

1 3D Tools

TikZ Library `3dtools`

```
\usetikzlibrary{3dtools} % LATEX and plain TEX
\usetikzlibrary[3dtools] % ConTEXt
```

This library provides additional tools to create 3d-like pictures. It is a collection of reasonably working tools, which however is not streamlined, and may be subject to substantial changes if the library ever happens to get further developed or published. This library loads the `3d`, `decorations` and `fpu` libraries.

TikZ has the `3d` and `tpp` libraries which deal with the projections of three-dimensional drawings. In addition there exist excellent packages like `tikz-3dplot`. The purpose of this library is to provide some means to manipulate the coordinates. It supports linear combinations of vectors, vector products and scalar products.

Note: Hopefully this library is only temporary and its contents will be absorbed in slightly extended versions of the `3d` and `calc` libraries. The cleanest way will be to record a screen depth when “saving” a coordinate with TikZ. Some limited support of such a functionality is provided in this library, see section 1.4. However, a full-fledged realization would require changes at the level of `tikz.code.tex` and can only be done consistently if the maintainer(s) of TikZ make some fundamental changes. Even if this happens, dealing with node anchors and so on, which so far are intrinsically two-dimensional (see, however, <https://github.com/ZhiyuanLck/dnnplot> for an impressive counterexample) will be nontrivial because one will have to specify the orientation in 3d as far as supported. Note also that it is quite conceivable that the viewers in the future will be able to achieve 3d ordering, so, in a way, recording the screen depth (see the `screendepth` function below) will become almost mandatory at a given point.

Filing a bug report or placing a feature request. This library is currently hosted under <https://github.com/marmotghost/tikz-3dtools>. The author is also active at the *noncommercial* Q & A site <https://topanswers.xyz/tex>, which offers, apart from the possibility of asking questions and browsing through the posts a chat in which one can discuss problems.

Why is this library not on CTAN? First of all, ideally this library is only temporary. Secondly, the author does not have a law degree, and finds it very hard to select the appropriate license for submitting the library to CTAN. The library is written as a fun project, everyone is free to use it, and trying to understand all the legal stuff that seems to be required to perform a successful submission to CTAN is not the kind of fun the author is after. This is not to say that CTAN does not have a point in requiring all these data.

1.1 Coordinate computations

The `3dtools` library has some options and styles for coordinate computations and manipulations.

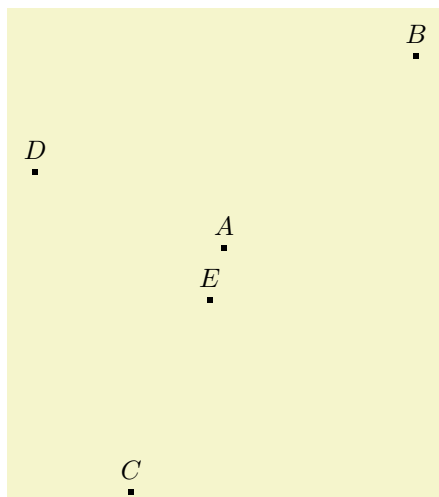
`/tikz/3d parse` (no value)

Parses an expression and inserts the result in form of a coordinate.

`/tikz/3d coordinate` (no value)

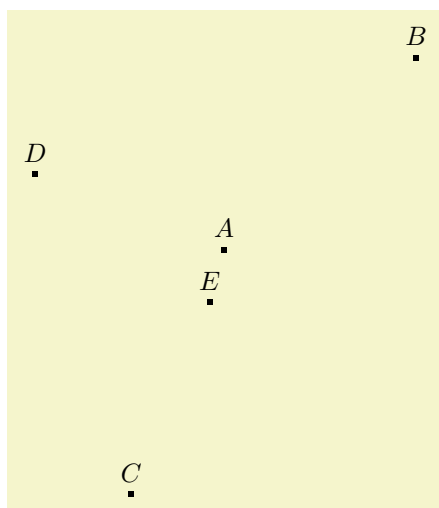
Allow one to define a 3d coordinate from other coordinates.

Both keys support both symbolic and explicit coordinates.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}
\path (1,2,3) coordinate (A)
(2,3,-1) coordinate (B)
(-1,-2,1) coordinate (C)
[3d parse={0.25*(1,2,3)x(B)}]
coordinate(D)
[3d parse={0.25*(C)x(B)}]
coordinate(E);
\path foreach \X in {A,...,E}
{(\X) node[fill,inner sep=1pt,
label=above:$\X$]{};};
\end{tikzpicture}
```

Notice that, as of now, only the syntax `\path (1,2,3) coordinate (A);` works, yet `\coordinate (A) at (1,2,3);` does *not* work, but leads to error messages.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}
\path (1,2,3) coordinate (A)
(2,3,-1) coordinate (B)
(-1,-2,1) coordinate (C)
[3d coordinate={ (D)=0.25*(1,2,3)x(B) },
3d coordinate={ (E)=0.25*(C)x(B) },
3d coordinate={ (F)=(A)-(B) },];
\path foreach \X in {A,...,E}
{(\X) node[fill,inner sep=1pt,
label=above:$\X$]{};};
\end{tikzpicture}
```

The actual parsings are done by the function `\pgfmaththdparse` that allows one to parse 3d expressions. The supported vector operations are + (addition +), - (subtraction -), * (multiplication of the vector by a scalar), x (vector product \times) and o (scalar product). Admittedly, this function is currently very poor. Enhancing it will be a top priority if this is ever to become a CTAN library/package.

`\pgfmaththdparse{⟨x⟩}`

Parses 3d expressions.

`TDx("vector")`

Yields the x -component of a 3d expression.

`TDy("vector")`

Yields the y -component of a 3d expression.

`TDz("vector")`

Yields the z -component of a 3d expression.

`screendepth("vector")`

Yields distance a coordinate is above (positive) or below (negative) the screen. The values are only really meaningful if the user has installed some reasonable view. The larger the screen depth of a

point is, the closer is the point to the observer. The function reconstructs the 3-bein¹ from lengths like `\pgf@xy` and so on, so the function is independent of the tool that is employed to install a view (cf. section 1.2). The screen depth is crucial to decide which objects are in front of other objects.

`tddistance("point 1","point 2")`

Yields the distance between *point 1* and *point 2*. You have to keep the parentheses, e.g. `tddistance("(P)","(Q)")` works if you defined the points (P) and Q!, but not `tddistance("P","Q")`;

`nscreenx`

Yields the *x*-component of the normal on the screen.

`nscreeny`

Yields the *y*-component of the normal on the screen.

`nscreenz`

Yields the *z*-component of the normal on the screen.

`x2d`

Yields the *x*-component of a symbolic coordinate on the screen.

`y2d`

Yields the *y*-component of a symbolic coordinate on the screen.

In order to pretty-print the result one may want to use `\pgfmathprintvector`, and use the math function TD for parsing.

