

# lintrans

by Dyson Dyson

Centre Name: The Duston School  
Centre Number: 123456  
Candidate Number: 123456

# Contents

<b>1</b>	<b>Analysis</b>	<b>1</b>
1.1	Computational Approach . . . . .	1
1.2	Stakeholders . . . . .	2
1.3	Research on existing solutions . . . . .	2
1.3.1	MIT ‘Matrix Vector’ Mathlet . . . . .	2
1.3.2	Linear Transformation Visualizer . . . . .	3
1.3.3	Desmos app . . . . .	4
1.3.4	Visualizing Linear Transformations . . . . .	4
1.4	Essential features . . . . .	5
1.5	Limitations . . . . .	5
1.6	Hardware and software requirements . . . . .	6
1.6.1	Hardware . . . . .	6
1.6.2	Software . . . . .	6
1.7	Success criteria . . . . .	7
<b>2</b>	<b>Design</b>	<b>9</b>
2.1	Problem decomposition . . . . .	9
2.2	Structure of the solution . . . . .	9
2.3	Algorithm design . . . . .	11
2.4	Usability features . . . . .	13
2.5	Variables and validation . . . . .	14
2.6	Iterative test data . . . . .	15
2.7	Post-development test data . . . . .	16
2.8	Issues with testing . . . . .	16
<b>3</b>	<b>Development</b>	<b>17</b>
3.1	Matrices backend . . . . .	17
3.1.1	MatrixWrapperclass . . . . .	17
3.1.2	Rudimentary parsing and evaluating . . . . .	19
3.1.3	Simple matrix expression validation . . . . .	24
3.1.4	Parsing matrix expressions . . . . .	26
3.2	Initial GUI . . . . .	30
3.2.1	First basic GUI . . . . .	30
3.2.2	Numerical definition dialog . . . . .	32
3.2.3	More definition dialogs . . . . .	35
3.3	Visualizing matrices . . . . .	39
3.3.1	Asking strangers on the internet for help . . . . .	39
3.3.2	Creating the plots package . . . . .	39
3.3.3	Implementing basis vectors . . . . .	41
3.3.4	Drawing the transformed grid . . . . .	43
3.3.5	Implementing animation . . . . .	46
3.3.6	Preserving determinants . . . . .	47
3.4	Improving the GUI . . . . .	50
3.4.1	Fixing rendering . . . . .	50
3.4.2	Adding vector arrowheads . . . . .	52
3.4.3	Implementing zoom . . . . .	54
3.4.4	Animation blocks zooming . . . . .	56
3.4.5	Rank 1 transformations . . . . .	57
3.4.6	Matrices that are too big . . . . .	58
3.4.7	Creating the DefineVisuallyDialog . . . . .	59
3.4.8	Fixing a division by zero bug . . . . .	61
3.4.9	Implementing transitional animation . . . . .	62
3.4.10	Allowing for sequential animation with commas . . . . .	64
3.5	Adding display settings . . . . .	66
3.5.1	Creating the dataclass (and implementing applicative animation) . . . . .	66
3.5.2	Creating the settings dialog . . . . .	68

