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Three dimensional coordinates into two dimensional coordinates transformation

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Remark. This is a development version. And has chaotic parts This file contains typos, unwanted logical mistakes and miscounts, and a maybe accidental letters, which came from a suddenly appearing double cursor in the editor. This is my first L^AT_EX().

There must be a new emphasisment made on the normed vector space and some other points throughout the text. I will change it carefully over the next days.

Contents

1	Introduction	3
2	Designing a $\mathbb{R}^{2 \times 3}$ coordinate system for our transformation from \mathbb{R}^3 to \mathbb{R}^2	4
2.1	Axis vector	4
2.2	The $_n$ index for $_{x,y,z}$ with $_x = 1$, $_y = 2$ and $_z = 3$	4
2.3	φ_n the angles for the coordinate axes	5
2.3.1	Degrees or radians?	5
2.4	r_n is the length of the unit on each axis	6
2.4.1	Taking the norm of \vec{e}_n to obtain r_n	6
2.5	\vec{e}_n are the three 2-D basis vectors	7
2.6	About the vector basis lemma	8
2.6.1	The general formula like the Hamel Basis	8
2.6.2	Connection to ijk-Notation	10
2.6.3	Coordinate system	10
2.7	Time to show the operation	10
3	The $\mathbb{R}^3 \rightarrow \mathbb{R}^2$ through $\mathbb{R}^{2 \times 3}$ transformation	11
3.1	Matrix version	11
3.2	Vectorbasis version	13
3.3	Function version	13
3.3.1	The functional $f(\vec{x})$	13
3.3.2	Composition of the functions $f \circ g$	14
3.4	Computer implementations of the transformation	15
3.4.1	Generic computer code	15
3.4.2	JavaScript computer code	15
4	Important proofs of the transformation behaviour	15
4.1	The origin stays in the origin	16
4.2	Points along one axis	16
4.3	Multiplications with constants	16
4.4	Additions and subtractions	17
4.5	Rule of linearity	17
5	Corollaries	17
5.1	Converting four Dimensions down to two dimensions	17
5.2	Alternative definition of the transformation by using dot products	18

6	Derivatives of $\vec{f}(\vec{x}) : V \rightarrow W$	18
7	Cauchy Sequences and Convergence	19
8	Summary	20
8.1	Summary of all necessary steps	20
9	Glossary	21
A	Temporarily moved down MORE TODO	21
A.1	Neighborhood	21
A.2	Convex sets	21
A.3	Orthogonality in the 2x3 matrix	22
A.4	Algebra	22
A.4.1	K-Vectorspace	22
A.4.2	Quotient rooms	22
A.5	Integration	22
B	Deconstructing and proving the 2x3 basis or not	23
B.1	2x3 standard basis	23
B.2	Lefthanded and righthanded system	24
C	Proving more rules of vector spaces	24
C.1	Dot product	24
C.2	The cross product	25
C.3	Normal vectors	25
C.4	About the norm	26
C.4.1	Vector norms	26
C.4.2	Matrix norms	27
C.4.3	Operator norms	27
C.5	Parallelogram equation	27
C.6	Normalizing a vector	28
C.7	Metrics	28
C.8	Transpose and TODO	28
C.9	The pseudo-inverse A^+ and least squares	29
D	An alternative graphics algorithm	30
D.1	Origin	30
D.2	Translation	30
D.3	Scaling	30
D.4	Skewing	30
D.5	Local 3x3 basis for change of units and per object rotation	30
D.5.1	Creating a 3x3 basis with cross products	31
D.6	Rotation	31
D.7	Frustum and Perspective	31
D.8	Dot product	31
D.9	Norm	32
D.10	Metric	32
D.11	Code Example	32
D.12	Another orthographic projection possible	36

1 Introduction

On a piece of paper you see three coordinate axes pointing into three directions in space. In reality these vectors are two dimensional. Because they point into three directions on the paper, and not into the real space.

In this document we will design a $\mathbb{R}^{2 \times 3}$ basis for the coordinate transformation. A basis is multiplied with the values of the coordinates to move for each component a piece, to end the move on the correct

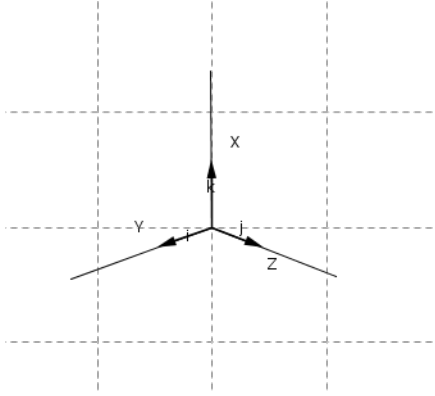


Figure 1: Picture of a right handed 3-D coordinate system with ijk -basis-vectors on the axes pointing into three dimensions. See [1] for introduction.

new point. In the case of cosines and sines, we move left and right and up and down, to tell you directly, what happens, when we multiply the coordinates with the matrix.

What we will do in the document

1. Choose angles for our coordinate axes around the unit circle to lay out three axes.
2. Write down the basis vectors for each coordinate axis
3. Assemble a matrix with the vector basis for a point by point transformation.
4. Read the example source code for a computer function, which is exactly two lines long. One for the new x and one for the new y .
5. Read other versions of the transformation, with functions, for example.
6. Derive the generic case of transforming coordinate systems down to the plane.

2 Designing a $\mathbb{R}^{2 \times 3}$ coordinate system for our transformation from \mathbb{R}^3 to \mathbb{R}^2

2.1 Axis vector

Remark. July, 25.

You will not read it during the text. Due to the problems with the linear independence definitions i will introduce the word *axis vector*.

Remark. A coordinate system is known to linear algebra. And the formulas are obviously the same combination. Only the three two dimensional axis vectors i talk about are missing. For myself, i am the first one to write about.

2.2 The $_n$ index for x, y, z with $x = 1, y = 2$ and $z = 3$

The index $_n$ in $r_n, \varphi_n, \vec{e}_n$ is the index for x, y, z . For example φ_n stands $\varphi_x, \varphi_y, \varphi_z$. r_n stands for r_x, r_y and r_z . \vec{e}_n is for $\vec{e}_x, \vec{e}_y, \vec{e}_z$. It is possible, that in the formulas x, y, z and $1, 2, 3$ may be used interchangeably. For example, when summing up the products of the coordinate components with the basis components, this happens. The formula is $\sum_{i=1}^3 \vec{x}_i \vec{e}_i$, which is a sum of x, y, z and the $\cos \varphi_n$ terms in the first components of \vec{e}_n for x' and a sum of x, y, z and the $\sin \varphi_n$ terms in the seconds components of \vec{e}_n for y' .

2.3 φ_n the angles for the coordinate axes

Why do we need angles? May be the first question. My answer is, we will arrange the basis vectors, easily around a circle, by their angle. Since they are two dimensional. The circle is available in two dimensions. With the arrangement around a circle, we get the right numbers, same lengths, instead of guessing wild numbers.

First draw three axes of a 3-D coordinate system on a piece of paper. Draw the horizontal x-Axis through the origin of the drawn coordinate system. You could directly add the y-axis, to see a 2-D coordinate system carrying your two dimensional 3-D system. A system with three vectors pointing into three directions, originating in the origin of the real \mathbb{R}^2 space.



Figure 2: A left-handed and a right handed coordinate system. They just have different angles in our 2-D projection.

Each of the three vectors has an angle, counted from the horizontal positive x-axis, going counter-clockwise around the origin. The angle between the axes themselves isn't what we want. We want the angle beginning on the real 2-D x-axis, to feed the cos and sin functions with, when calculating the real numbers of each basis vector.

In this document, i will call the angles $\angle \varphi_n$ or just φ_n . If they are measured in degrees or radians depends on the cosine and sine functions you use. And on how you would like to read your own definition.

Let φ_n be the set of axis angles, one for each axis. I put them into a set in this document to simplify the access by using the index n together with x, y, z or $1, 2, 3$. φ_x or φ_1 is the angle of the x-axis. φ_y or φ_2 is the angle of the y-axis and φ_z or φ_3 is the angle of the z-axis.

$$\varphi_n := \{\varphi_x, \varphi_y, \varphi_z\} = \{\varphi_1, \varphi_2, \varphi_3\}$$

We will need the three angles for the axes shortly. So don't forget it over the next lines.

2.3.1 Degrees or radians?

Depending on the cosine and sine functions and the input value for the angles, you may have to convert the degrees to radians, or the other way round, the radians to degrees. For example, the JavaScript Math.cos and Math.sin functions take the values in radians.

example The function rad converts degrees to radians, its useful for computer functions taking radians.

$$\text{rad}(\phi) := \frac{\pi}{180} \times \phi, \phi \in \mathbb{R}$$

Here is an example of three angles. The three axes have an angle of 120 degrees between each. But since we start counting counterclockwise and from the real horizontal axis of the plane, the angles are 210, 330, 90 in degrees, respectively. And because of the cosine and sine functions taking radians, we convert the values to radians.

$$\varphi_x = \text{rad}(210), \varphi_y = \text{rad}(330), \varphi_z = \text{rad}(90)$$

$$\varphi_x = \frac{\pi}{180} \times 210 = \frac{7\pi}{6}, \varphi_y = \frac{\pi}{180} \times 330 = \frac{11\pi}{6}, \varphi_z = \frac{\pi}{180} \times 90 = \frac{\pi}{2}$$

example The function `deg` converts the other way round and from radians to degrees. You multiply your value with the reciprocal of $\text{PI}/180$, namely $180/\text{PI}$ and get the other way round.

$$\text{deg}(\phi) := \frac{180}{\pi} \times \phi, \phi \in \mathbb{R}$$

example The first example was for the righthand coordinate system. Here are the angles for a lefthand system.

$$\varphi_x = \frac{\pi}{180} \times 0 = 0, \varphi_y = \frac{\pi}{180} \times 90 = \frac{\pi}{2}, \varphi_z = \frac{\pi}{180} \times 45 = \frac{\pi}{4}$$

If you would like to get hands on angles, cosines, sines, or need a refresher, [2] is a good choice. And as well [1] and [4] teach unit circles, polar coordinates, sines, cosines and wonderful mathematics.

2.4 r_n is the length of the unit on each axis

Before i show you the three vectors, and how to use them, we have to clear another piece of information belonging to each basis vector. In this document it is called r_n . The r is from radius. And it stands for the length of the basis vector. The length of the basis vector defines, how far a point in this direction will go by one unit.

$$r_n := \{r_x, r_y, r_z\} = \{r_1, r_2, r_3\}$$

The r originates from radius from the unit circle and from the parametrization of (x,y) via cosine and sine. In polar coordinates the cosine and sine are multiplied with r. Also to change the length of the hypotenuse, the vector \vec{r} , which is the third side to a triangle by cosine, sine and r. If r is left away, the length of the basis vector is 1. Or in other words, the distance $d((0,0), (x,y))$ from the origin to $(x,y) = (r \cos \varphi, r \sin \varphi)$ is 1, if $r = 1$ or if r is left away completely.

Pay attention to this point now, to keep the affine transformation, especially under rotation, correct. You should give all three axes the same r-value. I will define them in this document as r_n with one r_x, r_y and r_z for each coordinate axis, to keep it complete. But if you would like to change the units on your objects, i have to recommend, that you apply a local 3x3 basis with the disjoint unit lengths. This will keep the rotation correct. In the other case, the object would suddenly stretch the head, if you rotate it to the side, where the unit for example is longer.

So for the coordinate system, the best setting is $r_x = r_y = r_z$. Keeping them equal, you can rotate it realistic. But you dont need to keep the unit length of 1 for the vector. Elonginating the units on the axes make zooming transformations very easy.