`\pgfmathprintvector{\langle x \rangle}`

Pretty-prints vectors.

$$0.2 \vec{A} - 0.3 \vec{B} + 0.6 \vec{C} = (-1, -1.7, 1.5)$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{TD("0.2*(A)
-0.3*(B)+0.6*(C)")}%
$0.2\,\vec A-0.3\,\vec B+0.6\,\vec C
=(\pgfmathprintvector\pgfmathresult)$
```

The alert reader may wonder why this works, i.e. how would TikZ “know” what the coordinates *A*, *B* and *C* are. It works because the coordinates in TikZ are global, so they get remembered from the above example.

Warning. The expressions that are used in the coordinates will only be evaluated when they are retrieved. So, if you use, say, random numbers, you will get each time a *different* result. This is because this library is working with `\tikz@dc1@coord@{coord}`, where `\langle coord \rangle` is the name of the coordinate, say *A*. This is the string with which the coordinate was generated, e.g. (1,2,3). However, the coordinate will always be at the same location. So you may want to avoid using functions that change their values when declaring coordinates that get used later in coordinate calculations.

$$\vec{R} = (0.51, 0.81, 0.12)$$

$$\vec{R} = (0.29, 0.84, 0.62)$$

```
\usetikzlibrary {3dtools}
\begin{tikzpicture}
\path[overlay] (0.1+rnd,0.1+rnd,0.1+rnd)
coordinate (R);
\def\ppv{\pgfmathprintvector\pgfmathresult}
\draw[red] (R) circle[radius=0.1];
\node at (0,1)
{\pgfmathparse{TD("(R)")}%
$\vec R=(\ppv)$};
\draw[blue] (R) circle[radius=0.2];
\node at (0,0)
{\pgfmathparse{TD("(R)")}%
$\vec R=(\ppv)$};
\end{tikzpicture}
```

¹A 3-bein or dreibein is a German word that stands for a local frame, its literal translation is something like three-leg. Like the term eigenvector this is a foreign word that, to the best of my knowledge, has no commonly used English counterpart.

The main usage of `\pgfmathprintvector` is to strip off unnecessary zeros, which emerge since the internal computations are largely done with the `fp` library.

$$(1, 0, 0)^T \times (0, 1, 0)^T = (0, 0, 1)^T$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{TD("(1,0,0)x(0,1,0)")}%
$(1,0,0)^T\times(0,1,0)^T=
(\pgfmathprintvector\pgfmathresult)^T$
```

$$\vec{A} \cdot \vec{B} = 5$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{TD("(A)o(B)")}%
$\vec{A}\cdot\vec{B}=
\pgfmathprintnumber\pgfmathresult$
```

Notice that, as of now, the only purpose of brackets (\dots) is to delimit vectors. Further, the addition $+$ and subtraction $-$ have a *higher* precedence than vector products \times and scalar products \circ . That is, $(A)+(B)\circ(C)$ gets interpreted as $(\vec{A} + \vec{B}) \cdot \vec{C}$, and $(A)+(B)\times(C)$ as $(\vec{A} + \vec{B}) \times \vec{C}$.

$$(\vec{A} + \vec{B}) \cdot \vec{C} = -11$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{TD("(A)+(B)o(C)")}%
$(\vec{A}+\vec{B})\cdot\vec{C}=
\pgfmathprintnumber\pgfmathresult$
```

$$(\vec{A} + \vec{B}) \times \vec{C} = (9, -5, -1)$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{TD("(A)+(B)x(C)")}%
$(\vec{A}+\vec{B})\times\vec{C}=
(\pgfmathprintvector\pgfmathresult)$
```

Moreover, any expression can only have either one \circ or one \times , or none of these. Expressions with more of these can be accidentally right.

`axisangles("vector")`

Yields the the rotation angles that transforms the vector in the z -axis. Since an axis has a residual rotation symmetry, namely the rotation around this axis, only two angles are required, and thus returned. In the conventions of section 1.2, these are the angles ϕ and ψ . It corresponds to the macro `\tdplotgetpolarcoords{<x>}{<y>}{<z>}` from the `tikz-3dplot` package.

$$\angle(\vec{A}) = -116.57, -36.7$$

```
\usetikzlibrary {3dtools}
\pgfmathparse{axisangles("A")}%
$\sphericalangle(\vec{A})=
\pgfmathprintvector\pgfmathresult$
```

Computations in 3d sometimes involve projections of a point on a line or a plane. In 2d, projections of a point on a line can be conveniently done with the `calc` library, but this does in general not yield the correct projection in 3d. In order to make these projections more user friendly, `3dtools` offers the possibility to define extended objects such as lines or planes. This is the same concept as what is offered by plain TikZ, where the user can name coordinates and nodes, and, if the `intersections` library is loaded, also paths.

/tikz/3d/plane through=point 1 and point 2 and point 3 named name (no default)

Defines a plane of name *name* by the requirement that it goes through the three specified points. Internally the plane is stored in terms of its normal and a point it goes through.

/tikz/3d/plane with normal=normal through point 1 named name (no default)

Defines a plane of name *name* by the requirement that it goes through *point 1* and has the normal *normal*. Internally the plane is stored in terms of this normal and point.

/tikz/3d/line through=point 1 and point 2 named name (no default)

Defines a line of name *name* by the requirement that it goes through *point 1* and *point 1*.

/tikz/3d/line with direction=vector through point 1 named name (no default)

Defines a line of name *name* by the requirement that it goes through *point 1* and has direction *vector*.

`/tikz/3d/sphere with center=`*center* and radius *radius* named *name* (no default)
 Defines a sphere with center *center* and radius *radius*.

`/tikz/3d/intersection of=`*object 1* with *object 2* (no default)
 Computes the intersection of a named object *object 1* with another object *object 2*. Currently only intersections of lines with lines and planes with lines are supported. There is also some support for intersections of lines with spheres. The intersections get also named by some predefined names. Note that if intersections cannot be found, warnings will be issued. Due to the limited precision of \TeX the decision whether or not an intersection actually exists may be wrong in close cases.

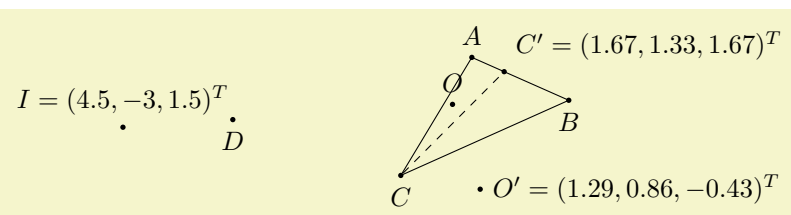
`/tikz/3d/aux keys/intersection 1` (initially I-1)
 Predefined name for the first intersection.

`/tikz/3d/aux keys/intersection 2` (initially I-2)
 Predefined name for the second intersection.

These extended objects can be used in projections.

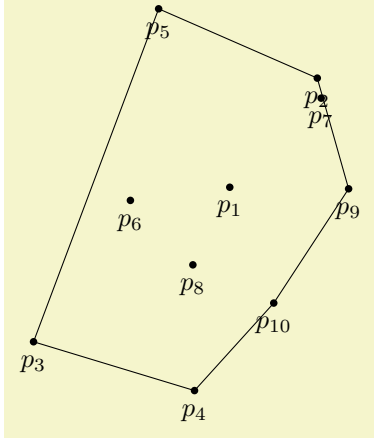
`/tikz/3d/project=`*point* on *named object* (no default)
 Computes the projection of a point on some extended object, and inserts the projection in the path.

The following code example illustrates the usage. It also makes use of the `install view` key, which we describe in section 1.2.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=110,psi=0,theta=60},
dot/.style={circle,inner sep=0pt,
minimum size=2pt,fill}]
\draw[every coordinate node/.append style={dot}]
(2,1,2) coordinate[label=above:{$A$}] (A) --
(1,2,1) coordinate[label=below:{$B$}] (B) --
(2,0,0) coordinate[label=below:{$C$}] (C) -- cycle
(0,0,0) coordinate[label=above:{$O$}] (O)
(3,-2,1) coordinate[label=below:{$D$}] (D);
\path[3d/plane through={ (A) and (B) and (C) named pABC},
3d/plane with normal={ (1,1,1) through (C) named ptwo},
3d/line through={ (A) and (B) named lAB},
3d/line through={ (O) and (D) named lOD}];
% project point on plane
\path[3d/project={ (O) on pABC}] coordinate (O');
% project point on line
\path[3d/project={ (C) on lAB}] coordinate (C');
% intersection of plane and line
\path[3d/intersection of={ lOD with pABC}] coordinate (I);
\draw[dashed] (C) -- (C')
coordinate[dot,label=above right:{$C'=\pgfmathparse{TD("(C')")}\%
(\pgfmathprintvector\pgfmathresult)^T$}];
\path (O') coordinate[dot,label=right:{$O'=\pgfmathparse{TD("(O')")}\%
(\pgfmathprintvector\pgfmathresult)^T$}];
\path (I) coordinate[dot,label=above:{$I=\pgfmathparse{TD("(I")}\%
(\pgfmathprintvector\pgfmathresult)^T$}];
\end{tikzpicture}
```

