frac{1}{t}, t\cos \frac{1}{t})$};

  \fill[red] (0.63662,0) circle (2pt)
    node [below right,fill=white,yshift=-4pt] {$(\frac{2}{\pi},0)$};
\end{tikzpicture}
```

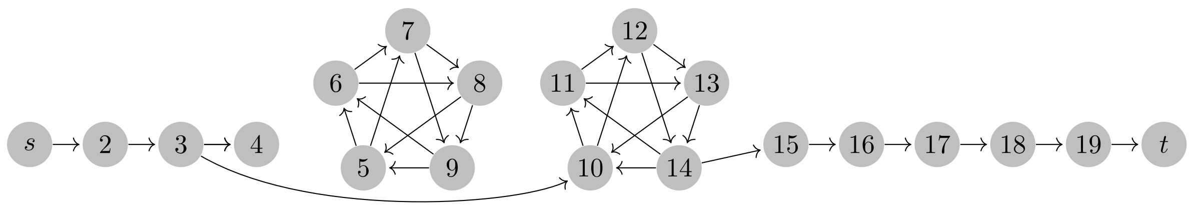
# Part X
# The System Layer

*by Till Tantau*

This part describes the low-level interface of PGF, called the *system layer*. This interface provides a complete abstraction of the internals of the underlying drivers.

Unless you intend to port PGF to another driver or unless you intend to write your own optimized frontend, you need not read this part.

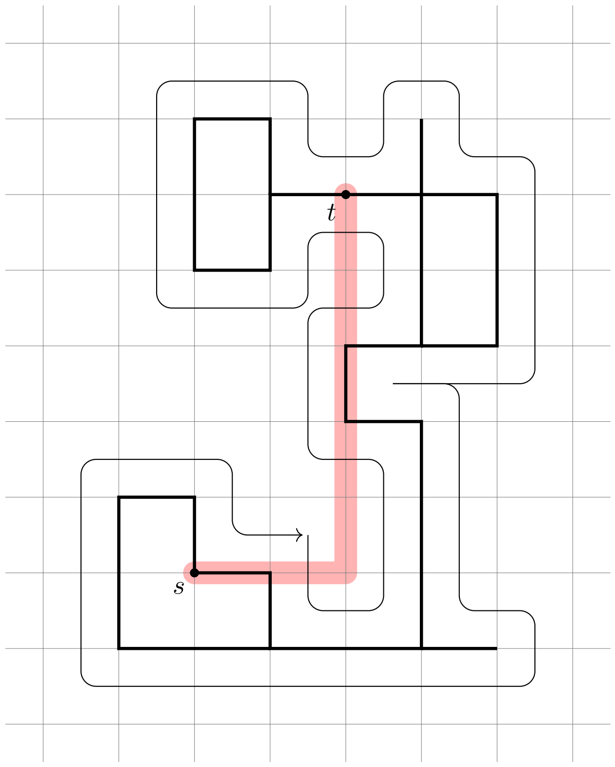
In the following it is assumed that you are familiar with the basic workings of the `graphics` package and that you know what TEX-drivers are and how they work.



```
\begin{tikzpicture}
  [shorten >=1pt,->,
   vertex/.style={circle,fill=black!25,minimum size=17pt,inner sep=0pt}]

  \foreach \name/\x in {s/1, 2/2, 3/3, 4/4, 15/11, 16/12, 17/13, 18/14, 19/15, t/16}
    \node[vertex] (G-\name) at (\x,0) {$\name$};

  \foreach \name/\angle/\text in {P-1/234/5, P-2/162/6, P-3/90/7, P-4/18/8, P-5/-54/9}
    \node[vertex,xshift=6cm,yshift=.5cm] (\name) at (\angle:1cm) {$\text$};

  \foreach \name/\angle/\text in {Q-1/234/10, Q-2/162/11, Q-3/90/12, Q-4/18/13, Q-5/-54/14}
    \node[vertex,xshift=9cm,yshift=.5cm] (\name) at (\angle:1cm) {$\text$};

  \foreach \from/\to in {s/2,2/3,3/4,3/4,15/16,16/17,17/18,18/19,19/t}
    \draw (G-\from) -- (G-\to);

  \foreach \from/\to in {1/2,2/3,3/4,4/5,5/1,1/3,2/4,3/5,4/1,5/2}
    { \draw (P-\from) -- (P-\to); \draw (Q-\from) -- (Q-\to); }

  \draw (G-3) .. controls +(-30:2cm) and +(-150:1cm) .. (Q-1);
  \draw (Q-5) -- (G-15);
\end{tikzpicture}
```

Part XI

# References and Index



```
\begin{tikzpicture}
  \draw[line width=0.3cm,color=red!30,line cap=round,line join=round] (0,0)--(2,0)--(2,5);
  \draw[help lines] (-2.5,-2.5) grid (5.5,7.5);
  \draw[very thick] (1,-1)--(-1,-1)--(-1,1)--(0,1)--(0,0)--
    (1,0)--(1,-1)--(3,-1)--(3,2)--(2,2)--(2,3)--(3,3)--
    (3,5)--(1,5)--(1,4)--(0,4)--(0,6)--(1,6)--(1,5)
    (3,3)--(4,3)--(4,5)--(3,5)--(3,6)
    (3,-1)--(4,-1);
  \draw[below left] (0,0) node(s){$s$};
  \draw[below left] (2,5) node(t){$t$};
  \fill (0,0) circle (0.06cm) (2,5) circle (0.06cm);
  \draw[->,rounded corners=0.2cm,shorten >=2pt]
    (1.5,0.5)-- ++(0,-1)-- ++(1,0)-- ++(0,2)-- ++(-1,0)-- ++(0,2)-- ++(1,0)--
   ++(0,1)-- ++(-1,0)-- ++(0,-1)-- ++(-2,0)-- ++(0,3)-- ++(2,0)-- ++(0,-1)--
   ++(1,0)-- ++(0,1)-- ++(1,0)-- ++(0,-1)-- ++(1,0)-- ++(0,-3)-- ++(-2,0)--
   ++(1,0)-- ++(0,-3)-- ++(1,0)-- ++(0,-1)-- ++(-6,0)-- ++(0,3)-- ++(2,0)--
   ++(0,-1)-- ++(1,0);
\end{tikzpicture}
```