2.4.1 Taking the norm of \vec{e}_n to obtain r_n

If you have some existing basis and you would like to figure out, how long r is, you can go the other way round and take the norm of the vector. Taking the norm means to measure the length of the vector. This is done with the euclidean norm, or the 2-norm for regular purposes.

$$r_n = \sqrt{\vec{e}_n \cdot \vec{e}_n} = \sqrt{(\vec{e}_n, \vec{e}_n)} = (\sum_{i=1}^2 \vec{e}_i^2)^{\frac{1}{2}} = \|\vec{e}_n\|$$

itt

With this formula you can not only measure the length of the basis vectors, but any vector in the \mathbb{R}^3 and the \mathbb{R}^2 space. More advanced measurements include the p-Norm, which is $\sqrt[p]{\sum_{i=1}^n |\vec{x}_i|^p} 1 \leq p \leq \infty$ and $\sup_{i=1..n} |\vec{x}_i|$ for $p = \infty$ and the max-Norm $\|\vec{x}\|_\infty = \sup\{|\vec{x}_i|\}$. There are matrix norms like $\|A\| = \max_{i=1..m} \sum_{j=1}^n A_{ij}$, which for example yields the largest row of a m by n matrix. Norms are used everywhere in mathematics for measuring the lengths or getting the absolut values of the vectors and matrices. And the distance function $d(\vec{x}, \vec{y}) = \|\vec{x} - \vec{y}\|$ is used to measure the distance between to points or two vector tips. A vector space V with a distance function $d(x, y) = \|x - y\|$. is called a metric space (V, d) . And a complete metric space with a norm, written $(V, \|\cdot\|)$, is a Banach space.

A vector can be normalized to give $\|\vec{x}\| = 1$, by dividing the vector components by the length, say $\vec{w}_{normalized} = \frac{\vec{w}}{\|\vec{w}\|}$. See the appendix for more on norms and for example for a proof of the normalization.

2.5 \vec{e}_n are the three 2-D basis vectors

We have drawn some axes on a piece of paper and taken the angles starting from zero counterclockwise on the x-axis.

Now we will write down the three basis vectors. Each vector points from the origin exactly along the first unit of the together belonging axis.

Let \vec{e}_n be the set of three two dimensional basis vectors. In this document and some literature and scripts, we call them \vec{e}_x , \vec{e}_y and \vec{e}_z . Another well known names for the basis vectors are \vec{i} , \vec{j} or \vec{k} for example. That is equal to the picture of the coordinate axes at ?? in this document.

The three vectors point into the three directions of the three coordinate axes. Exactly along one unit, since we are going to define with them the length of one unit of the corresponding axis together with the positive direction of the coordinate axis. Multiplying the 2×3 basis with the 3×1 points later results in wonderful 2×1 points.

$$\vec{e}_n := \{\vec{e}_x, \vec{e}_y, \vec{e}_z\} = \{\vec{e}_1, \vec{e}_2, \vec{e}_3\}$$

There we have the set for the three basis vectors. We give them the letter e and a subscript for the coordinate component in the numeric order of $x = 1, y = 2, z = 3$. To arrange these vectors we already got around the unit circle. To measure the angles, beginning on the horizontal coordinate axis or zero, until we reach the vector. The vectors point into the positive direction of the described axis.

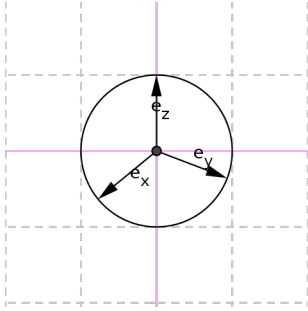


Figure 3: The three basis vectors point into the positive directions of the desired coordinate axes each. They are arranged around a circle with the trigonometric functions of cosine and sine. The coordinate system shown is a righthanded coordinate system.

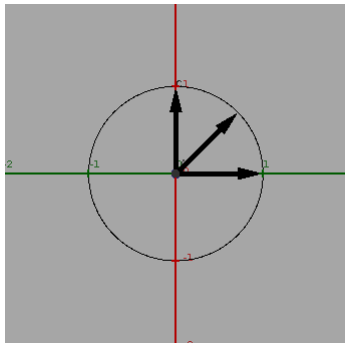


Figure 4: The three two dimensional basis vectors $\in \mathbb{R}^{2 \times 3}$ as a lefthanded coordinate system.

To reach all three (x,y) at the tips of the vectors, we will now pull out the cosine and sine functions and stuff them together with r and φ into a 2×1 vector with two components. So any (x,y) on one line

from the origin to far distance can be reached like in polar coordinates¹ with the following parametrization.

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} r \cos \varphi \\ r \sin \varphi \end{pmatrix}$$

Which can alternatively be written like $(x, y) = (r \cos \varphi, r \sin \varphi)$.

Modeling the three two dimensional basis vectors with this information, we get the following three two dimensional basis vectors. They point along the coordinate axes and are the ruler for our transformation.

$$\begin{aligned} \vec{e}_x &:= (r_x \cos(\varphi_x), r_x \sin(\varphi_x))^T = \begin{pmatrix} r_x \cos(\varphi_x) \\ r_x \sin(\varphi_x) \end{pmatrix} \\ \vec{e}_y &:= (r_y \cos(\varphi_y), r_y \sin(\varphi_y))^T = \begin{pmatrix} r_y \cos(\varphi_y) \\ r_y \sin(\varphi_y) \end{pmatrix} \\ \vec{e}_z &:= (r_z \cos(\varphi_z), r_z \sin(\varphi_z))^T = \begin{pmatrix} r_z \cos(\varphi_z) \\ r_z \sin(\varphi_z) \end{pmatrix} \end{aligned}$$

Each component of (x, y, z) has now an own basis vector. By multiplying the cos terms for the x' and the sin terms for y' with the corresponding component of (x, y, z) and summing the three products up for each of x' and y' , we directly obtain the right coordinate on the plane. All we would have to do is to connect the points again, or to fill the space between.

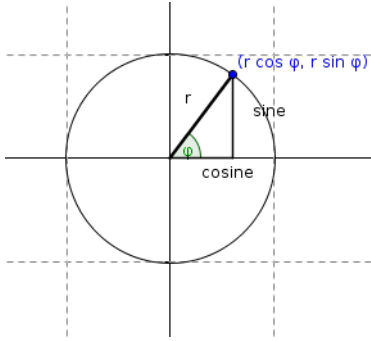


Figure 5: A picture of the unit circle, the hypotenuse r , the adjacent cosine, the opposite sine and the angle φ . It is a circle of radius r , and no longer the unit circle, if $r \neq 1$.

2.6 About the vector basis lemma

2.6.1 The general formula like the Hamel Basis

Remark. This section needs to be formulated again.

Remark II. Meanwhile i am sure, that Hamel-Basis is the right term to use here for the "generic formula". TODO.

I am talking about multiplying the coordinates with the new vector basis, which i state to be the same as the coordinate system we drew on a piece of paper at the beginning. We wrote down the angles, made out the unit length, and wrote down the three basis vectors with the information. Where is this coming from?

¹Interested readers may find in [1], [2] and [4] everything about polar coordinates, parametrization of x and y with cosine and sine, the unit circle and the distance or radius r and more to these topics.

$$\mathbf{E}_{\mathbb{R}^2} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Figure 6: The standard basis for the \mathbb{R}^2 spans up the two dimensional space. The basis is true in $\mathbb{R}^{2 \times 3}$ but in \mathbb{R}^2 just a linear combination of $\lambda \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ and $\mu \begin{pmatrix} 0 \\ 1 \end{pmatrix}$.

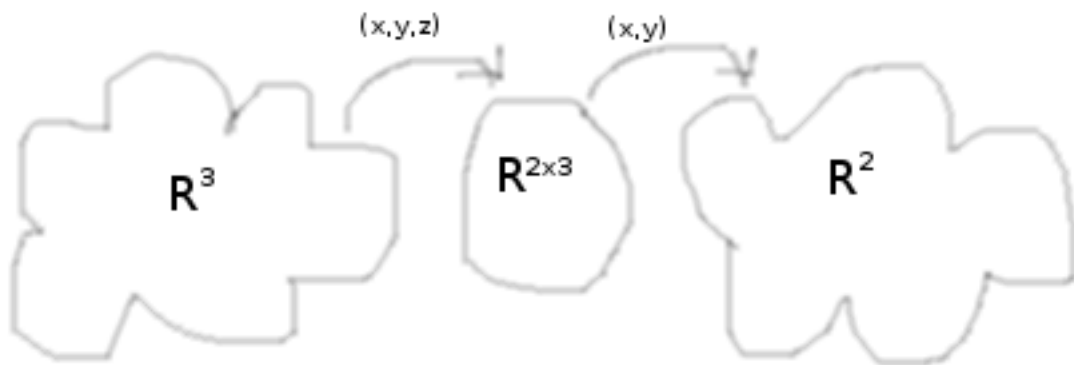


Figure 7: A temporary picture of the process. We multiply the 3-D points with the 2x3 matrix and get the 2-D points back.

Every mathematics, physics or related course has a lesson, where the orthogonal basis of an object it's coordinate system is introduced. Orthogonality has some wonderful properties, and solving differential equations and other complicated systems take help from orthogonal vector sets.

A orthogonal basis is a set of 2 or three or up to infinite orthogonal or perpendicular vectors. They describe the coordinate system, the space, the dimensions, and one has to show for excercises, that the basis is linearly independent, that each basis vector points into its own dimension and not into the others.

Another excercise is to orthogonalize the existing vectors with Gram-Schmidt.

The one lemma we need is this general theorem for multiplying a vector with the a basis of a target coordinate system.

The plane gives us two possible directions, to go horizontal or vertical. And in a cartesian coordinate system with infinite points, we can choose any direction around a center point (x,y). Which is in the case of our coordinate system the origin at (0,0,0) or (0,0). We will see later, that the zero vector stays in the origin fo both systems. Any not straight move will go horizontally or vertically by componentwise amounts. Any straight move horizontally or vertically will go by one of the components only.

Remark Edward was doing it right, then wrong (wrong with his pseudo-term). The basis is correct, but the space was $\mathbb{R}^{2 \times 3}$. In $\mathbb{R}^{2 \times 3}$ the basis can be shown. In \mathbb{R}^2 it is just a linear combination of three scalars with three vectors. I will be able to formulate this out in the next versions and have nice images for explanation in mind, which i will draw for.

The point is, the general formula holds with a 2x3 basis.

The basis acts as a middler between the two spaces. We walk through the $\mathbb{R}^{2 \times 3}$ when going from \mathbb{R}^3 to \mathbb{R}^2 .

In \mathbb{R}^2 the basis is linearly dependent, and not a basis, but multiplying the coordinates with, yield the right image of the set of points processed. On the other side, in $\mathbb{R}^{2 \times 3}$ the basis can be explained, what i

will do in the next versions. Have to read the text again, to catch my thread.

The formula for multiplying a vector with a base to get a new vector is this.²

$$\vec{w} = \sum_{i=1}^n \vec{v}_i \vec{e}_i$$

It is done componentwise for each row of the vector. n is the number of the source dimensions. In our case it is $n = 3$. We are summing three products for each component of the new vector. Our old \vec{v} is a $\vec{v} \in \mathbb{R}^3$.

With \vec{v}_i as the coordinate component and \vec{e}_i as the corresponding basis vector in the right component. \vec{w} is the resulting new vector. The new vector \vec{w} is a $\vec{w} \in \mathbb{R}^2$.

In our scenario is $V \subseteq \mathbb{R}^3, \vec{v} \in V$ and $W \subseteq \mathbb{R}^2, \vec{w} \in W$.

2.6.2 Connection to ijk-Notation

This is also equal to

$$\vec{v} = x\vec{i} + y\vec{j} + z\vec{k}$$

what also explains, what the ijk-Notation means. If you dont use it already for determining determinants for calculating cross products (C.2). It is for describing a vector. Dont forget, our i, j, k basis is two dimensional, because we draw on a 2-D plane like the computer screen or a piece of paper.

With a 3x3 basis the vector $x\vec{i} + y\vec{j} + z\vec{k}$ is equal to $\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix}$. But with a 2x3 basis the vector $x\vec{i} + y\vec{j} + z\vec{k}$ is becoming $\begin{pmatrix} x' \\ y' \end{pmatrix}$

2.6.3 Coordinate system

Remark. Needs to be formulated. New on July 23

The best i can do in the future editions of this text and for the concrete definition, is to say coordinate axes and coordinate system, without needing to know the horrible mathematic details, whose basis is used and whose not, and what words are right or wrong for.

The three vectors build the three coordinate axes of a three dimensional coordinate system in two dimensions. Nothing else.

The coordinates are transferred absolutely correct, they move along the vectors. They move the right units and only sideways and upwards. The proportions are exact and can be controlled.

More rational is to say, a human designed this coordinate system and has put it right way round into the matrix, no matter how difficult another view of mathematics on the same vectors could become.