`/tikz/convex hull of={`*(list of coordinates)*`}` (no default)
 Style that inserts a path for the 2-dimensional convex hull of a list of named coordinates.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}
\path foreach \X in {1,...,10}
{ (rnd*360:rnd*3) coordinate (p\X)
node[circle,inner sep=1pt,fill,label=below:$p_{\X}$]{};
\draw[convex hull of={p1,p2,p3,p4,p5,p6,p7,p8,p9,p10}];
\end{tikzpicture}
```

1.2 Orthonormal projections

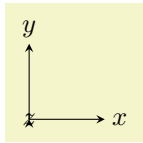
The `3dtools` library can be used together with the `tikz-3dplot` package and/or the `tpp` library. It also has its own means to install orthonormal projections. Orthonormal projections emerge from subjecting 3-dimensional vectors to orthogonal transformations and projecting them to 2 dimensions. They are not to be confused with the perspective projections, which are more realistic and supported by the `tpp` library. Orthonormal projections may be thought of a limit of perspective projections at large distances, where large means that the distance of the observer is much larger than the dimensions of the objects that get depicted.

`/tikz/3d/install view`

(no value)

Installs a 3d orthonormal projection.

The initial projection is such that x is right an y is up, as if we had no third direction.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view]
\draw[-stealth] (0,0,0) -- (1,0,0)
node[pos=1.2] {$x$};
\draw[-stealth] (0,0,0) -- (0,1,0)
node[pos=1.2] {$y$};
\draw[-stealth] (0,0,0) -- (0,0,1)
node[pos=1.2] {$z$};
\end{tikzpicture}
```

The 3d-like pictures emerge by rotating the view. The conventions for the parametrization of the orthogonal rotations in terms of three rotation angles ϕ , ψ and θ are

$$O(\phi, \psi, \theta) = \begin{pmatrix} c_\phi c_\psi & s_\phi c_\psi & -s_\psi \\ c_\phi s_\psi s_\theta - s_\phi c_\theta & s_\phi s_\psi s_\theta + c_\phi c_\theta & c_\psi s_\theta \\ c_\phi s_\psi c_\theta + s_\phi s_\theta & s_\phi s_\psi c_\theta - c_\phi s_\theta & c_\psi c_\theta \end{pmatrix}. \quad (1)$$

Here, $c_\phi := \cos \phi$, $s_\phi := \sin \phi$ and so on.

`/tikz/3d/phi`

(initially 0)

3d rotation angle.

`/tikz/3d/psi`

(initially 0)

3d rotation angle.

`/tikz/3d/theta`

(initially 0)

3d rotation angle.

The rotation angles can be used to define the view. The conventions are chosen in such a way that they resemble those of the `tikz-3dplot` package, which gets widely used. This matrix can be written as

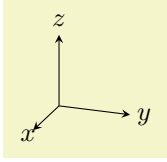
$$O(\phi, \psi, \theta) = R_x(\theta) \cdot R_y(\psi) \cdot R_z(\phi),$$

where

$$R_x(\theta) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\theta) & \sin(\theta) \\ 0 & -\sin(\theta) & \cos(\theta) \end{pmatrix}, \quad R_y(\psi) = \begin{pmatrix} \cos(\psi) & 0 & -\sin(\psi) \\ 0 & 1 & 0 \\ \sin(\psi) & 0 & \cos(\psi) \end{pmatrix},$$

$$R_z(\phi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & \sin(\phi) \\ 0 & -\sin(\phi) & \cos(\phi) \end{pmatrix}$$

are rotations about the x , y and z axis, respectively. For $\psi = 0$, $O(\phi = \phi_d, \psi = 0, \theta = \theta_d) = R^d(\theta_d, \phi_d)$ from the `tikz-3dplot` package. Note, however, that there seems to be an inconsistency in equation (2.1) of that package.²



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=110,psi=0,theta=70}]
\draw[-stealth] (0,0,0) -- (1,0,0)
node[pos=1.2] {$x$};
\draw[-stealth] (0,0,0) -- (0,1,0)
node[pos=1.2] {$y$};
\draw[-stealth] (0,0,0) -- (0,0,1)
node[pos=1.2] {$z$};
\end{tikzpicture}
```

`/tikz/3d/define orthonormal dreibein=<options>`

(no default, initially empty)

Defines a local dreibein from three input points. The initial choice of these points are $A=(A)$, $B=(B)$, $C=(C)$, and the initial choice for the basis vectors is $\mathbf{ex}=(ex)$, $\mathbf{ey}=(ey)$, $\mathbf{ez}=(ez)$. In terms of these points, (ex) is parallel to $(B) - (A)$, (ey) is in the plane that contains (A) , (B) and (C) , and is orthogonal to (ex) , and (ez) is orthogonal to (ex) and (ey) . All the basis vectors are normalized to length 1.

`/tikz/3d/screen coords`

(no value)

Defines locally screen coordinate system, i.e. this style brings you back to the original coordinate system in `tikzpictures`. It is taken from `tikz-3dplot`, where this style is called `tdplot_screen_coords`.

1.3 Visibility considerations

When drawing objects in 3d, some parts are “visible”, i.e. in the foreground, while other parts are “hidden”, i.e. in the background. In what follows, we discuss some basic means that allow one to determine whether some stretch is visible or hidden. Very often this amounts to find critical values of some parameter(s) (such as angles) at which some curve changes from visible to hidden, or vice versa. One of the major players in this game is the normal on the screen, which is given by the last row of the orthogonal matrix O of (1). For $\psi = 0$, this normal is also the normal in the so-called “main” coordinates of `tikz-3dplot` with the identifications $\theta = \texttt{\textbackslashtdplotmaintheta}$ and $\phi = \texttt{\textbackslashtdplotmainphi}$.

1.3.1 Example 1: latitude circle on sphere

Here is an example. Suppose we wish to draw a latitude circle on a sphere for $\psi = 0$. Since the system has a rotational symmetry around the z axis, we can set $\phi = 0$ as well. The normal on the screen then becomes

$$\vec{n}_{\text{screen}} = (0, -\sin(\theta), \cos(\theta))^T.$$

²I do not know how to contact the author.

The latitude circle can be parametrized as

$$\vec{\gamma}_{\text{lat}}(\beta) = (r \cos(\beta), r \sin(\beta), h)^T,$$

where $r = R \cos(\lambda)$ and $h = R \sin(\lambda)$ with R being the radius of the sphere and λ the latitude angle of the latitude circle. The critical angles β_{crit} at which the curve transitions from hidden to visible are then given by the solutions of

$$\vec{n}_{\text{screen}} \cdot \vec{\gamma}_{\text{lat}}(\beta_{\text{crit}}) = -r \sin(\beta) \sin(\theta) + h \cos(\theta) \stackrel{!}{=} 0.$$

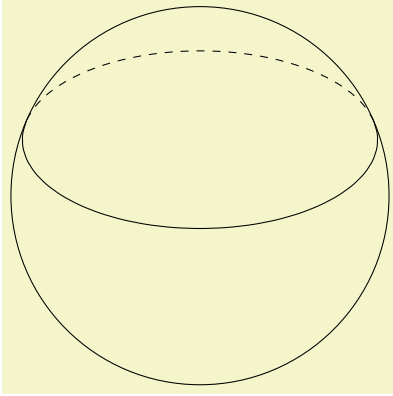
Since $-1 \leq \sin(\beta) \leq 1$, this equation only has solutions if

$$\left| \frac{h}{r} \cot(\theta) \right| \leq 1. \quad (2)$$

The solutions are then given by

$$\beta_{\text{crit}}^{(1)} = \arcsin\left(\frac{h}{r} \cot(\theta)\right) \quad \text{and} \quad \beta_{\text{crit}}^{(2)} = 180 - \beta_{\text{crit}}^{(1)},$$

and $\beta_{\text{crit}}^{(1)} = \beta_{\text{crit}}^{(2)}$ if the inequality (2) is saturated. The following code example illustrates this. Notice that it could be made more concise with the `3d` library.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[declare function={%
R=2.5;lambda=20;theta=60;
r=R*cos(lambda);h=R*sin(lambda);
betacrit=asin(h/r*cot(theta));}]
\draw (0,0) circle[radius=R];
\begin{scope}[smooth,
3d/install view={phi=0,psi=0,theta=theta}]
\draw[dashed]
plot[variable=\t,
domain=betacrit:180-betacrit]
({r*cos(\t)},{r*sin(\t)},h);
\draw
plot[variable=\t,
domain=betacrit:-180-betacrit]
({r*cos(\t)},{r*sin(\t)},h);
\end{scope}
\end{tikzpicture}
```