3.5.3	Fixing a bug with transitional animation . . . . .	71
3.5.4	Adding the determinant parallelogram . . . . .	72
3.5.5	Adding the determinant text . . . . .	73
3.6	Fixing bugs and adding polish . . . . .	75
3.6.1	Fixing an animation crash . . . . .	75
3.6.2	Limiting parallel lines . . . . .	76
3.6.3	Giving focus to the expression box . . . . .	77
3.6.4	Fixing a crash when animating singular matrices in sequence . . . . .	78
3.6.5	Allowing animations to be cancelled . . . . .	78
3.6.6	Validating expression input . . . . .	79
3.6.7	Adding keyboard shortcuts . . . . .	81
3.6.8	Centering text in the determinant parallelogram . . . . .	82
3.6.9	Defining matrices as expressions . . . . .	84
3.7	Implementing eigenstuffs . . . . .	92
3.7.1	Drawing eigenvectors . . . . .	92
<b>References</b>		<b>94</b>
<b>A Project code</b>		<b>96</b>
A.1	updating.py . . . . .	96
A.2	global_settings.py . . . . .	98
A.3	crash_reporting.py . . . . .	101
A.4	__main__.py . . . . .	105
A.5	__init__.py . . . . .	106
A.6	gui/validate.py . . . . .	106
A.7	gui/utility.py . . . . .	107
A.8	gui/settings.py . . . . .	107
A.9	gui/main_window.py . . . . .	109
A.10	gui/__init__.py . . . . .	124
A.11	gui/session.py . . . . .	125
A.12	gui/plots/classes.py . . . . .	126
A.13	gui/plots/widgets.py . . . . .	136
A.14	gui/plots/__init__.py . . . . .	143
A.15	gui/dialogs/define_new_matrix.py . . . . .	143
A.16	gui/dialogs/settings.py . . . . .	149
A.17	gui/dialogs/__init__.py . . . . .	156
A.18	gui/dialogs/misc.py . . . . .	157
A.19	matrices/utility.py . . . . .	163
A.20	matrices/wrapper.py . . . . .	165
A.21	matrices/__init__.py . . . . .	169
A.22	matrices/parse.py . . . . .	170
A.23	typing_/__init__.py . . . . .	177
<b>B Testing code</b>		<b>178</b>
B.1	conftest.py . . . . .	178
B.2	backend/test_session.py . . . . .	178
B.3	backend/matrices/test_parse_and_validate_expression.py . . . . .	179
B.4	backend/matrices/utility/test_coord_conversion.py . . . . .	182
B.5	backend/matrices/utility/test_float_utility_functions.py . . . . .	183
B.6	backend/matrices/utility/test_rotation_matrices.py . . . . .	183
B.7	backend/matrices/matrix_wrapper/test_evaluate_expression.py . . . . .	185
B.8	backend/matrices/matrix_wrapper/test_setting_and_getting.py . . . . .	189

# 1 Analysis

One of the topics in the A Level Further Maths course is linear transformations, as represented by matrices. This is a topic all about how vectors move and get transformed in the plane. It's a topic that lends itself exceedingly well to visualization, but students often find it hard to visualize this themselves, and there is a considerable lack of good tools to provide visual intuition on the subject. There is the YouTube series *Essence of Linear Algebra* by 3blue1brown[8], which is excellent, but I couldn't find any good interactive visualizations.

My solution is to develop a desktop application that will allow the user to define  $2 \times 2$  matrices and view these matrices and compositions thereof as linear transformations of a 2D plane. This will give students a way to get to grips with linear transformations in a more hands-on way, and will give teachers the ability to easily and visually show concepts like the determinant and invariant lines.

## 1.1 Computational Approach

This solution is particularly well suited to a computational approach since it is entirely focussed on visualizing transformations, which require complex mathematics to properly display. It will also have lots of settings to allow the user to configure aspects of the visualization. As previously mentioned, visualizing transformations in one's own head is difficult, so a piece of software to do it would be very valuable to teachers and learners, but current solutions are considerably lacking.

My solution will make use of abstraction by allowing the user to define a set of matrices which they can use in expressions. This allows them to use a matrix multiple times and they don't have to keep track of any of the numbers. All the actual processing and mathematics happens behind the scenes and the user never has to worry about it - they just compose their defined matrices into transformations. This abstraction allows the user to focus on exploring the transformations themselves without having to do any actual computations. This will make learning the subject much easier, as they will be able to gain a visual intuition for linear transformations without worrying about computation until after they've built up that intuition.

I will also employ decomposition and modularization by breaking the project down into many smaller parts, such as one module to keep track of defined matrices, one module to validate and parse matrix expressions, one module for the main GUI, as well as sub-modules for the widgets and dialog boxes, etc. This decomposition allows for simpler project design, easier code maintenance (since module coupling is kept to a minimum, so bugs are isolated in their modules), inheritance of classes to reduce code repetition, and unit testing to inform development. I also intend this unit testing to be automated using GitHub Actions.

Selection will also be used widely in the application. The GUI will provide many settings for visualization, and these settings will need to be checked when rendering the transformation. For example, the user will have the option to render the determinant, so I will need to check this setting on every render cycle and only render the determinant parallelogram if the user has enabled that option. The app will have many options for visualization, which will be useful in learning, but if all these options were being rendered at the same time, then there would be too much information for the user to properly process, so I will let the user configure these display options to their liking and only render the things they want to be rendered.