It is for the practical use, to use after plotting to project something 3-D onto the 2-D plane.

2.7 Time to show the operation

The operation of multiplying the (x,y,z) coordinate with our $\mathbb{R}^{2 \times 3}$ coordinate axis vectors in order is the following:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} xr_x \cos \varphi_x + yr_y \cos \varphi_y + zr_z \cos \varphi_z \\ xr_x \sin \varphi_x + yr_y \sin \varphi_y + zr_z \sin \varphi_z \end{pmatrix}$$

Right, this small formula brings over the $\mathbb{R}^{2 \times 3}$ the unexpected images of the preimage from R^3 to R^2 .

²The formula can be found in many mathematics, chemistry and physics lecture scripts, and a good introduction is [3].

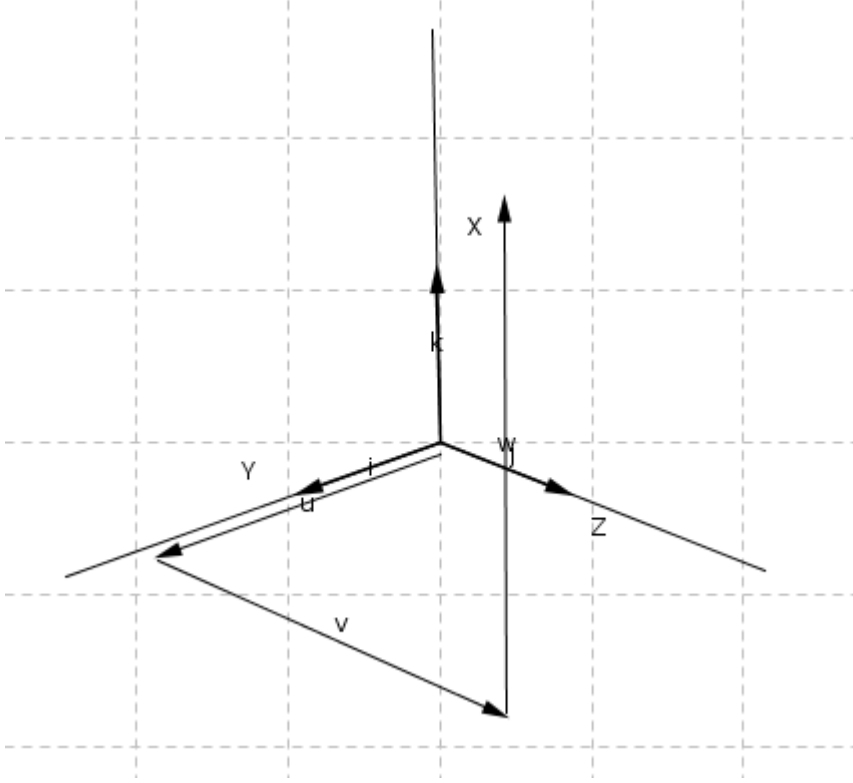


Figure 8: The path a point goes from the origin. Along the first axis, then from that parallel to the second along that axis, and last parallel to the third axis as many units as the coordinate says. You can not see on this picture, how it is deconstructed by cosine and sine into left and right moves. To see, just draw the two missing sides of the triangles under each move. The z axis has a cosine of 0. I will paint a new picture for.

It is almost time to finish the matrix and to go through a set of points to draw the new set of resulting points. For this i close the explaining chapters and come to the part of the formal mathematical definitions.

Remark. \LaTeX and i are new to each other. For the theorems, proofs, defintions, corollaries, examples there is the possibility of a personal layout.

3 The $\mathbb{R}^3 \rightarrow \mathbb{R}^2$ through $\mathbb{R}^{2 \times 3}$ transformation

Let V be the set of all points $(x, y, z) \in V \subseteq \mathbb{R}^3$ which are about to become transformed. $V := \{\vec{v} = (x, y, z)^T | x, y, z \in \mathbb{R}, \vec{v} \in V \subseteq \mathbb{R}^3\}$. Let W be the set of all points $(x', y') \in W \subseteq \mathbb{R}^2$ which are the result of the transformation $W := \{\vec{w} = (x', y')^T | \vec{w} \in W \subseteq \mathbb{R}^2, x', y' \in \mathbb{R}, \mathbf{A}\vec{v} = (x', y')\}$.

Remark study in progress.

Remark. What about the prime behind x and y. x' , y' looks bad.

3.1 Matrix version

A $m \times n$ matrix is a rectangle or square of numbers.

$$\mathbf{A} = (a_{ij})_{i,j \in \mathbb{N}^+} = \begin{pmatrix} a_{11} & \dots & a_{mn} \\ \vdots & \ddots & \vdots \\ a_{m1} & \dots & a_{mn} \end{pmatrix}$$

Matrix multiplication, from left to right in the matrix and from top to bottom in the vector, and that row by row, is achieved by

$$\mathbf{A}\vec{v} = \left(\sum_{j=1}^n a_{ij} \vec{v}_j \right)_{i=1..m} = \begin{pmatrix} a_{11}v_1 + a_{12}v_2 + \dots + a_{1n}v_n \\ \vdots \\ a_{m1}v_1 + a_{m2}v_2 + \dots + a_{mn}v_n \end{pmatrix} = \begin{pmatrix} w_1 \\ \vdots \\ w_m \end{pmatrix} = \vec{w}$$

This formula is not much different from the multiplication with a vector basis, but it also accounts for the rows in the formula. The vector basis multiplication implies the componentwise row operations by using vectors.

Definition 1 Let \mathbf{A} be the matrix containing the three, two dimensional and trigonometric, basis vectors in order, one each column. You get a rectangular 2×3 matrix $\mathbf{A} \in \mathbb{R}^{2 \times 3} : \mathbb{R}^3 \rightarrow \mathbb{R}^2$. With the basis vectors $\begin{pmatrix} r_n \cos \varphi_n \\ r_n \sin \varphi_n \end{pmatrix}$ in the three columns.

$$\mathbf{A} := (\vec{e}_x \quad \vec{e}_y \quad \vec{e}_z) = \begin{pmatrix} r_x \cos(\varphi_x) & r_y \cos(\varphi_y) & r_z \cos(\varphi_z) \\ r_x \sin(\varphi_x) & r_y \sin(\varphi_y) & r_z \sin(\varphi_z) \end{pmatrix}$$

\mathbf{A} should be treated as operator $\mathbf{A} \in \mathbb{R}^{2 \times 3} : \mathbb{R}^3 \rightarrow \mathbb{R}^2$. $(\mathbf{A})(\vec{x}) = \mathbf{A}\vec{x}$, $(\vec{x}) \mapsto \mathbf{A}\vec{x}$.

Remark. Make this another definition.

The operator lives itself in $L(V, W)$. $L(V, W)$ contains all linear operators from V to W . \mathbf{A} is mapping the input, which is 3-D from $V \subseteq \mathbb{R}^3$ onto the 2-D subset $W \subseteq \mathbb{R}^2$. The operator is NOT invertible due to a loss of one dimension and a lack of linear independence.

Remark This chapter needs to be overworked.

My fundamental theorem of transforming 3-D Points into 2-D Points (Matrix) 1 If you multiply \mathbf{A} , the 2×3 matrix of the three two-dimensional basis vectors, with the three-coordinate point (x, y, z) , the result is a two coordinate point, (x', y') . This point (x', y') is the correct point on the two dimensional plane, representing the point (x, y, z) from the three dimensional coordinate system, you are transforming.

$$\mathbf{A} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

Applying the operator \mathbf{A} transforms the point $(x, y, z) \in V \subseteq \mathbb{R}^3$ into a new point $(x', y') \in W \subseteq \mathbb{R}^2$.

Proof:

$$\mathbf{A} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \left(\sum_{j=1}^3 a_{ij} \vec{v}_j \right)_{i=1,2} = \begin{pmatrix} x r_x \cos(\varphi_x) + y r_y \cos(\varphi_y) + z r_z \cos(\varphi_z) \\ x r_x \sin(\varphi_x) + y r_y \sin(\varphi_y) + z r_z \sin(\varphi_z) \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

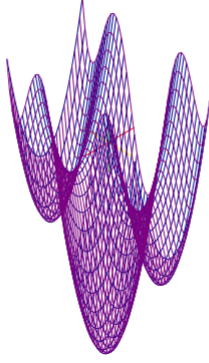


Figure 9: $f(x, y) = x^2 + y^2 + 3y \sin y$ from $[-5, 5]$ and $[-3, 3]$ on a Canvas2DRenderingContext

3.2 Vectorbasis version

$$\vec{w} = \sum_{i=1}^n \vec{v}_i \vec{e}_i$$

My fundamental theorem of transforming 3-D points into 2-D points (Vectorbasis) 1 *If you multiply the three linear dependent two dimensional vectors with the three dimensional coordinates, they are mapped correctly onto the two dimensional coordinate system.*

Remark. A Hamel-Basis requires a linearly independent set of basis vectors. Which we can not provide. We change the dimension.

$$\vec{v} = (x, y, z)^T$$

$$\vec{w} = x\vec{e}_x + y\vec{e}_y + z\vec{e}_z \text{ which is equal to } x\vec{i} + y\vec{j} + z\vec{k}$$

$$\vec{w} = \sum_{i=1}^n \vec{v}_i \vec{e}_i = \begin{pmatrix} xr_x \cos(\varphi_x) + yr_y \cos(\varphi_y) + zr_z \cos(\varphi_z) \\ xr_x \sin(\varphi_x) + yr_y \sin(\varphi_y) + zr_z \sin(\varphi_z) \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

TODO.

Breaking the rule of linear independence to map from 3-D to 2-D 1 *To transfer the points from 3-D to 2-D with the same formula, as mapping ordinary points with a vector basis into the corresponding coordinate system, it is o.k., to remove the third dimension from the basis and to multiply the 3-D coordinates with three 2-D vectors to get a correct mapping onto the projection plane.*

Remark. Formulation needs overworking.

3.3 Function version

The first days, i could not see the forest, because of all these trees. The operation can be written as function, or as part of a composition of functions. A big gain for this point by point transformation is the easy usability. For example, to create surface plots and other functional graphs from three dimensional space on a flat screen or printed paper.

3.3.1 The functional $f(\vec{x})$

We begin with $f(\vec{x}) : V \subseteq \mathbb{R}^3 \rightarrow \mathbb{R}^2$.

$f(\vec{x})$ is mapping the three dimensional coordinates onto our designed coordinate system. The multiplication of the components with the horizontal and vertical displacements which are represented by the axes of our coordinate system is the fix content of our function. Assume we have the angles and units

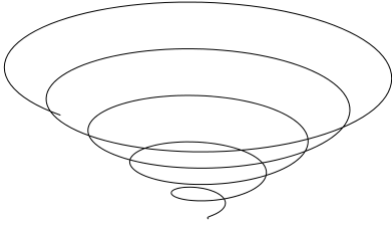


Figure 10: This is $g(t)$ from 3.3.2 plotted with the cheap3danimate.html code within $[-2, 2] \times [-2, 2]$.

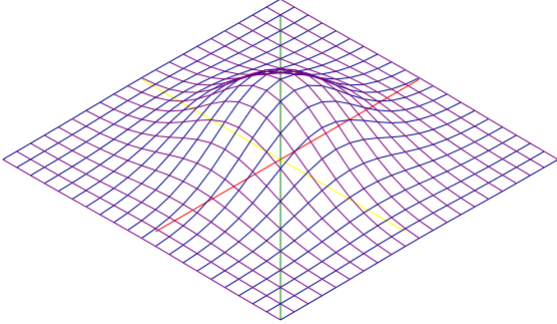


Figure 11: This is $\exp -x^2 - y^2$ from 3.3.2 plotted with the cheap3danimate.html code within $[-2, 2] \times [-2, 2]$.

designed and the function is well defined for its purpose.

$$f(\vec{x}) := \begin{pmatrix} \vec{x}_1 r_x \cos \varphi_x + \vec{x}_2 r_y \cos \varphi_y + \vec{x}_3 r_z \cos \varphi_z \\ \vec{x}_1 r_x \sin \varphi_x + \vec{x}_2 r_y \sin \varphi_y + \vec{x}_3 r_z \sin \varphi_z \end{pmatrix}$$

My fundamental theorem of transforming 3-D points into 2-D points (Functional) 1

3.3.2 Composition of the functions $f \circ g$

There are various possibilities to combine the output of g and the input of f . The following functions are compositions of two functions and take some input and return our 2-D points. f is transforming the vector returned by g . g is taking the input in all examples and f is reworking the coordinates. In other words, f is the same function as previously shown in 3.3.1.