1.3.2 Example 2: arbitrary circle on sphere

A somewhat more advanced question is to draw an arbitrary circle on a sphere. That is, we are given a sphere around a center C or radius R and a point P inside the sphere. If C and P coincide, we need to define a normal n , otherwise $n = P - C$. How can one draw a circle on the sphere, distinguishing between visible and hidden stretches?

First test: $|P - C| < R$. The circle only makes sense if $|P - C| < R$. The radius of the circle is $r = \sqrt{R^2 - |P - C|^2}$. Call the normal on the screen n_{screen} .

Case $n \parallel n_{\text{screen}}$. If n and n_{screen} are linearly dependent, the circle is completely hidden if the screen depth of P is smaller than the screen depth of C , $\text{sd } P < \text{sd } C$, and visible otherwise. We can choose a coordinate system in which

$$e_z = \frac{n}{|n|}, \quad e_x \text{ arbitrary but } \perp e_z \quad \text{and} \quad e_y = e_z \times e_x$$

to draw the circle.

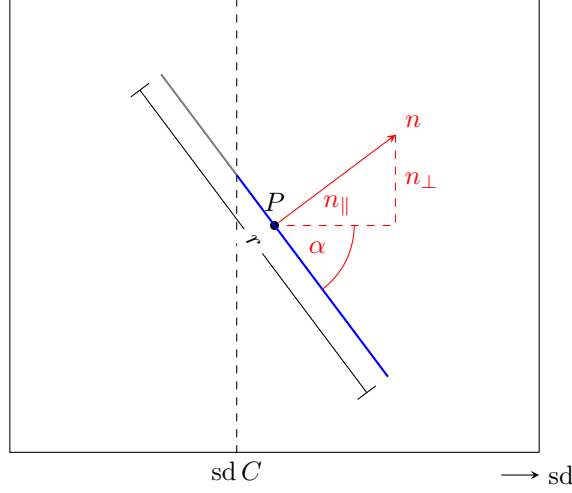


Figure 1: $n \not\parallel n_{\text{screen}}$.

Case $n \not\parallel n_{\text{screen}}$. From now on we assume that n and n_{screen} are not linearly dependent. This means that they span a plane, and we can choose n_{screen} to point in the x -direction of this plane (see figure 1).

The normal can be decomposed in a part parallel to n_{screen} , n_{\parallel} , and a perpendicular part, n_{\perp} . The projection of the circle on this plane is a line, and has slope $\alpha = \arctan(-n_{\parallel}/n_{\perp})$. If $r \cos \alpha > |\text{sd } P - \text{sd } C|$, the circle has both hidden and visible stretches, from between $-r \cos \alpha$ and $\text{sd } P - \text{sd } C$ it is hidden and between $\text{sd } P - \text{sd } C$ and $r \cos \alpha$ it is solid.

We are going to draw the circle in a coordinate system defined by

$$e_z = \frac{n}{|n|}, \quad e_y = e_z \times n_{\text{screen}} \quad \text{and} \quad e_x = e_y \times e_z.$$

The circle is then in the x - y plane, and the positive x -direction is the direction of increasing screen depth (or visibility). If $r \cos \alpha > |\text{sd } P|$, then the stretch between $\beta := |\arccos(\frac{\text{sd } C - \text{sd } P}{r \cos \alpha})|$ and $-\beta$ is visible, between β and $360^\circ - \beta$ it is hidden.

1.3.3 Example 3: outlines of shapes

Another type of visibility considerations concerns the contours of shapes. To be specific, consider a surface parametrized by

$$\vec{f}(u, v) = \begin{pmatrix} u \\ R(u) \cos(v) \\ R(u) \sin(v) \end{pmatrix} \quad (3)$$

with some function $R(u)$. What is the contour of an orthonormal projection of the surface on the screen? It is the boundary between the hidden and visible parts. What distinguishes the visible from the hidden parts? It is the projection of the normal of the surface on the screen, $F(u, v) := n_S(u, v) \cdot n_{\text{screen}}$. The hidden and visible stretches are separated by the zeros of this projection. In the case of our surface (3),

$$\vec{n}_S(u, v) = \vec{\nabla}_u f(u, v) \times \vec{\nabla}_v f(u, v) = R(u) \begin{pmatrix} -R'(u) \\ \cos(v) \\ \sin(v) \end{pmatrix}, \quad (4)$$

and for $\psi = 0$

$$\vec{n}_{\text{screen}} = \begin{pmatrix} \sin(\theta) \sin(\phi) \\ -\sin(\theta) \cos(\phi) \\ \cos(\theta) \end{pmatrix}. \quad (5)$$

So we need to find the zeros of

$$\begin{aligned} F(u, v) &= -\cos(\theta) \sin(v) + \sin(\theta) \cos(\phi) \cos(v) + R'(u) \sin(\theta) \sin(\phi) \\ &=: a \sin(v) + b \cos(v) + c. \end{aligned} \quad (6)$$