Validation will also be prevalent because the matrix expressions will need to follow a strict format, which will be validated. The buttons to render and animate the matrix will only be clickable when the given expression is valid, so I will need to check this and update the buttons every time the text in the text box is changed. I will also need to parse matrix expressions so that I can evaluate them properly. All this validation ensures that crashes due to malformed input are practically impossible, and makes the user's life easier since they don't need to worry about if their input is in the right format - the app will tell them.

I will also make use of iteration, primarily in animation. I will have to re-calculate positions and

values to render everything for every frame of the animation and this will likely be done with a simple `for` loop. A `for` loop will allow me to just loop over every frame and use the counter variable as a way to measure how far through the animation we are on each frame. This is preferable to a `while` loop, since that would require me to keep track of which frame we're on with a separate variable.

Finally, the core of the application is visualization, so that will definitely be used a lot. I will have to calculate positions of points and lines based on given matrices, and when animating, I will also have to calculate these matrices based on the current frame. Then I will have to use the rendering capabilities of the GUI framework that I choose to render these calculated points and lines onto a widget, which will form the viewport of the main GUI. I may also have to convert between coordinate systems. I will have the origin in the middle with positive  $x$  going to the right and positive  $y$  going up, but I may need to convert that to standard computer graphics coordinates with the origin in the top left, positive  $x$  going to the right, and positive  $y$  going down. This visualization of linear transformations is the core component of the app and is the primary feature, so it is incredibly important.

## 1.2 Stakeholders

Stakeholders for my app include A Level Further Maths students and teachers, who learn and teach linear transformations respectively. They will be able to provide useful input as to what they would like to see in the app, and they can provide feedback on what they like and what I can add or improve. I already know from experience that linear transformations are tricky to visualize and a computer-based visualization would be useful. My stakeholders agreed with this. Multiple teachers said that a desktop app that could render and animate linear transformations would be useful in a classroom environment and students said that it would be helpful to have something that they could play around with at home and use to get to grips with matrices and linear transformations. They also said that an online version would probably be easier to use, but I have absolutely no experience in web development and I'm much more comfortable making a desktop app.

Some teachers also suggested that it would be useful to have an option to save and load sets of matrices. This would allow them to have a single save file containing some matrices, and then just load this file to use for demonstrations in the classroom. This would probably be quite easy to implement. I could just wrap all the relevant information into one object and use Python's `pickle` module to save the binary data to a file, and then load this data back into the app in a similar way.

My stakeholders agreed that being able to see incremental animation - where, for example, we apply matrix **A** to the current scene, pause, and then apply matrix **B** - would be beneficial. This would be a good demonstration of matrix multiplication being non-commutative. **AB** is not always equal to **BA**. Being able to see this in terms of animating linear transformations would be good for learning.

They also agreed that a tutorial on using the software would be useful, so I plan to implement this through an online written tutorial hosted with GitHub Pages, and perhaps a video tutorial as well. This would make the app much easier to use for people who have never seen it before. It wouldn't be a lesson on the maths itself, but just a guide on how to use the software.

## 1.3 Research on existing solutions

There are actually quite a few web apps designed to help visualize 2D linear transformations but many of them are hard to use and lacking many features.

### 1.3.1 MIT 'Matrix Vector' Mathlet

Arguably the best app that I found was an MIT 'Mathlet' - a simple web app designed to help visualize a maths concept. This one is called 'Matrix Vector'[9] and allows the user to drag an input vector

around the plane and see the corresponding output vector, transformed by a matrix that the user can define, although this definition is finicky since it involves sliders rather than keyboard input.

This app fails in two crucial ways in my opinion. It doesn't show the basis vectors or let the user drag them around, and the user can only define and therefore visualize a single matrix at once. This second problem was common among every solution I found, so I won't mention it again, but it is a big issue in my opinion and my app will allow for multiple matrices. I like the idea of having a draggable input vector and rendering its output, so I will probably have this feature in my app, but I also want the ability to define multiple matrices and be able to drag the basis vectors to visually define a matrix. Being able to drag the basis vectors will help build intuition, so I think this would greatly benefit the app.