Example 1. A call to $g(t)$ is returning a vector \vec{v} passed to $f(\vec{x})$ by using the composition $f \circ g : f(g(t)) = \vec{w}$

$$g(t) := \begin{pmatrix} t * \text{Math.cos}(t) \\ t * \text{Math.sin}(t) \\ t \end{pmatrix}$$

Example 2. $g(x, y) = (x, y, z)$ this function will give us a surface plot. See figure 3.3.2.

$$g(x, y) := \begin{pmatrix} x \\ y \\ \exp -x^2 - y^2 \end{pmatrix}$$

Example 3. A $g(x, y, z)$ or $g(\vec{x})$ a three-d or vector-valued function returning a three-d vector.

$$g(x, y, z) := \begin{pmatrix} next \\ next \\ next \end{pmatrix}$$

The vector field.

$$\begin{aligned} g(\vec{x}) : \mathbb{R}^3 &\rightarrow \mathbb{R}^3 \\ f(\vec{x}) : \mathbb{R}^3 &\rightarrow \mathbb{R}^2 \end{aligned}$$

3.4 Computer implementations of the transformation

3.4.1 Generic computer code

This should be in a border box.

The following is example code for various computer systems.

```
x_ = x*r*cos(alpha) + y*r*cos(beta) + z*r*cos(gamma)
y_ = x*r*sin(alpha) + y*r*sin(beta) + z*r*sin(gamma)
```

These are the one and only two lines of code you need.

3.4.2 JavaScript computer code

This is a full EcmaScript 6 snippet with all necessary informations.

```
let rad = (deg) => Math.PI/180*deg;
let r_x = 1, r_y = 1, r_z = 1;
let phi_x = rad(220), phi_y = rad(330), phi_z = rad(90);
let xAxisCos = r_x*Math.cos(phi_x),
    yAxisCos = r_y*Math.cos(phi_y),
    zAxisCos = r_z*Math.cos(phi_z),
    xAxisSin = r_x*Math.sin(phi_x),
    yAxisSin = r_y*Math.sin(phi_y),
    zAxisSin = r_z*Math.sin(phi_z);
let transform2d = ([x,y,z]) => [
    x*xAxisCos+ y*yAxisCos+ z*zAxisCos,
    x*xAxisSin+ y*yAxisSin+ z*zAxisSin];
let transform2dAll = (P) => P.map(transform2d);

let examplePoints = transform2dAll([[1,2,3], [3,4,5], [14,24,15]]);
```

This is the realistic amount of code to write to transform all points from 3-D to 2-D.

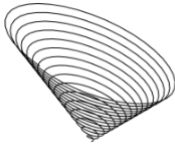


Figure 12: A conical helix $(t/2*\text{Math.cos}(t), t*\text{Math.sin}(t), t)$ shown as $(x,y,z)=f(t)$ with `implement.html` on a `Canvas2DRenderingContext` testing the javascript example code.

4 Important proofs of the transformation behaviour

Remark. This document is still under construction.

A very important thing is to show, that the linearity of the transformation is in order. With a wrong function, bad thing can happen. With the right functions, linear combinations should stay in the subspace.

4.1 The origin stays in the origin

A trivial proof is to prove, that the zero vector $\vec{0} \in \mathbb{R}^3$ maps to the zero vector $\vec{0} \in \mathbb{R}^2$.

Proof:

$$\mathbf{A} \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0+0+0 \\ 0+0+0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

4.2 Points along one axis

Another trivial proof is to prove, that coordinates lying on one axis are a multiple of the basis vector of the axis.

Proof:

$$\mathbf{A} \begin{pmatrix} a \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} ar_x \cos \varphi_x + 0 + 0 \\ ar_x \sin \varphi_x + 0 + 0 \end{pmatrix} = a\vec{e}_x$$

$$\mathbf{A} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 + r_y \cos \varphi_y + 0 \\ 0 + r_y \sin \varphi_y + 0 \end{pmatrix} = \vec{e}_y$$

$$\mathbf{A} \begin{pmatrix} 0 \\ 0 \\ -b \end{pmatrix} = \begin{pmatrix} 0 + 0 - br_z \cos \varphi_z \\ 0 + 0 - br_z \sin \varphi_z \end{pmatrix} = -b\vec{e}_z$$

4.3 Multiplications with constants

Another trivial proof is to show, that $\mathbf{A}(\lambda\vec{x}) = \lambda\mathbf{A}\vec{x}$. It doesnt matter, where you multiply with the constant. You can multiply the original vector, or the resulting vector. You reach the same point.

Proof:

$$\begin{aligned} \mathbf{A}(\lambda\vec{x}) &= \mathbf{A} \begin{pmatrix} \lambda x \\ \lambda y \\ \lambda z \end{pmatrix} \\ &= \begin{pmatrix} \lambda x r_x \cos(\varphi_x) + \lambda y r_y \cos(\varphi_y) + \lambda z r_z \cos(\varphi_z) \\ \lambda x r_x \sin(\varphi_x) + \lambda y r_y \sin(\varphi_y) + \lambda z r_z \sin(\varphi_z) \end{pmatrix} \\ &= \lambda \begin{pmatrix} x r_x \cos(\varphi_x) + y r_y \cos(\varphi_y) + z r_z \cos(\varphi_z) \\ x r_x \sin(\varphi_x) + y r_y \sin(\varphi_y) + z r_z \sin(\varphi_z) \end{pmatrix} \\ &= \lambda \begin{pmatrix} x' \\ y' \end{pmatrix} \\ &= \lambda \mathbf{A}\vec{x} \end{aligned}$$

4.4 Additions and subtractions

Another trivial proof is to show, that $\mathbf{A}(\vec{v} + \vec{w}) = \mathbf{A}\vec{v} + \mathbf{A}\vec{w}$. It does not matter, if you add the original or the results. The outcome is the same point, the same vector.

Proof:

$$\begin{aligned}
 \mathbf{A} \begin{pmatrix} x+u \\ y+v \\ z+w \end{pmatrix} &= \begin{pmatrix} (x+u)r_x \cos(\varphi_x) + (y+v)r_y \cos(\varphi_y) + (z+w)r_z \cos(\varphi_z) \\ (x+u)r_x \sin(\varphi_x) + (y+v)r_y \sin(\varphi_y) + (z+w)r_z \sin(\varphi_z) \end{pmatrix} \\
 &= \begin{pmatrix} xr_x \cos(\varphi_x) + yr_y \cos(\varphi_y) + zr_z \cos(\varphi_z) \\ xr_x \sin(\varphi_x) + yr_y \sin(\varphi_y) + zr_z \sin(\varphi_z) \end{pmatrix} + \begin{pmatrix} ur_x \cos(\varphi_x) + vr_y \cos(\varphi_y) + wr_z \cos(\varphi_z) \\ ur_x \sin(\varphi_x) + vr_y \sin(\varphi_y) + wr_z \sin(\varphi_z) \end{pmatrix} \\
 &= \begin{pmatrix} x' \\ y' \end{pmatrix} + \begin{pmatrix} u' \\ v' \end{pmatrix} \\
 &= \mathbf{A} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \mathbf{A} \begin{pmatrix} u \\ v \\ w \end{pmatrix}
 \end{aligned}$$

4.5 Rule of linearity

Corollary From the previous two proofs, it is obvious to see, that

$$\mathbf{A}(\lambda\vec{v} + \kappa\vec{w}) = \lambda\mathbf{A}\vec{v} + \kappa\mathbf{A}\vec{w} = \lambda \begin{pmatrix} x' \\ y' \end{pmatrix} + \kappa \begin{pmatrix} u' \\ v' \end{pmatrix}$$

which is a standard formulation of the rule of linearity. For example, you can find this rule in the form $\mathbf{A}(c\vec{x} + d\vec{y}) = c\mathbf{A}\vec{x} + d\mathbf{A}\vec{y}$ in [3], but also in every linear algebra 1 lecture script.

5 Corollaries

5.1 Converting four Dimensions down to two dimensions

The theorem can be used to handle more dimensions, for example can four two-dimensional vectors represent a 4-D space on the 2-D plane. They get converted into the correct 2-D points. For Example, if you use a 2x4 matrix and convert all points at each instance of t you have a moving object into the direction of the fourth basis vector.

$$\mathbf{A} := (\vec{e}_x \quad \vec{e}_y \quad \vec{e}_z \quad \vec{e}_t) = \begin{pmatrix} r_x \cos(\varphi_x) & r_y \cos(\varphi_y) & r_z \cos(\varphi_z) & r_t \cos(\varphi_t) \\ r_x \sin(\varphi_x) & r_y \sin(\varphi_y) & r_z \sin(\varphi_z) & r_t \sin(\varphi_t) \end{pmatrix}$$

Here the basis is four times of two dimensions. A 2x4 matrix with four two dimensional basis vectors, one for each axis.

$$\mathbf{A} \begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = \sum_n \vec{e}_n \vec{x}_n = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

Proof:

$$\mathbf{A} \begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} = \begin{pmatrix} xr_x \cos(\varphi_x) + yr_y \cos(\varphi_y) + zr_z \cos(\varphi_z) + tr_t \cos(\varphi_t) \\ xr_x \sin(\varphi_x) + yr_y \sin(\varphi_y) + zr_z \sin(\varphi_z) + tr_t \sin(\varphi_t) \end{pmatrix}$$

$$= x\vec{e}_x + y\vec{e}_y + z\vec{e}_z + t\vec{e}_t = \sum_n \vec{e}_n \vec{x}_n = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

The same method can be used, to convert points or vectors from any other number of dimensions, down to the xy -plane. It can also be used in a general m by n case.³

5.2 Alternative definition of the transformation by using dot products

Underways, i came to another conclusion. If i pull the two row vectors out of the matrix and define them as two column vectors, then i can dot each with the coordinate vector and write the dot product into the component of the resulting vector.

$$\vec{v} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad \vec{c} = \begin{pmatrix} r_x \cos \varphi_x \\ r_y \cos \varphi_y \\ r_z \cos \varphi_z \end{pmatrix} \quad \vec{s} = \begin{pmatrix} r_x \sin \varphi_x \\ r_y \sin \varphi_y \\ r_z \sin \varphi_z \end{pmatrix}$$

$$\vec{w} = \begin{pmatrix} \vec{v} \cdot \vec{c} \\ \vec{v} \cdot \vec{s} \end{pmatrix}$$

The result is $\vec{w} \in W$, $W \subseteq \mathbb{R}^2$.

This can also be done with up to infinite dimensions which result in two coordinates then. Just add the dimensions to \vec{v} , \vec{c} , \vec{s} and see.

Proof:

$$\begin{pmatrix} \vec{v} \cdot \vec{c} \\ \vec{v} \cdot \vec{s} \end{pmatrix} = \begin{pmatrix} xr_x \cos(\varphi_x) + yr_y \cos(\varphi_y) + zr_z \cos(\varphi_z) \\ xr_x \sin(\varphi_x) + yr_y \sin(\varphi_y) + zr_z \sin(\varphi_z) \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

6 Derivatives of $\vec{f}(\vec{x}) : V \rightarrow W$

Again we begin with $\vec{f}(\vec{x}) : V \subseteq \mathbb{R}^3 \rightarrow W \subseteq \mathbb{R}^2$.

$$\vec{f}(\vec{x}) := \begin{pmatrix} \vec{x}_1 r_x \cos \varphi_x + \vec{x}_2 r_y \cos \varphi_y + \vec{x}_3 r_z \cos \varphi_z \\ \vec{x}_1 r_x \sin \varphi_x + \vec{x}_2 r_y \sin \varphi_y + \vec{x}_3 r_z \sin \varphi_z \end{pmatrix}$$

The first derivatives after the vector are the following by using the product rule and partial differentiation. The scalar component of the input is gone, because the derivative is 1 and the other summand of the derived product is zero, because the cosine or sine function are treated like either like a constant or like a function and become zero because there is the wrong variable to differentiate in the angle.

$$\begin{aligned} \partial_1(\vec{f}_1(\vec{x})) &= r_x \cos \varphi_x \\ \partial_2(\vec{f}_2(\vec{x})) &= r_x \sin \varphi_x \end{aligned}$$

The derivatives of the angles are not taken. But it seems to be obvious, that the sin and cosine would be rotating around by 90 degrees each time the derivative of the derivative with respect to the angle is taken. The slope is the vector, because the point is moving by that vector from its current position a straight line, when multiplied.

$$\begin{aligned} \partial_1(\vec{f}(\vec{x})) &= \vec{e}_x \\ \partial_2(\vec{f}(\vec{x})) &= \vec{e}_y \\ \partial_3(\vec{f}(\vec{x})) &= \vec{e}_z \end{aligned}$$

³<http://de.wikipedia.org/wiki/Abbildungsmatrix>, shows the m by n case.