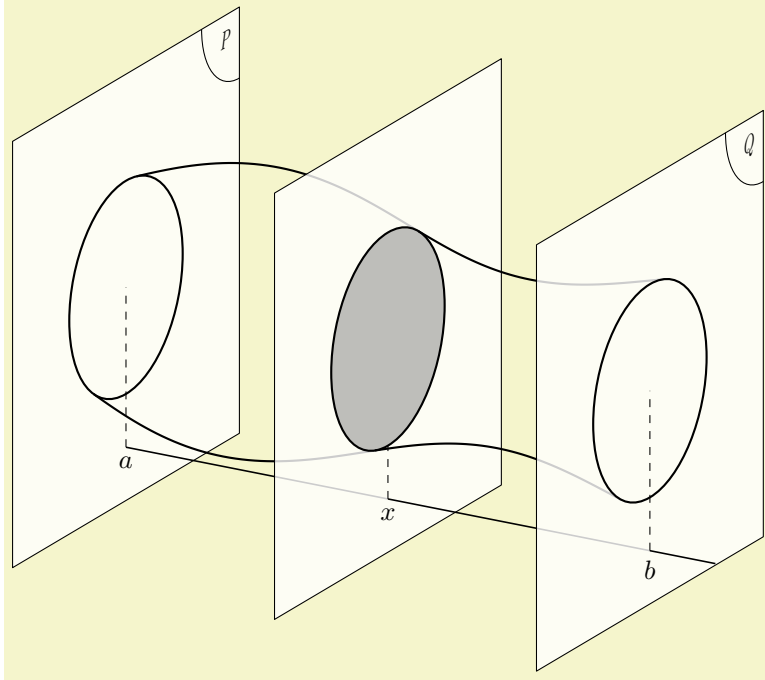
This equation can be solved for $x := \sin(v)$ using $\cos(v) = \pm\sqrt{1 - \sin^2(v)} = \pm\sqrt{1 - x^2}$. It is clear that, since $\sin(v)$ is bounded (and so is $\cos(v)$), this equation does not always have a solution. In particular, if $R'(u)$ is too large, there might not be a solution. This just means that for a given u all points are hidden or visible. This happens e.g. when you look at a cone from the top or bottom. A more advanced code could deal with these cases, the one presented below (which is taken from topanswers.xyz) does not. Note also that these are local visibility conditions, a seemingly visible stretch can always be covered by some other stretch that is a finite distance away in u direction.

However, for “reasonable” configurations, there are two solutions of the quadratic equation, as they should, they correspond to the upper and lower contour in the code example below. They are a bit unilluminating and given by

$$[\sin(v)]_{1,2} = -\frac{a\sqrt{a^2 + b^2 - c^2} \pm bc}{a^2 + b^2}, \quad (7a)$$

$$[\cos(v)]_{1,2} = -\frac{b\sqrt{a^2 + b^2 - c^2} \mp ac}{a^2 + b^2}, \quad (7b)$$

where a , b and c are implicitly defined in (6). Hence, for “reasonable” configurations, it is straightforward to plot the contour of the surface with L^AT_EX.



```

\usetikzlibrary {3dtools}
\begin{tikzpicture}[declare function={phi=30;theta=70;},
3d/install view={phi=phi,psi=0,theta=theta},
line cap=butt,line join=round,
declare function={%
  R(\u)=1.5+sin(\u*45)/(2+\u/8);%<- input
  Rprime(\u)=(R(\u+0.01)-R(\u-0.01))/0.02;%<- numerical derivative
  a=cos(phi)*sin(theta);% see equation {eq:vcrit}
  b=-1*cos(theta);%
  c(\u)=sin(theta)*sin(phi)*Rprime(\u);%
  sv1(\u)=-((b*c(\u)+sqrt(a*a+b*b-c(\u)*c(\u))*abs(a))/(a*a+b*b));%
  sv2(\u)=-((b*c(\u)+sqrt(a*a+b*b-c(\u)*c(\u))*abs(a))/(a*a+b*b));%
  cv1(\u)=-((a*c(\u)+sqrt(a*a+b*b-c(\u)*c(\u))*abs(b))/(a*a+b*b));%
  cv2(\u)=-((a*c(\u)+sqrt(a*a+b*b-c(\u)*c(\u))*abs(b))/(a*a+b*b));%
},
icircle/.style={thick},
iplane/.style={fill=white,fill opacity=0.8},
iline/.style={semithick},
extra/.code={},annot/.code={\tikzset{extra/.code={#1}}}
\newcommand\DrawIntersectingPlane[2][]{%
\begin{scope}[canvas is yz plane at x=#2,transform shape,#1]
\draw[iplane] (3,3) -- (-3,3) -- (-3,-3) -- (3,-3) -- cycle;
\draw[icircle] (0,0) circle[radius={R(#2)}];
\tikzset{extra}
\end{scope}}
%
\DrawIntersectingPlane[annot={%
\path (2.9,2.9) node[below left,transform shape]{$P$};
\draw (2,3) arc[start angle=180,end angle=270,radius=1];
\draw[dashed] (0,-2.25) node[below,transform shape=false]{$a$} -- (0,0);
}]{0}
\draw[iline] (0,0,-2.25) -- (4,0,-2.25);
\draw[thick,smooth,variable=\u,domain=0:4]
plot (\u,{R(\u)*cv1(\u)},{R(\u)*sv1(\u)})
plot (\u,{R(\u)*cv2(\u)},{R(\u)*sv2(\u)});
\DrawIntersectingPlane[icircle/.append style={fill=gray,fill opacity=0.5},
annot={%
\draw[dashed] (0,-2.25) node[below,transform shape=false]{$x$} -- (0,-1.5);
}]{4}
\draw[iline] (4,0,-2.25) -- (8,0,-2.25);
\draw[thick,smooth,variable=\u,domain=4:8]
plot (\u,{R(\u)*cv1(\u)},{R(\u)*sv1(\u)})
plot (\u,{R(\u)*cv2(\u)},{R(\u)*sv2(\u)});
%
\DrawIntersectingPlane[annot={%
\path (2.9,2.9) node[below left,transform shape]{$Q$};
\draw (2,3) arc[start angle=180,end angle=270,radius=1];
\draw[dashed] (0,-2.25) node[below,transform shape=false]{$b$} -- (0,0);
}]{8}
\draw[iline] (8,0,-2.25) -- (9,0,-2.25);
\end{tikzpicture}

```

There are some special cases that may be of particular interest: $R'(u) = 0$ for a cylinder and $R'(u) = -r/h$ for a cone of height h and base radius r .

1.4 “Physical” coordinates

It is quite conceivable that users may want to use different coordinate systems for defining different coordinates. The following functions aim at supporting this. It should be said, though, that these functions are even more “experimental” than what has been discussed thus far. The main point is that, apart from the “physical” x and y coordinates, i.e. the coordinates of an point on the screen, one can also keep track of the physical z coordinate, or screen depth, which indicates how far a given point is above ($z > 0$) or below ($z < 0$) the screen. To accomplish this, one needs to switch on the recording of physical components.

`/tikz/3d/record physical components`

(no value)

Switches on recording of physical components of coordinates.

The physical components can then be retrieved with various functions.

TDphysx("vector")

Yields the physical x -component of a 3d named coordinate.

TDphysy("vector")

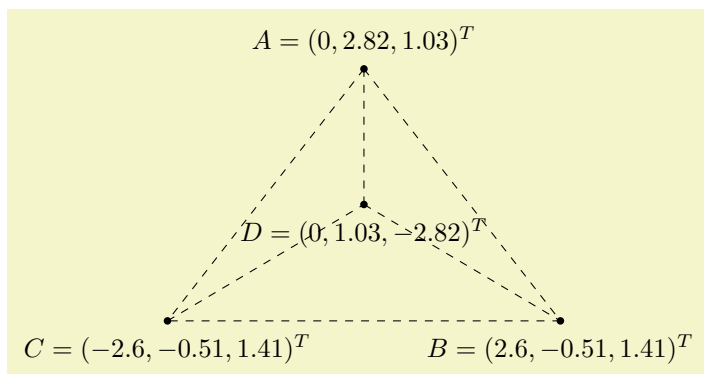
Yields the physical y -component of a 3d named coordinate.

TDphysz("vector")

Yields the physical z -component of a 3d named coordinate.

TDphys("vector")

Yields an array containing physical x , y and z -components of a 3d named coordinate.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/record physical components,
dot/.style={circle,inner sep=1pt,fill}]
\begin{scope}[3d/install view={phi=0,psi=0,theta=70}]
\path (0,0,3) coordinate (A);
\path[3d/install view={phi=30}] (3,0,0) coordinate (B);
\path[3d/install view={phi=150}] (3,0,0) coordinate (C);
\path[3d/install view={phi=270}] (3,0,0) coordinate (D);
\end{scope}
\draw[dashed] foreach \X [remember=\X as \Y (initially D)]
in {B,C,D}
{(A) -- (\X) (\Y) -- (\X)}
coordinate[dot,label=below:{$\X=\pgfmathparse{TDphys("\X")}%
(\pgfmathprintvector\pgfmathresult)^T$}]
(A) coordinate[dot,label=above:{$A=\pgfmathparse{TDphys("A")}%
(\pgfmathprintvector\pgfmathresult)^T$}]
\end{tikzpicture}
```

Once one has defined physical coordinates, one can use them to compute e.g. distances between coordinates defined in different frames.

$$\begin{aligned}\vec{A}_{\text{phys}} &= (0, 2.82, 1.03), \\ \vec{B}_{\text{phys}} &= (2.6, -0.51, 1.41), \\ d_{\text{phys}}(\vec{A}, \vec{B}) &= 4.24\end{aligned}$$

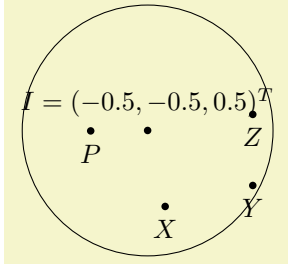
```
\usetikzlibrary {3dtools}
$\pgfmathsetmacro{\vecA}{TDphys("A")}%
\pgfmathsetmacro{\vecB}{TDphys("B")}%
\pgfmathsetmacro{\physdist}{%
sqrt(TD("(\vecA)-(\vecB)o(\vecA)-(\vecB)")}%
\begin{array}{l}
\vec A_{\mathrm{phys}}=(\pgfmathprintvector\vecA),\\
\vec B_{\mathrm{phys}}=(\pgfmathprintvector\vecB),\\
d_{\mathrm{phys}}(\vec A,\vec B)=%
\pgfmathprintnumber\physdist
\end{array}$
```

These are the things that work. However, there are, unfortunately, more than enough things that do not work. They include shifted frames, other coordinate systems such as spherical ones, all coordinates that are defined in canvas is xy plane at $z=0$ or relatives, etc.

1.5 Predefined path constructions and pics

`/tikz/3d/circumsphere center=<options>` (no default, initially empty)

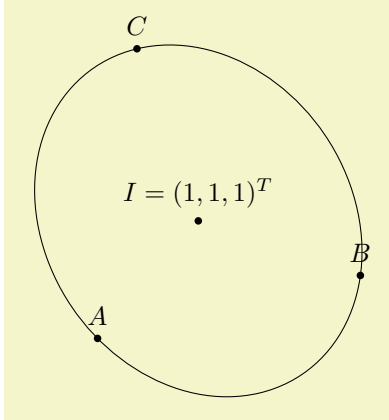
Computes the center of a sphere for a given set of four non-coplanar points. The initial choice of these points are $A=(A)$, $B=(B)$, $C=(C)$, $D=(D)$. The underlying maths can be found at <https://topanswers.xyz/tex?q=1233#a1467>.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[dot/.style={circle,inner sep=1pt,fill}]
\begin{scope}[3d/install view={phi=100,psi=0,theta=70}]
\path (1,0,0) coordinate (X)
(0,1,0) coordinate (Y)
(0,1,1) coordinate (Z)
(1,-1,1) coordinate (P);
\path[3d/circumsphere center={A={X},B={Y},C={Z},D={P}}]
coordinate (I);
\end{scope}
\pgfmathsetmacro{\csr}{sqrt(TD("(X)-(I)o(X)-(I)"))}
\draw (I) circle[radius=\csr];
\path foreach \X in {X,Y,Z,P}
{(\X) coordinate[dot,label=below:{$\X$}]}
(I) (I) coordinate[dot,label=above:{$I=\pgfmathparse{TD("(I)")}%
(\pgfmathprintvector\pgfmathresult)^T$}];
\end{tikzpicture}
```

`/tikz/3d/circumcircle center=<options>` (no default, initially empty)

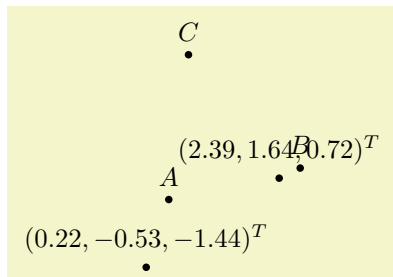
Computes the center of a circle for a given set of three non-collinear points. The initial choice of these points are $A=(A)$, $B=(B)$, $C=(C)$.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[declare function={a=3;},
dot/.style={circle,inner sep=1pt,fill},
3d/install view={phi=100,psi=0,theta=70}]
\path (a,0,0) coordinate (A)
(0,a,0) coordinate (B)
(0,0,a) coordinate (C);
\path[3d/circumcircle center]
coordinate (I);
\pgfmathsetmacro{\myr}{%
sqrt(TD("(A)-(I)o(A)-(I)"))}
\tikzset{3d/define orthonormal dreibein}
\begin{scope}[x={ex},y={ey}]
\draw (I) circle[radius=\myr];
\end{scope}
\path foreach \X in {A,B,C}
{(\X) coordinate[dot,label=above:{$\X$}]}
(I) (I) coordinate[dot,label=above:{$I=%
\pgfmathparse{TD("(I)")}%
(\pgfmathprintvector\pgfmathresult)^T$}];
\end{tikzpicture}
```

`/tikz/3d/intersection of three spheres=<options>` (no default, initially empty)

Computes the intersection intersections of three spheres around $A=(A)$, $B=(B)$, and $C=(C)$. The radii are stored in rA , rB and rC , respectively. The names of the intersection solutions are stored in the keys $i1$ and $i2$, the initial values of which are $i1$ and $i2$.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[declare function={a=1.5;},
dot/.style={circle,inner sep=1pt,fill},
3d/install view={phi=100,psi=0,theta=70}]
\path (a,0,0) coordinate (A)
(0,a,0) coordinate (B)
(0,0,a) coordinate (C);
\path[3d/intersection of three spheres=
{rA=2,rB=2.5,rC=3}];
\path (i1)
coordinate[dot,label=above:{$%
\pgfmaphparse{TD("(i1)")}%
(\pgfmaphprintvector\pgfmaphresult)~T$}];
\path (i2)
coordinate[dot,label=above:{$%
\pgfmaphparse{TD("(i2)")}%
(\pgfmaphprintvector\pgfmaphresult)~T$}];
\path foreach \X in {A,B,C}
{(\X) coordinate[dot,label=above:{$\X$}]};
\end{tikzpicture}
```

`/tikz/pics/3d circle through 3 points=<options>` (no default, initially empty)

Draws a circle through 3 points in 3 dimensions. If the three coordinates are close to linearly dependent, the circle will not be drawn. *This pic will most likely be removed from the documentation and no longer be supported/developed.*

`/tikz/3d circle through 3 points/A` (initially (1,0,0))

First coordinate. Can be either symbolic or explicit. Symbolic coordinates need to be defined via `\path (x,y,z) coordinate (name);`.