The second derivatives are already zero, because the returned vectors are constants with respect to the taken input variable. In a different meaning, there is no second derivative, because the coordinate system is linear. It is a straight line. It has no curves, so no tangent. There is no curvature, so no second derivative. But it is perfect. And calculus is right, because the three vectors are three straight lines.

$$\begin{aligned}\partial_1^2(\vec{f}(\vec{x})) &= 0 \\ \partial_2^2(\vec{f}(\vec{x})) &= 0 \\ \partial_3^2(\vec{f}(\vec{x})) &= 0\end{aligned}$$

Conclusion. The first derivative represents the axis vector. The gradient gives us the complete coordinate system. If we use the gradient then in another composition (with matrix vector multiplication with a three coordinate vector), we can apply the mapping again.

$$\nabla \vec{f} := \begin{pmatrix} \vec{e}_x \\ \vec{e}_y \\ \vec{e}_z \end{pmatrix} = \mathbf{A}^T$$

Looks like we have to transpose the row vector again. Because the gradient seems to be the same as the 3 by 2 matrix \mathbf{A}^T and not like our original coordinate system.

$$(\nabla \vec{f})^T := (\vec{e}_x \quad \vec{e}_y \quad \vec{e}_z) = \mathbf{A}$$

Now we could reuse the vector of vectors (the matrix) and multiply again with coordinates. But before, we come to another conclusion, which i had underways, after writing down the transposed gradient, the next morning, reading a lecture script about Analysis 2 (vector calculus).

$$(\nabla \vec{f})^T \Leftrightarrow \mathbf{J}(\vec{f}(\vec{x})) := \begin{pmatrix} \partial_1 f_1 & \partial_2 f_1 & \partial_3 f_1 \\ \partial_1 f_2 & \partial_2 f_2 & \partial_3 f_2 \end{pmatrix}$$

The transposed gradient of the vector function $\vec{f}(\vec{x}) : V \rightarrow W$ is the Jacobi Matrix, which is equal to the matrix, i discussed already. This possible makes another re-ordering necessary. But first look yourself.

7 Cauchy Sequences and Convergence

Convergence means, that a sequence comes step by step closer together, until the sequence items come so close together, that the distance goes to zero. The sequence itself gets closer and closer to the point. When the n goes to infinity, the distance goes to zero.

For myself, i imagine it is like it is going the path of $1, \bar{9}$ and said to converge against 2.

$$\forall \epsilon > 0 : \exists n_0 \in \mathbb{N} : \forall n \geq n_0 : \|v_m - v_n\| < \epsilon$$

For every ϵ greater than 0 exists some index n_0 of the sequence. Which has not to be the first index because of the zero, but is the first n, where the distance of the sequence vector compared to the former sequence vector is smaller than our epsilon value.

The limit goes to some value, if the series converges.

$$\lim_{n \rightarrow \infty} v_n \rightarrow \vec{v}$$

The norm or the distance goes to zero, after going under epsilon at some point n_0 .

$$\|v_n - v_m\| = d(v_n - v_m) \rightarrow 0$$

In three dimensions, all vector components of the sequence have to converge to some value. It depends on your sequence, whether it returns one vector with three components or is a vector build by three sequences.

Anyways, $(\vec{v}_n)_{n \in \mathbb{N}^+}$ has to follow the ordinary rules, that $\lim_{n \rightarrow \infty} (\vec{v}_n) = \vec{v}$. In shorthand, the sequence has to converge against the limit $\lim_{n \rightarrow \infty} v_n \rightarrow \vec{v}$. Or even shorter, that $(\vec{v}_n) \rightarrow \vec{v}$

For my 3-D to 2-D transformation, the following propositions are made by me.

First. If the sequence (v_n) converges to \vec{v} . Then $(\mathbf{A}\vec{v})$ converges to $\mathbf{A}\vec{v}$.

$$\begin{aligned} (v_n)_{n \in \mathbb{N}^+} &\rightarrow \vec{v} \\ (\mathbf{A}v_n)_{n \in \mathbb{N}^+} &\rightarrow \mathbf{A}\vec{v} \end{aligned}$$

Second. It is better to put the matrix outside of the parens, if you let a computer calculate this.

For the proof it is maybe neccessary, to put the \mathbf{A} back into the parens. But ractically i would like to know the rule and then take the smallest calculation.

$$\begin{aligned} (\mathbf{A}v_n) &= \mathbf{A}(v_n) \\ \mathbf{A}(v_n) &\rightarrow \mathbf{A}\vec{v} \end{aligned}$$

Doesnt this also imply that the matrix times the limit yields the right values?

$$\mathbf{A} \lim_{n \rightarrow \infty} (v_n) = \mathbf{A}\vec{v} = \vec{w}$$

So we got to show, that there is a n_0 and that some series converges.

Let there be some sequence $(\mathbf{A}v_n)_{n \in \mathbb{N}^+}$. We start at $n = 1$ and when there is some n_0 than the distance must shrink under epsilon and finally go to zero.

$$\|\mathbf{A}v_n - \mathbf{A}v_m\| \leq \epsilon, \forall m, n > n_0$$

8 Summary

8.1 Summary of all neccessary steps

1. Lay out the three basis vectors around a circle and write down the angles φ_n . Programmers have to write down a variable for anyways.
2. Write down the basis vectors \vec{e}_n as $r_n \cos \varphi_n$ and $r_n \sin \varphi_n$ (two dimensional). Dont multiply with r_n for a unit length of 1 or multiply with r_n to change the length of the basis vector.
3. Put the three basis vectors \vec{e}_n into a matrix \mathbf{A} . Programmers can directly code the two lines of multiplication and forget the formal rest.
4. Iterate over your points and multiply each (x, y, z) with the matrix \mathbf{A} , which acts as a linear operator, and put (x', y') into your new set.⁴

Remark

About the word *unit*. I am not really sure, if i have to use *base vector* for a vector of any length and *unit vector* only for the *unit length* of 1. Because of the misleading mismatch with the *unit* of the thought *coordinate axes*, which the *base vector* defines, i tend in the first versions to misuse the word *unit vector* for both. If you find this, or any other formal mistake, be sure, it is not wanted :-)) I will try to remove more of these spelling errors⁵ in the next versions.

⁴Alternatively you can use the dot product to dot (x, y, z) with the cosine vector for x' and dot (x, y, z) with the sine vector for y' . The calculation is identical then.

⁵The *Gerholdian operator*, the *Gerholdian basis*, the *Gerhold projection matrix*, the *Gerhold transformation* are my favourite nicknames for my late discovery, making sure, the three two dimensional and trigonometric basis vectors, which i explained, sit in the matrix.

9 Glossary

I am nativly a german speaking man. To reduce the risk of misunderstanding me, i will write down the terms, which i use in this document. So you can read from my definition, what i mean with and decide by yourself, whats the correct word, i wanted to use.

Remark. This doesnt contain the right info. I should use basis and coordinate axes interchangeably, but i use other words.

assumed english	german	personal definition
basis	Basis	A system of vectors, with which any coordinate has to be A basis transforms your coordinates into your desired coord A basis is regularly a set of linearly independent vectors. For example are $(1, 0)$ and $(0, 1)$ the basis for the \mathbb{R}^2 and $(3, 4)$ is a combination of $3 \times (1, 0)$ and $4 \times (0, 1)$, The basis is also synonymous for the coordinate axes.
vector, point, coordinate	Vektor, Punkt, Koordinate	A vector has a length and a direction. The tails of the vectors here meet in the origin. The point of the vector, or the word for the coordinates in the cartes The words point, vector, coordinate are used interchangeab on what your numbers mean.
component	Komponente	A component of a vector or a matrix or a point is one of t
operator	Operator	A matrix is a linear map or a linear operator. The former and the latter is functional analysis. Well, a better applica both, so both should be used. But possibly i currently inte The definition of the 2x3 operator is not complete, it is for looses the third dimensions also, when restoring, with say

Remark incomplete.

A Temporarily moved down MORE TODO

A.1 Neighborhood

Remark. This should come together with topology. With metrics and distance. Maybe i can move the metric stuff from downwards up to this.

The neighborhood of a point (x, y, z) is a ball or a sphere with a radius r . The ball has inner points, the sphere just is the border of the ball. The ball got the formula $B_r(x, y, z) : x^2 + y^2 + z^2 \leq r$ and the sphere collects all points around with the radius of one $B_r(\vec{v}) := (x, y, z) : x^2 + y^2 + z^2 = r$.

A.2 Convex sets

Convex sets contain the path beetween two points inside the set. That means, that the direct way from a to be is not crossing the borders of the set. This can be imagined with real borders of a set. A round set, or a rectangle have all points inside together with their path. A star for example, where you have two points at two of the tips is not convex, the direct path, the straight line would cross the border of the star, leave the star, and reenter the star. There is a formula, which gives the points on the path.

$$u = \lambda \vec{x} + (1 - \lambda) \vec{y}, \lambda \in [0, 1], x, y \in V \implies u \in V$$

The factor lambda lies between 0 and 1. If $\lambda = 0.1$ then is $(1 - \lambda) = 0.9$, if $\lambda = 0.2$ then is $(1 - \lambda) = 0.8$ and so on. The result is lying on the straight line beetween \vec{x} and \vec{y} . I have taken two vectors $\vec{x}, \vec{y} \in \mathbb{R}^2$ and drawn them. The points lie on the line beetween the two points.

There is an inequality, which convex functions have to satisfy. And you may know it. It is the *triangle inequality*

$$\|\lambda \vec{x} + (1 - \lambda) \vec{y}\| \leq \lambda \|\vec{x}\| + (1 - \lambda) \|\vec{y}\|$$

or what expresses, that a function is convex.

$$f(\lambda \vec{x} + (1 - \lambda) \vec{y}) \leq \lambda f(\vec{x}) + (1 - \lambda) f(\vec{y})$$

What is again the *triangle inequality*.

Our image is very precise, because we designed a real coordinate system. What is happening to our new vector?

$$\lambda \mathbf{A}\vec{x} + (1 - \lambda) \mathbf{A}\vec{y} = \mathbf{A}(\lambda \vec{x} + (1 - \lambda) \vec{y})$$

By the rule of linearity.

Remark. To be studied within the next days.

A.3 Orthogonality in the 2x3 matrix

Remark. This is my note, just a few days old. I am sorry for the crap inside the document. Ok. Its a dev version. I said that. But my first words about the right angle of the xy plane, for whose two axes the three inputs are combined to one final position, are stumbled a little.

I think this is more about the right angle in the two dimensions and the linear combination of the three input values, once for each direction of the right angle here. It is still the 3-D on 2-D coordinate system with image and it should do exactly that.

Probably already found. 2-D (in each column, the two rows) mapping orthogonal, 3-D is linear (three moves left-right, three up-down) in the 2x3. In the 3x2 case the converse. Do never forget, that cos and sin are \perp and form a right angle. TODO.

I mean. In each of the three column vectors, the map to the plane is defined by orthogonality of the two rows. Even if we change from the perpendicular sine and cosine to some weird nbers, it would be interpreted as x and y and depend on the base used in the R2.

Funny Remark. For the advanced mathematician. Seeing cross products, euler doing cross formulas, is it some idea, to take three 2x2 matrices, to cross them over, maybe restore the xy dimensions correctly and take the third one over the difference of the two? Maybe this is easier, to take z from the mix with x and from the mix with y. And if it can not be decided, because of the point being covered by more than one position (where these algebra classes land on the same value)? And if the last one can not be decided, is this an application for probability, to get this document full over the months?