`/tikz/3d circle through 3 points/B` (initially (0,1,0))

Second coordinate, like above.

`/tikz/3d circle through 3 points/C` (initially (0,0,1))

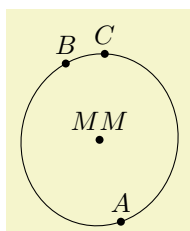
Third coordinate, like above.

`/tikz/3d circle through 3 points/center name` (initially M)

Name of the center coordinate that will be derived.

`/tikz/3d circle through 3 points/auxiliary coordinate prefix` (initially tmp)

In TikZ the coordinates are global. The code for the circle is more comprehensible if named coordinates are introduced. Their names will begin with this prefix. Changing the prefix will allow users to avoid overwriting existing coordinates.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={%
phi=30,psi=0,theta=70}]
\foreach \X in {A,B,C}
{\pgfmaphsetmacro{\myx}{3*(rnd-1/2)}
\pgfmaphsetmacro{\myy}{3*(rnd-1/2)}
\pgfmaphsetmacro{\myz}{3*(rnd-1/2)}
\path (\myx,\myy,\myz) coordinate (\X);}
\path pic{3d circle through 3 points={%
A={(\A)},B={(\B)},C={(\C)},center name=MM}};
\foreach \X in {A,B,C,MM}
{\fill (\X) circle[radius=1.5pt]
node[above]{$\X$}};
\end{tikzpicture}
```

`/tikz/pics/3d/circle on sphere=<options>` (no default, initially empty)

Draws a circle on as sphere. It distinguishes between foreground and background. Notice that this pic defines its own dreibein, so it will define coordinates that draw their names from `/tikz/3d/aux keys/ex`, `/tikz/3d/aux keys/ey` and `/tikz/3d/aux keys/ez`. It will also define a coordinate (`nscreen`) which contains the normal to the screen. The foreground path will use the style `/tikz/3d/visible`, and the hidden path will be drawn with the style `/tikz/3d/hidden`.

`/tikz/3d/circle on sphere/C` (initially (0,0,0))

Coordinate of the center of the sphere.

`/tikz/3d/circle on sphere/P` (initially (0,0,0))

Coordinate of the center of the circle.

`/tikz/3d/circle on sphere/n` (initially (0,0,1))

Normal. This is only needed if the center of the circle coincides with the center of the sphere.

`/tikz/3d/circle on sphere/auxiliary coordinate prefix` (initially `tmp`)

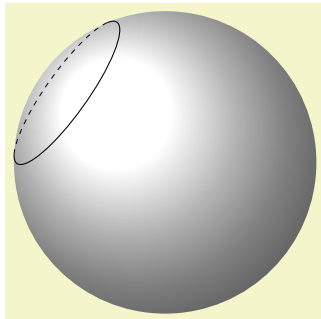
This pic installs a symbolic coordinate for the center of the circle. The auxiliary prefix can be used to avoid overwriting existing coordinates. The initial choice of the prefix will lead to a coordinate with name (`tmpP`).

`/tikz/3d/circle on sphere/fore layer= $\langle layer \rangle$` (no default, initially `main`)

Layer of the visible faces.

`/tikz/3d/circle on sphere/back layer= $\langle layer \rangle$` (no default, initially `main`)

Layer of the hidden faces.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=110,theta=70},
declare function={R=2;}]
\shade[ball color=white,3d/screen coords] circle[radius=R];
\path pic{3d/circle on sphere={R=R,P={(0.5,-1.2,1)}}};
\end{tikzpicture}
```

`/tikz/pics/3d incircle= $\langle options \rangle$` (no default, initially `empty`)

Inscribes a circle in a triangle in 3 dimensions.

`/tikz/3d incircle/A` (initially (1,0,0))

First coordinate. Can be either symbolic or explicit.

`/tikz/3d incircle/B` (initially (0,1,0))

Second coordinate, like above.

`/tikz/3d incircle/C` (initially (0,0,1))

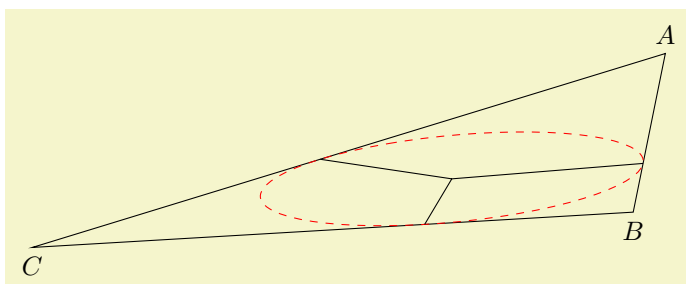
Third coordinate, like above.

`/tikz/3d incircle/center name` (initially `I`)

Name of the center coordinate that will be derived.

`/tikz/3d incircle/auxiliary coordinate prefix` (initially `tmpp`)

In TikZ the coordinates are global. The code for the circle is more comprehensible if named coordinates are introduced. Their names will begin with this prefix. Changing the prefix will allow users to avoid overwriting existing coordinates.



```

\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=110,psi=0,theta=70}]
\draw
  (8,5,5) coordinate[label=above:{$A$}] (A) --
  (1,2,0) coordinate[label=below:{$B$}] (B) --
  (5,-5,0) coordinate[label=below:{$C$}] (C) -- cycle;
\path pic[red,dashed]{3d incircle={%
A={(A)},B={(B)},C={(C)},center name=I}};
\draw (I) -- (tmppa) (I) -- (tmppb) (I) -- (tmppc);
\end{tikzpicture}

```

/tikz/3d/polyhedron/draw face with corners= $\langle list\ of\ corners \rangle$ (no default, initially empty)

Draws a face of a polyhedron through the specified corners. It distinguishes between “visible” and “hidden” faces. The user can specify a point inside the corner. Then the outwards pointing normal of the face can either have a negative projection on the screen, in which case the face is hidden, or else it is visible.

/tikz/3d/polyhedron/O= $\langle coordinate \rangle$ (no default, initially (0,0,0))

Coordinate inside the polyhedron.

/tikz/3d/polyhedron/L= $\langle coordinate \rangle$ (no default, initially (1,1,1))

Coordinate of light source.

/tikz/3d/polyhedron/shading function= $\langle name \rangle$ (no default, initially tikztdpolyhedronshade)

Function of the projection of the light source on the normal of the respective face that determines the shading.

/tikz/3d/polyhedron/fore layer= $\langle layer \rangle$ (no default, initially main)

Layer of the visible faces.

/tikz/3d/polyhedron/back layer= $\langle layer \rangle$ (no default, initially main)

Layer of the hidden faces.

/tikz/3d/polyhedron/color= $\langle color \rangle$ (no default, initially yellow)

Color of the polyhedron.

/tikz/3d/polyhedron/fore= $\langle style \rangle$ (no default, initially draw,solid)

Style for visible faces. One can turn of the fill by adding `fill=none`.

/tikz/3d/polyhedron/back= $\langle style \rangle$ (no default, initially draw,dashed,fill opacity=0)

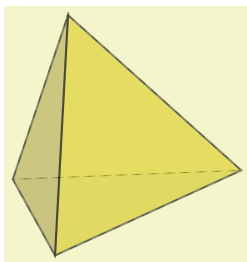
Style for visible faces.

/tikz/3d/polyhedron/complete dashes= $\langle style \rangle$ (no default, initially on 2pt off 2pt)

Switches on dashes for the edges which start and end with an on phase.

/tikz/cheating dash= $\langle style \rangle$ (no default, initially on 2pt off 2pt)

Switches on dashes with an on phase. Taken from [Mark Wibrow's answer](#).



```
\usetikzlibrary {3dtools}
\pgfdeclarelayer{background}
\pgfdeclarelayer{foreground}
\pgfsetlayers{background,main,foreground}
\begin{tikzpicture}
\begin{scope}[3d/install view={phi=110,psi=10,theta=70},scale=2]
\path (0,0,1) coordinate (v1)
({sqrt(8/9)},0,-1/3) coordinate (v2)
({-sqrt(2/9)},{sqrt(2/3)},-1/3) coordinate (v3)
({-sqrt(2/9)},{-sqrt(2/3)},-1/3) coordinate (v4);
\tikzset{3d/polyhedron/.cd,
fore layer=foreground,back layer=background,
fore/.append style={opacity=0.4,thick},
back/.append style={opacity=0.4},
draw face with corners={{(v1)},{(v2)},{(v3)}}},
draw face with corners={{(v1)},{(v2)},{(v4)}}},
draw face with corners={{(v1)},{(v3)},{(v4)}}},
draw face with corners={{(v2)},{(v3)},{(v4)}}}}
\end{scope}
\end{tikzpicture}
```

The library has also some experimental pics for cones, truncated cones and cylinders. They share a couple of common keys.

/tikz/3d/r (initially 1)

Key for radii, e.g. of cylinders or cones.

/tikz/3d/h (initially 1)

Key for heights, e.g. of cylinders or cones.

/tikz/3d/R (initially 2)

Key for larger radii, e.g. of a frustum.

/tikz/pics/3d/visible (initially draw,solid)

Style for visible lines.

/tikz/pics/3d/hidden (initially draw,very thin,cheating dash)

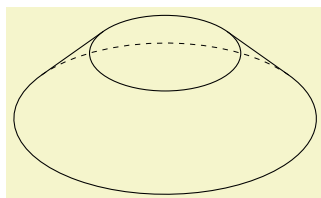
Style for hidden lines.

/tikz/pics/3d/cone (initially empty)

Draws a cone with the basis in the current xy plane.

/tikz/pics/3d/frustum (initially empty)

Draws a cone with the basis in the current xy plane.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=110,psi=0,theta=60}]
\pic{3d/frustum};
\end{tikzpicture}
```

/tikz/pics/ycylinder (initially empty)

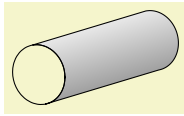
A cylinder in the y -direction. This pic requires the `calc` library. As of now it does only work for $\psi=0$.

/tikz/pics/3d/mantle (initially draw)

Style for cylinder mantle. If no fill option is specified, it will be shaded.

/tikz/pics/3d/top (initially draw)

Style for cylinder top.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}[3d/install view={phi=30,psi=0,theta=80}]
\pic{ycylinder={r=0.4,h=3,
top/.style={fill=blue}}};
\end{tikzpicture}
```

To do:

- transform to plane given by three non-degenerate coordinates
- transform to plane given by normal and one point
- maybe layering/visibility

1.6 Path management

This is poor marmots version of path management. The idea is that one can store paths, and redraw them, possibly in reversed order. This recording tool uses the `show path construction` decoration from the `decorations.pathreplacing` library. In order to make use of these tools, you need to load the library.

`/tikz/store path=<name>` (no default, initially empty)

Records a path under the name `<name>`. If you want to draw and record a path at the same time, use `postaction={store path=<name>}`.

`/tikz/stored path/coordinate prefix=<prefix>` (no default, initially stored-)

Prefix for the stored coordinates. If you store several paths and want to possibly combine them, you may want to give each path a unique prefix.

`/tikz/stored path/reset coordinate index` (no value)

Resets the counter for the stored coordinates. Mainly for internal use.

`/tikz/stored path/restore path=<name>` (no default, initially empty)

Restores a saved path of name `<name>` using the `insert path` key.

`/tikz/stored path/restore reversed path=<name>` (no default, initially empty)

Restores a saved path of name `<name>` using the `insert path` key in *reversed* order.

`/tikz/stored path/first coordinate of=<name>` (no default, initially empty)

Inserts the first coordinate of the path named `<name>` using the `insert path` key.

`/tikz/stored path/last coordinate of=<name>` (no default, initially empty)

Inserts the last coordinate of the path named `<name>` using the `insert path` key.

`/tikz/stored path/coordinate with index=n of <name>` (no default, initially empty)

Inserts the n^{th} coordinate of the path named `<name>` using the `insert path` key. Notice that at present there is no sanity check. If n is larger than the number of stored coordinates, there will be an error.

`tikztdindexoflastcoordinate`

Yields index of the last coordinate of a stored path. This can be used to test if a path is empty.

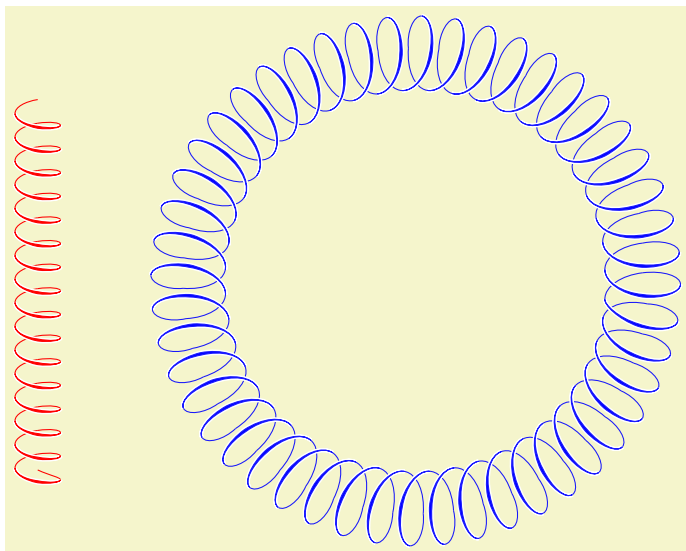
1.7 3D-like decorations

`/tikz/decorations/3d complete coil` (no value)

3d-like coil where the front is thicker than the back.

`/tikz/decorations/3d coil closed` (no value)

Indicates that the coil is closed.



```
\usetikzlibrary {3dtools}
\begin{tikzpicture}
\draw[decoration={3d coil color=red,aspect=0.35, segment length=3.1mm,
amplitude=3mm,3d complete coil},
decorate] (0,1) -- (0,6);
\draw[decoration={3d coil color=blue,3d coil opacity=0.9,aspect=0.5,
segment length={2*pi*3cm/50}, amplitude=5mm,3d complete coil,
3d coil closed},
decorate] (5,3.5) circle[radius=3cm];
\end{tikzpicture}
```

1.8 Remarks on the implementation

When the library gets loaded, the version gets checked. If the version is earlier than 3.1.1, a warning is issued. In this case, one cannot use the library unless one updates the pgf installation. If you have an earlier version than 3.1.3, some elaborate pics may not work as they use `\pgfutil@pushmacro` and `\pgfutil@popmacro`, which were added in version 3.1.3. If the version is earlier than 3.1.6, the internal macro `\pgfutil@pushmacro` will be fixed.

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