A.4 Algebra

TODO

A.4.1 K-Vectorspace

Move to the beginning. But do not change emphasisment on the design of the coordinate system on the plane.

The euclidean space is a K-Vectorspace.

TODO

A.4.2 Quotient rooms

Taking away the z coordinate and setting it to zero shows us a parallel projection of the xy plane.

This is a quotient room of the three dimensional room. Written V/W . A quotient room collapses a dimension or more.

Inside of the topic. Equivalenceclasses are written in Brackets. They have properties like $[v] + [w] = [v+w]$.

I recently got into the topic and am learning more about. This section can be updated in some hours.

A.5 Integration

Since the function is continuous, it is possible to measure the objects, or to integrate over the surfaces, to get some areas and volumes together.

B Deconstructing and proving the 2x3 basis or not

B.1 2x3 standard basis

A 2x3 basis is a set of six matrices being constructed out of five basis vectors. In the Appendix of [3], there is a basis of a 2x3 matrix printed, together with a few arguments. The professor constructed a 2x3 standard basis by multiplying the 2-D standard basis vectors with the 3-D standard vectors.

$$\begin{aligned} e_1^{\mathbb{R}^2} &= \begin{pmatrix} 1 \\ 0 \end{pmatrix} e_2^{\mathbb{R}^2} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \\ e_1^{\mathbb{R}^3} &= \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} e_2^{\mathbb{R}^3} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} e_3^{\mathbb{R}^3} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \end{aligned}$$

Multiplying $e_i^{\mathbb{R}^2}$ with $(e_j^{\mathbb{R}^3})^T$ yields six independent matrices, which, when added, form the standard basis.

$$E^{\mathbb{R}^{2 \times 3}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

My task is now, to deconstruct our formula, to meet the requirements.

$$\begin{aligned} e_1^{\mathbb{R}^2} &= \begin{pmatrix} u \\ 0 \end{pmatrix} e_2^{\mathbb{R}^2} = \begin{pmatrix} 0 \\ v \end{pmatrix} \\ e_1^{\mathbb{R}^3} &= \begin{pmatrix} a \\ 0 \\ 0 \end{pmatrix} e_2^{\mathbb{R}^3} = \begin{pmatrix} 0 \\ b \\ 0 \end{pmatrix} e_3^{\mathbb{R}^3} = \begin{pmatrix} 0 \\ 0 \\ c \end{pmatrix} \\ E^{\mathbb{R}^{2 \times 3}} &= \begin{pmatrix} ua & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & ub & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & uc \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ va & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & vb & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & vc \end{pmatrix} \end{aligned}$$

Here we can substitute

$$ua = r_x \cos \varphi_x, va = r_x \sin \varphi_x, ub = r_y \cos \varphi_y, vb = r_y \sin \varphi_y, uc = r_z \cos \varphi_z, vc = r_z \sin \varphi_z,$$

It should result in

$$\begin{aligned} &\begin{pmatrix} r_x \cos \varphi_x & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & r_y \cos \varphi_y & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & r_z \cos \varphi_z \\ 0 & 0 & 0 \end{pmatrix} + \\ &\begin{pmatrix} 0 & 0 & 0 \\ r_x \sin \varphi_x & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & r_y \sin \varphi_y & 0 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & r_z \sin \varphi_z \end{pmatrix} \\ &= \begin{pmatrix} r_x \cos \varphi_x & r_y \cos \varphi_y & r_z \cos \varphi_z \\ r_x \sin \varphi_x & r_y \sin \varphi_y & r_z \sin \varphi_z \end{pmatrix} \end{aligned}$$

Remark. My first conclusions, while inventing the chapter and the exercise. To be removed.

From trigonometry, we know, that cosine and sine form a right angle. They are perpendicular to each other. But taking the norm of the vector results in r , not in 0, because $\sin^2 + \cos^2 = 1$. $r \sin^2 + r \cos^2 = r^2$. This is not orthogonal in terms of the dot product, which should result in 0, if the angle is 90 degrees.

For simplification we should do a few things. First, we assume $r_x = r_y = r_z = 1$. Without a factor in front of sine and cosine, they both together have unit length of one. With $\left\| \begin{pmatrix} \frac{r_x \cos \varphi_x}{r_x} \\ \frac{r_x \sin \varphi_x}{r_x} \end{pmatrix} \right\| = 1$ the vector

is normalized.

Secondly, we substitute the cosine and sine terms with simple letters. Sine, cosine and r form a triangle. Thinking of a triangle, and $\sin = \text{opposite/hypotenuse}$ and $\cos = \text{adjacent/hypotenuse}$, will make it easier for us to find the factors and to solve this system.

$$\cos = \frac{\text{adjacent}}{\text{hypotenuse}} \sin = \frac{\text{opposite}}{\text{hypotenuse}}$$

B.2 Lefthanded and righthanded system

Without calculating them, but quick-concluding them from the existing, i get the following matrices, which look like bases, containing only zeros and ones. With the quick issue, that the length of the columns with two ones is square root of two, while zero and one has length one.

$$E_{lefthand}^{\mathbb{R}^{2 \times 3}} = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \end{pmatrix}$$

$$E_{righthand}^{\mathbb{R}^{2 \times 3}} = \begin{pmatrix} -1 & 1 & 0 \\ -1 & -1 & 1 \end{pmatrix}$$

Remark Proof or contradictions TODO

C Proving more rules of vector spaces

Remark. The linearity proofs should go together with the formula in the main part about.

C.1 Dot product

The dot product, scalar product or inner product is the sum of the vector component products. (\vec{v}, \vec{w}) is $\sum_{i=1}^n \vec{v}_i \vec{w}_i$.

$$\sum_{i=1}^n \vec{v}_i \vec{w}_i = 0 \text{ means, that } \vec{v} \perp \vec{w}$$

The basis formula is this

$$(v, w) = \sum_{i=1}^n \vec{v}_i \vec{w}_i$$

A product with the zero vector.

$$(\vec{0}, w) = \sum_{i=1}^n \vec{0}_i \vec{w}_i = 0$$

Linear combinations.

$$(\lambda \vec{v}, \vec{w}) = \sum_{i=1}^n \lambda \vec{v}_i \vec{w}_i = \lambda \sum_{i=1}^n \vec{v}_i \vec{w}_i = \lambda (\vec{v}, \vec{w})$$

$$(\lambda \vec{v}, \vec{w} + \vec{x}) = \sum_{i=1}^n \lambda \vec{v}_i (\vec{w}_i + \vec{x}_i) = \lambda \left(\sum_{i=1}^n \vec{v}_i \vec{w}_i + \sum_{i=1}^n \vec{v}_i \vec{x}_i \right) = \lambda ((\vec{v}, \vec{w}) + (\vec{v}, \vec{x}))$$

$$(\lambda \vec{v}, \kappa \vec{w}) = \sum_{i=1}^n \lambda \vec{v}_i \kappa \vec{w}_i = \lambda \kappa \sum_{i=1}^n \vec{v}_i \vec{w}_i = \lambda \kappa (\vec{v}, \vec{w})$$

$$\begin{aligned}
& (\lambda \vec{v} + \mu \vec{x}, \kappa \vec{w} + \nu \vec{y}) \\
&= \sum_{i=1}^n (\lambda \vec{v}_i + \mu \vec{x}_i)(\kappa \vec{w}_i + \nu \vec{y}_i) \\
&= (\lambda \vec{v}, \kappa \vec{w}) + (\lambda \vec{v}, \nu \vec{y}) + (\kappa \vec{w}, \mu \vec{x}) + (\kappa \vec{w}, \nu \vec{y}) \\
&= \lambda(\kappa(\vec{v}, \vec{w}) + \nu(\vec{v}, \vec{y})) + \kappa(\mu(\vec{w}, \vec{x}) + \nu(\vec{w}, \vec{y}))
\end{aligned}$$

C.2 The cross product

$$\begin{pmatrix} \vec{i} & \vec{j} & \vec{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{pmatrix} = \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} \vec{i} - \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} \vec{j} + \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \vec{k} = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix}$$

You write a new vector $x\vec{i} - y\vec{j} + z\vec{k}$ (pay attention to the minus) with the determinants, which you obtain by scratching current column and the first row. You multiply the determinant with i, j, or k. Which

$$\vec{a} \times \vec{b} = (a_2b_3 - a_3b_2)\vec{i} - (a_1b_3 - a_3b_1)\vec{j} + (a_1b_2 - a_2b_1)\vec{k} = \vec{c}$$

If the cross product does not yield a new vector, but the zero vector, the two vectors are not on the same plane.

First i could not make out, what to proof now. But i can orient myself with [1]. The proof works like this: You have to prove, that $(v \times w) \cdot v = 0$, so that $(v \times w) \perp w$ and that $(v \times w) \cdot w = 0$ and also $(v \times w) \perp w$. I will calculate this alone, without looking again. Just calculate out the cross product and multiply with the components of the one vector you dot. After rearranging the terms, the result must be zero.

$$\left(\begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} \vec{i} - \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} \vec{j} + \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \vec{k} \right) \cdot (\vec{a}_1\vec{i} + \vec{a}_2\vec{j} + \vec{a}_3\vec{k}) = ? 0$$

and

$$\left(\begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} \vec{i} - \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} \vec{j} + \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \vec{k} \right) \cdot (\vec{b}_1\vec{i} + \vec{b}_2\vec{j} + \vec{b}_3\vec{k}) = ? 0$$

C.3 Normal vectors

Are perpendicular to the surface, a curve or another vector and give the orientation.

For 2-D space, the normal vector of the standard basis $\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ is obtained by multiplying the vector with the standard normal matrix $\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$.

$$\mathbf{N}_{\mathbb{R}^2} := \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

You should multiply the 2x3 matrix with some vector and you will get a perpendicular vector back.

$$\vec{n} = \mathbf{N}\vec{w} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} -b \\ a \end{pmatrix}$$

Proof. The resulting normal vector has to be perpendicular to the source vector, so their dot product must be zero.

$$\vec{n} \cdot \vec{w} = \sum_{i=1}^2 \vec{n}_i \vec{w}_i = -ab + ab = 0$$

For three dimensional vectors the proof is similar, and the dot product should also return zero for a proof. A perpendicular vector is obtained by permuting the identity matrix (standard basis) and changing sign.

C.4 About the norm

C.4.1 Vector norms

The norm is the word for the vector length. Or better, it is the multidimensional *absolute value* of a vector. Remember from single variable calculus that $|-x| = x$ and $|x| = x$. The norm kind of does this with all values and puts them together.

Our first norm used here is the euclidean norm, also known as the 2-norm. This is taking the square root of the sum of the squares of the absolute values of the components $\|\vec{x}\| = \sqrt{\sum_{i=1}^n |x_i|^2}$. In linear algebra, functional analysis and topology lectures there are three fundamental properties of the norm repeating. Definiteness, homogeneity and the triangle inequality.

Definiteness Show that $\|\vec{x}\| = 0 \iff \vec{x} = 0$

$$\|\vec{x}\| = \|\vec{0}\| = \sqrt{0^2 + 0^2} = 0$$

Homogeneity Show that $\|a\vec{x}\| = |a|\|\vec{x}\|$

$$\|a\vec{x}\| = \sqrt{|a\vec{x}_1|^2 + |a\vec{x}_2|^2} = \sqrt{|a|^2(|\vec{x}_1|^2 + |\vec{x}_2|^2)} = |a|\sqrt{|\vec{x}_1|^2 + |\vec{x}_2|^2} = |a|\|\vec{x}\|$$

Triangle inequality Show that $\|\mathbf{A}(\vec{v} + \vec{w})\| \leq \|\mathbf{A}\vec{v}\| + \|\mathbf{A}\vec{w}\|$

This means, the path over two sides of the triangle is longer, than the side left over, no matter which way you turn. And it is a triangle, because the three points in the space are by at least one unit.

$$\sqrt{\sum_{i=1}^n |\vec{v}_i + \vec{w}_i|^2} \leq \sqrt{\sum_{i=1}^n |\vec{v}_i|^2} + \sqrt{\sum_{i=1}^n |\vec{w}_i|^2}$$

Ok here we go again.

$$(\vec{v} + \vec{w}, \vec{v} + \vec{w})^{\frac{1}{2}} \leq (\vec{v}, \vec{v})^{\frac{1}{2}} + (\vec{w}, \vec{w})^{\frac{1}{2}}$$

This time i tried it algebraically, to first remove the root by squaring both sides.

$$(\vec{v} + \vec{w}, \vec{v} + \vec{w}) \leq (\vec{v}, \vec{v}) + 2(\vec{v}, \vec{v})^{\frac{1}{2}}(\vec{w}, \vec{w})^{\frac{1}{2}} + (\vec{w}, \vec{w})$$

Written as sum this is

$$\sum_{i=1}^n \vec{v}_i^2 + 2\vec{v}_i\vec{w}_i + \vec{w}_i^2 \leq \sum_{i=1}^n \vec{v}_i^2 + 2\left(\sum_{i=1}^n \vec{v}_i\vec{v}_i\right)^{\frac{1}{2}}\left(\sum_{i=1}^n \vec{w}_i\vec{w}_i\right)^{\frac{1}{2}} + \sum_{i=1}^n \vec{w}_i^2$$

This can be simplified. Now assume i split the left side up into three sums. And for more simplification i leave the equal (v,v) and (w,w) on both sides away, since they are summed, not multiplied. We get

$$2(\vec{v}, \vec{w}) \leq 2(\vec{v}, \vec{v})^{\frac{1}{2}}(\vec{w}, \vec{w})^{\frac{1}{2}}$$

Now i square it again to get rid of the square roots, and compare finally.

$$4(\vec{v}, \vec{w})^2 \leq 4(\vec{v}, \vec{v})(\vec{w}, \vec{w})$$

Which is

$$4 \sum_{j=1}^n \sum_{i=1}^n \vec{v}_i\vec{w}_j \leq 4 \sum_{j=1}^n \sum_{i=1}^n \vec{v}_i^2\vec{w}_j^2$$

Remark. When reading myself, i am sure, this last step is wrong, and the two vectors left have to be squared, too. I will calculate that again and correct then.

(I still think i am right with this correction, and i have already written this inequality down a couple of times with different orderings.)

Cauchy-Schwarz inequality There is another interesting inequality.

TODO

$$|\vec{v} \cdot \vec{w}|^2 \leq \|\vec{v}\|^2 \|\vec{w}\|^2$$

The absolute value of the dot product squared is less or equal to the product of the two norms squared. Squaring the two norms to the right cancels the outer square root on the norms away, so that you multiply with the full vector length squared. So both sides are squares. Left is the dot product of the two vectors squared, on the right side the squared lengths of the two vectors are multiplied. So which square or rectangle is larger? You know by the formula anyways.

$$\begin{aligned} \left| \sum_{i=1}^n \vec{v}_i \vec{w}_i \right|^2 &\leq \left(\left(\sum_{i=1}^n |\vec{v}_i|^2 \right)^{\frac{1}{2}} \right)^2 \left(\left(\sum_{i=1}^n |\vec{w}_i|^2 \right)^{\frac{1}{2}} \right)^2 \\ \left| \sum_{i=1}^n \vec{v}_i \vec{w}_i \right|^2 &\leq \left(\left(\sum_{j=1}^n \sum_{i=1}^n |\vec{v}_i|^2 |\vec{w}_i|^2 \right)^{\frac{1}{2}} \right)^2 = \left| \sum_{i=1}^n \vec{v}_i \vec{w}_i \right|^2 \leq \sum_{j=1}^n \sum_{i=1}^n (|\vec{v}_i| |\vec{w}_i|)^2 \end{aligned}$$

Remark This subsection is not complete. And may contain mistakes.

Remark If i am reading right, it contains really a mistake.

C.4.2 Matrix norms

There are a few possible ways to measure the multidimensional absolute values of a matrix.

Row wise. Sum up each row vector, and return the largest. This is the row norm.

$$\|A\|_{row} = \max_{i=1..n} \sum_{j=1} |A_{ij}|$$

Column wise. Sum up each column vector, and return the largest. This is the column norm.

$$\|A\|_{column} = \max_{j=1..n} \sum_{i=1} |A_{ij}|$$

C.4.3 Operator norms

The operator norm is a dependent norm. It depends on the currently used norm.

$$\|A\| = \|\phi\| := \sup\{\phi(\vec{x}) : \|\vec{x}\| = 1\}$$

Remark. This is by heart. But i sure i am not through with using it correctly.

C.5 Parallelogram equation

$$2(\|v\|^2 + \|w\|^2) = \|v + w\|^2 + \|v - w\|^2$$

This equation says, that the square sum of the parallelogram equals the square sum of the four sides.⁶

Proof:

$$2\left(\sum_{i=1}^n \vec{v}_i^2 + \sum_{i=1}^n \vec{w}_i^2\right) = \sum_{i=1}^n \vec{v}_i^2 + 2\vec{v}_i \vec{w}_i + \vec{w}_i^2 + \vec{v}_i^2 - 2\vec{v}_i \vec{w}_i + \vec{w}_i^2 = \sum_{i=1}^n 2\vec{v}_i^2 + 2\vec{w}_i^2 = 2 \sum_{i=1}^n \vec{v}_i^2 + \sum_{i=1}^n \vec{w}_i^2 = 2\left(\sum_{i=1}^n \vec{v}_i^2 + \sum_{i=1}^n \vec{w}_i^2\right)$$

⁶This is a direct translated citation from a lecture script. <http://pages.math.tu-berlin.de/~ferus/skripten.html> from Lineare Algebra I.

C.6 Normalizing a vector

If you wish to take the length of the vector, you take the norm $\|\vec{v}\|_V$ in three dimensions or $\|\vec{w}\|_W$ in two dimensions. If you wish to reduce or enlarge a vector to unit length, that $\|\vec{v}\| = 1$ or $\|\vec{w}\| = 1$, you can do this, by updating the or creating a new vector, by dividing the old vector components through the old vectors length. Taking the norm then, results in 1.

$$\vec{w}_{normalized} = \frac{\vec{w}}{\|\vec{w}\|} \implies \|\vec{w}_{normalized}\| = 1$$

Proof:

$$\begin{aligned} \vec{w} &= \begin{pmatrix} a \\ b \end{pmatrix} \\ \left\| \begin{pmatrix} a \\ b \end{pmatrix} \right\| &= \sqrt{a^2 + b^2} \\ \vec{w}_{normalized} &= \frac{\vec{w}}{\|\vec{w}\|} = \begin{pmatrix} \frac{a}{\sqrt{a^2 + b^2}} \\ \frac{b}{\sqrt{a^2 + b^2}} \end{pmatrix} \\ \|\vec{w}_{normalized}\| &= \sqrt{\left(\frac{a}{\sqrt{a^2 + b^2}}\right)^2 + \left(\frac{b}{\sqrt{a^2 + b^2}}\right)^2} = \sqrt{\frac{a^2 + b^2}{a^2 + b^2}} = \sqrt{1} = 1 \end{aligned}$$

C.7 Metrics

Where a norm is, there will be a metric induced. The measurement of the distance between two points is defined by the d-function. It is the length of the difference vector between the two points.

$$d(\vec{x}, \vec{y}) = \|\vec{x} - \vec{y}\| = \sqrt{\sum_{i=1}^n |\vec{x}_i - \vec{y}_i|^2}$$

Metrics have three fundamental properties.

1. If the distance is zero, the vectors are equal.

$$d(x, y) = 0 \iff x = y$$

2. It does not matter, whether you read $d(x, y)$ or $d(y, x)$, the number must be equal. The absolute value function $|\pm n| = n, \pm n \in \mathbb{Q}$ makes sure

$$d(x, y) = d(y, x)$$

3. The third one is the triangle inequality. Going over another point is always a step longer.

$$d(x, z) \leq d(x, y) + d(y, z)$$

Remark This subsection is not complete and has to be continued. The plan is to measure or estimate now the differences between the original coordinates and the new planar coordinates.

C.8 Transpose and TODO

A 2x3 matrix also has a transpose. Multiplying both result in two different square matrices. $\mathbf{A}^T \mathbf{A}$ is a 3x3 matrix. And $\mathbf{A} \mathbf{A}^T$ is a 2 by 2 matrix.

$$\begin{pmatrix} r_x \cos(\varphi_x) & r_y \cos(\varphi_y) & r_z \cos(\varphi_z) \\ r_x \sin(\varphi_x) & r_y \sin(\varphi_y) & r_z \sin(\varphi_z) \end{pmatrix}^T = \begin{pmatrix} r_x \cos(\varphi_x) & r_x \sin(\varphi_x) \\ r_y \cos(\varphi_y) & r_y \sin(\varphi_y) \\ r_z \cos(\varphi_z) & r_z \sin(\varphi_z) \end{pmatrix}$$

Multiplying out the transposes yield the following forms.

AA^T , a 2 by 2 matrix.

$$AA^T = \begin{pmatrix} \sum_{i=1}^3 r_n^2 \cos^2 \varphi_n & \sum_{i=1}^3 r_n^2 \cos \varphi_n \sin \varphi_n \\ \sum_{i=1}^3 r_n^2 \cos \varphi_n \sin \varphi_n & \sum_{i=1}^3 r_n^2 \sin^2 \varphi_n \end{pmatrix} = \begin{pmatrix} a & b \\ b & c \end{pmatrix}$$

In the 2x2 matrix AA^T is $a_{ij} = a_{ji}$.

I will abbreviate $\cos \varphi_n$ with C_n and $\sin \varphi_n$ with S_n .

$A^T A$ a 3x3 matrix

$$A^T A = \begin{pmatrix} C_x^2 + S_x^2 & C_x C_y + S_x S_y & C_x C_z + S_x S_z \\ C_y C_x + S_y S_x & C_y^2 + S_y^2 & C_y C_z + S_y S_z \\ C_z C_x + S_z S_x & C_z C_y + S_z S_y & C_z^2 + S_z^2 \end{pmatrix} = \begin{pmatrix} r_x^2 & a & b \\ a & r_y^2 & c \\ b & c & r_z^2 \end{pmatrix}$$

Also in the 3x3 matrix $A^T A$ is $a_{ij} = a_{ji}$.

A little bit refined the 3x3 matrix becomes this. Also, to forget about r_n is $r_n = 1$.

$$A^T A = \begin{pmatrix} 1 & \sin(\varphi_x + \varphi_y) & \sin(\varphi_x + \varphi_z) \\ \sin(\varphi_x + \varphi_y) & 1 & \sin(\varphi_y + \varphi_z) \\ \sin(\varphi_x + \varphi_z) & \sin(\varphi_y + \varphi_z) & 1 \end{pmatrix}$$

Remark Missing are $|AA^T|$ and $|A^T A|$ and $(AA^T)^{-1}$ and $(A^T A)^{-1}$ and various tries to combine them to $P = A(A^T A)^{-1} A^T$.

The determinant of the

Remark. I would like to post a picture of the handwritten page with the abstract sums of the 2x2 determinant, but i have no camera. I wish i had one, but that will be another day, another month, maybe in another year, until i can afford one.

Remark. The stuff possibly moves.

A 2x2 determinant and inverse have the following formulas.

A 3x3 determinant and inverse have the following formulas.

Remark. I thought about creating three crossover 2x2 matrices from the original and to invert them, to look if we can puzzle the right information back together. But it will take more days, by time i have and can give until i get to.

TODO

C.9 The pseudo-inverse A^+ and least squares

In a lecture script about numerical linear algebra i found the formulas for the pseudo inverses.

For a m by n matrix with $m \geq n$ it is $A^T(AA^T)^{-1}$

For a m by n matrix with $m \leq n$ it is $(A^T A)^{-1} A^T$

Least squares gives the possibility, to restore at last two of the three coordinates. How deep i can get in restoring the third dimension approximatly? I think i could close the case with the incomplete restauration, saying, that we loose the information generally, when going from two to three dimensions, because we have not enough information to restore the data. How far you can span up the z dimension vector. We will see, when i get here.

TODO

D An alternative graphics algorithm

Remark This section is new on July 10.

It is obvious, that we want to draw some graphics on our 2-D Canvas.

D.1 Origin

Setting the origin is an easy task. Assuming, the regular origin is at (0,0,0) and (0,0), we just need to add the shift to the coordinate. You can shift the 3-D Origin or the 2-D Origin.

```
x = Ox + x;
y = Oy + y;
z = Oz + z;
```

D.2 Translation

You simply add the translation vector to each point.

```
x = Tx + x;
y = Ty + y;
z = Tz + z;
```

D.3 Scaling

To scale the object you just have to multiply with the constant.

```
x = Sx * x;
y = Sy * y;
z = Sz * z;
```

D.4 Skewing

Skewing or shearing is not difficult. I took a skewing matrix and forgot about the empty fields.

```
u = x, v = y, w = z;
x = u + k_xy*v + k_xz*w;
y = k_yx*u + v + k_yz*w;
z = k_zx*u + k_zy*v + w;
```

D.5 Local 3x3 basis for change of units and per object rotation

If you wish to introduce different units for different directions, you have to apply a local basis, if the picture is moving angular. Applying the local 3x3 basis to an object makes sure, it will be rotatable, but without side effects. If you would change the units of r on the projection, then the rotation will give unrealistic results, since suddenly the object stretches to an unexpected size, when entering the zone.

The matrix applied locally is a 3x3 matrix $\begin{pmatrix} xBX & yBX & zBX \\ xBY & yBY & zBY \\ xBZ & yBZ & zBZ \end{pmatrix}$. For example is $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$ is

the original and orthonormal (orthogonal and unit length) standard basis for the \mathbb{R}^3 and the result is the same as if you do not apply any basis to the object, as the assumed default coordinate system in \mathbb{R}^3 is orthonormal.

```
u = x, v = y, w = z;
x = u*xBX + v*yBX + w*zBX;
y = u*xBY + v*yBY + w*zBY;
z = u*xBZ + v*yBZ + w*zBZ;
```

This of course transforms the object by the directions and the length of the three three dimensional basis vectors.

D.5.1 Creating a 3x3 basis with cross products

```
function cross(a,b) {
    // does not multiply with the ijk components, diy
    return [a[1]*b[2]-a[2]*b[1], -a[0]*b[2]+a[2]*b[0], a[0]*b[1]-a[1]*b[0]];
}

// if you look and remember C.2 you see the third determinant only giving (1-0)k
var u = [1,0,0];
var v = [0,1,0];
var w = cross(u,v);
// w = [0,0,1]

// if you look and remember C.2 you see the third determinant only giving (-1-0)k
var u = [-1,0,0];
var v = [0,1,0];
var w = cross(u,v);
// w = [0,0,-1]
```

D.6 Rotation

Rotating the object can be done in three dimensional space by applying the regular rotation matrices.

```
// once
var rotxcos = Math.cos(xAngleRad), rotxsin = Math.sin(xAngleRad);
var rotycos = Math.cos(yAngleRad), rotysin = Math.sin(yAngleRad);
var rotzcos = Math.cos(zAngleRad), rotzsin = Math.sin(zAngleRad);
// for each point
u = x, v = y, w = z;
y = v * rotxcos - w * rotxsin
z = v * rotxsin + w * rotxcos
u = x, v = y, w = z;
x = u * rotycos + w * rotysin;
z = -u * rotysin + w * rotycos;
u = x, v = y, w = z;
x = u * rotzcos - v * rotzsin;
y = u * rotzsin + v * rotzcos;
```

D.7 Frustum and Perspective

Apply the perspective to the 3x3 set of points before projecting.

TODO

D.8 Dot product

The dot product or inner product or scalar product is the sum of the component products and one of the most important basic formulas in space.

```
function dot(a,b) {
    var sum = 0;
    for (var i = 0, j = a.length; i < j; i++) sum += a[i]*b[i];
    return sum;
}
```

D.9 Norm

The euclidean norm is the length of the vector. Its the square root pulled out of the sum of all components squared.

```
function norm(a) {
    var sum = 0;
    for (var i = 0, j = a.length; i < j; i++) sum += a[i]*a[i];
    return Math.sqrt(sum);
}
```

A p-Norm version, the second argument is the exponent p and p-th root.

```
function norm(a,p) {
    var sum = 0;
    if (p===undefined) p = 2;
    if (p===Infinity) {
        var max = 0;
        for (var i = 0, j = a.length; i < j; i++) {
            max = Math.max(Math.abs(a[i]), max);
        }
        return max;
    }
    for (var i = 0, j = a.length; i < j; i++) sum += Math.pow(Math.abs(a[i]),p);
    for (i = 2; i <= p; i++) sum = Math.sqrt(sum);
    return sum;
}
```

D.10 Metric

The distance function gives us the distance between two points, that is the length of the vector from tip to tip.

```
function d(a,b) {
    var sum = 0;
    for (var i = 0, j = a.length; i < j; i++) sum += Math.pow(a[i]-b[i],2);
    return Math.sqrt(sum);
}
```

D.11 Code Example

Here is an implementation of these function together with the EcmaScript 6 snippet in modern EcmaScript 5.

```
(function (exports) {

function rad(deg) {
    return Math.PI/180*deg;
}

var r_x = 1, r_y = 1, r_z = 1;

var phi_x = rad(210), phi_y = rad(330), phi_z = rad(90);

var xAxisCos = r_x * Math.cos(phi_x),
    yAxisCos = r_y * Math.cos(phi_y),
    zAxisCos = r_z * Math.cos(phi_z),
    xAxisSin = r_x * Math.sin(phi_x),
    yAxisSin = r_y * Math.sin(phi_y),
```



```

    zAxisSin = r_z * Math.sin(phi_z);

function transform2d(vec3) {
    return [
        vec3[0]*xAxisCos + vec3[1]*yAxisCos + vec3[2]*zAxisCos,
        vec3[0]*xAxisSin + vec3[1]*yAxisSin + vec3[2]*zAxisSin
    ];
}

function transform2dAll(avec3) {
    return avec3.map(transform2d);
}

function settrans(op) {
    if (op.phi_n) {
        phi_x = op.phi_n[0];
        phi_y = op.phi_n[1];
        phi_z = op.phi_n[2];
    }
    if (op.r_n) {
        r_x = op.r_n[0];
        r_y = op.r_n[1];
        r_z = op.r_n[2];
    }
    xAxisCos = r_x * Math.cos(phi_x);
    yAxisCos = r_y * Math.cos(phi_y);
    zAxisCos = r_z * Math.cos(phi_z);
    xAxisSin = r_x * Math.sin(phi_x);
    yAxisSin = r_y * Math.sin(phi_y);
    zAxisSin = r_z * Math.sin(phi_z);
}

function gettrans() {
    return {
        phi_n: [phi_x, phi_y, phi_z],
        r_n: [r_x, r_y, r_z]
    };
}

function draw2dAll(ctx, points2, scale) {
    ctx.save();
    scale = scale || 1;
    var x = scale * points2[0][0], y = scale * points2[0][1];
    ctx.moveTo(x, -y);
    ctx.beginPath();
    for (var i = 0, j = points2.length; i < j; i++) {
        x = scale * points2[i][0], y = scale * points2[i][1];
        ctx.lineTo(x, -y);
        ctx.moveTo(x, -y);
    }
    ctx.closePath();
    ctx.stroke();
    ctx.restore();
}

function rotate3dAll(xAngleRad, yAngleRad, zAngleRad, points3) {
    var rotxcos = Math.cos(xAngleRad), rotxsin = Math.sin(xAngleRad);
    var rotycos = Math.cos(yAngleRad), rotysin = Math.sin(yAngleRad);

```

```

    var rotzcos = Math.cos(zAngleRad), rotzsin = Math.sin(zAngleRad);
    var p, x, y, z, u, v, w;
    for (var i = 0, j = points3.length; i < j; i++) {
        p = points3[i], x = p[0], y = p[1], z = p[2];
        u = x, v = y, w = z;
        y = v * rotxcos - w * rotxsin
        z = v * rotxsin + w * rotxcos
        u = x, v = y, w = z;
        x = u * rotycos + w * rotysin;
        z = -u * rotysin + w * rotycos;
        u = x, v = y, w = z;
        x = u * rotzcos - v * rotzsin;
        y = u * rotzsin + v * rotzcos;
        p[0]=x;
        p[1]=y;
        p[2]=z;
    }
}

function rotate2dAll(zAngle, points2) {
    var rotzcos = Math.cos(zAngleRad), rotzsin = Math.sin(zAngleRad);
    var p, x, y, u, v;
    for (var i = 0, j = points2.length; i < j; i++) {
        p = points2[i], x = p[0], y = p[1];
        u = x, v = y;
        x = u * rotzcos - v * rotzsin;
        y = u * rotzsin + v * rotzcos;
        p[0]=x;
        p[1]=y;
    }
}

function translate3dAll(transvec, points3) {
    var p, x, y, z;
    var Tx = transvec[0],
    Ty = transvec[1],
    Tz = transvec[2];
    for (var i = 0, j = points3.length; i < j; i++) {
        p = points3[i];
        p[0]+=Tx;
        p[1]+=Ty;
        p[2]+=Tz;
    }
}

function translate2dAll(transvec, points2) {
    var p;
    var Tx = transvec[0],
    Ty = transvec[1];
    for (var i = 0, j = points2.length; i < j; i++) {
        p = points2[i];
        p[0]+=Tx;
        p[1]+=Ty;
    }
}

function scale3dAll(scaleX, scaleY, scaleZ, points3) {
    var p;

```

```

    for (var i = 0, j = points3.length; i < j; i++) {
        p = points3[i];
        p[0]*=scaleX;
        p[1]*=scaleY;
        p[2]*=scaleZ;
    }
}

function scale2dAll(scaleX, scaleY, points2) {
    var p;
    for (var i = 0, j = points2.length; i < j; i++) {
        p = points2[i];
        p[0]*=scaleX;
        p[1]*=scaleY;
    }
}

function compareAll(points3, points2, callback) {
    var results = [];
    for (var i = 0, j = points3.length; i < j; i++) {
        results.push(callback(points3[i], points2[i]));
    }
    return results;
}

exports.gettrans = gettrans;
exports.settrans = settrans;
exports.transform2d = transform2d;
exports.transform2dAll = transform2dAll;
exports.rotate3dAll = rotate3dAll;
exports.rotate2dAll = rotate2dAll;
exports.scale3dAll = scale3dAll;
exports.scale2dAll = scale2dAll;
exports.translate3dAll = translate3dAll;
exports.translate2dAll = translate2dAll;
exports.compareAll = compareAll;
exports.rad = rad;
exports.draw2dAll = draw2dAll;

}(typeof exports !== "undefined" ? exports : this));

```

Last but not least here is a code snippet doing all the things together.

```

var n = points3.length;
var i = 0;
while (i < n) {
    var x,y,z, u,v,w;

    // local operations
    translate;
    rotate;
    scale;

    // world operations
    translate;
    rotate;
    scale;
}

```

}

D.12 Another orthographic projection possible

Remark. Before i figured out, how to compose three 2-D vectors for an orthographic projection, i did it wrong. But when doing it false, i had the most intelligent idea. I simply added z to y, after turning the plane around. I wanted to turn the axes, but failed, because i used the wrong formula. *After moving this paragraph out of the corollaries, i think, i can write the story again. In the next versions.*

Even less difficult to create a 3-D righthand coordinate system is this. Rotate the xy -plane by for example 225 degrees or $\frac{\pi}{180} \times 225 = \frac{15\pi}{12} = \frac{5}{4}\pi = 1.25\pi$ radians. Now the x-axis and the y-axis point downwards. This means, the real y-axis on the real 2-D coordinate system is now 'free'. So add the z-coordinate in by just adding it to y.

$$A = \begin{pmatrix} \cos \angle a & -\sin \angle a \\ \sin \angle a & \cos \angle a \end{pmatrix}$$

$$v = (x, y, z)^T, w = (v_1, v_2)^T = (x, y)^T$$

$$A \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

$$w = \begin{pmatrix} x' \\ y' + z \end{pmatrix}$$

Example This is an EcmaScript 5 code. First rotate the xy plane to point downwards. Then add the z coordinate to y. That moves the point upwards again for the z-value. This results in an orthographic projection. Which is less flexible, but still one.

```
var angle = 1.25*Math.PI; // 225 deg
var cos = Math.cos(angle), sin = Math.sin(angle);
// for each point now
var u = x, w = y;
x = cos * u - sin * w; // rotate the point like we rotate the xy plane
y = sin * u + cos * w; // let the positive x,y axes point downwards
y += z; // the trick, let z now go upwards by just adding it to the vertical coord.
```

Remark. Have to write this again.

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