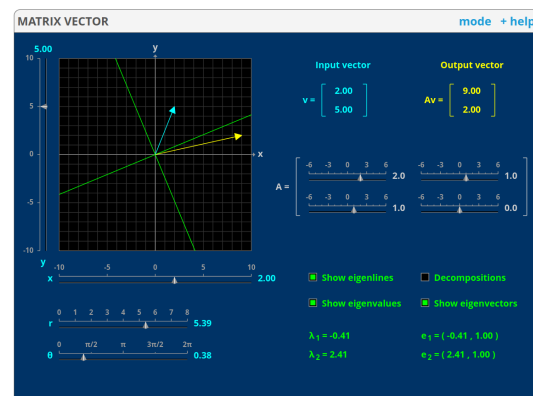


Figure 1.1: The MIT 'Matrix Vector' Mathlet

However, in the comments on this Mathlet, a user called 'David S. Bruce' suggested that the Mathlet should display the basis vectors, to which a user called 'hrm' (who I assume to be the 'H. Miller' to whom the copyright of the whole website is accredited) replied saying that this Mathlet is primarily focussed on eigenvectors, that it is perhaps badly named, and that displaying the basis vectors 'would make a good focus for a second Mathlet about  $2 \times 2$  matrices'. This Mathlet does not exist. But I do like the idea of showing the eigenvectors and eigenlines, so I will definitely have that in my app. Showing the invariant lines or lack thereof will help with learning, since these are often hard to visualize.

### 1.3.2 Linear Transformation Visualizer

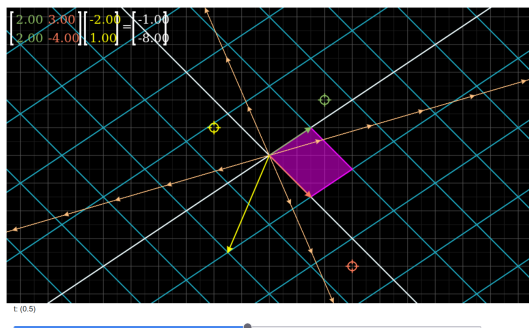


Figure 1.2: 'Linear Transformation Visualizer' halfway through an animation

Another web app that I found was one simply called 'Linear Transformation Visualizer' by Shad Sharma[25]. This one was similarly inspired by 3blue1brown's YouTube series. This app has the ability to render input and output vectors and eigenlines, but it can also render the determinant parallelogram; it allows the user to drag the basis vectors; and it has the option to snap vectors to the background grid, which is quite useful. It also implements a simple form of animation where the tips of the vectors move in straight lines from where they start to where they end, and the animation is controlled by dragging a slider labelled  $t$ . This isn't particularly intuitive.

I really like the vectors snapping to the grid, the input and output vectors, and rendering the determinant. This app also renders positive and negative determinants in different colours, which is really nice - I intend to use that idea in my own app, since it helps create understanding about negative determinants in terms of orientation changes. However, I think that the animation system here is flawed and not very easy to use. My animation will likely be a button, which just triggers an animation, rather than a slider. I also don't like the way vector dragging is handled. If you click anywhere on the grid, then the closest vector target (the final position of the target's associated vector) snaps to that location. I think it would be more intuitive to have to drag the vector from its current location to where you want it. This was also a problem with the MIT Mathlet.

### 1.3.3 Desmos app

One of the solutions I found was a Desmos app[6], which was quite hard to use and arguably over-complicated. Desmos is not designed for this kind of thing - it's designed to graph pure mathematical functions - and it shows here. However, this app brings some really interesting ideas to the table, mainly functions. This app allows you to define custom functions and view them before and after the transformation. This is achieved by treating the functions parametrically as the set of points  $(t, f(t))$  and then transforming each coordinate by the given matrix to get a new coordinate.



Figure 1.3: The Desmos app halfway through an animation, rendering  $f(x) = \frac{\sin^2 x}{x}$  in orange

Desmos does this for every point and then renders the resulting transformed function parametrically. This is a really interesting technique and idea, but I'm not going to use it in my app. I don't think arbitrary functions fit with the linearity of the whole app, and I don't think it's necessary. It's just overcomplicating things, and rendering it on a widget would be tricky, because I'd have to render every point myself, possibly using something like OpenGL. It's just not worth implementing.

Additionally, this Desmos app makes things quite hard to see. It's hard to tell where any of the vectors are - they just get lost in the sea of grid lines. This image also hides some of the extra information. For instance, this image doesn't show the original function  $f(x) = \frac{\sin^2 x}{x}$ , only the transformed version. This app easily gets quite cluttered. I will give my vectors arrowheads to make them easily identifiable amongst the grid lines.

### 1.3.4 Visualizing Linear Transformations



Figure 1.4: The GeoGebra applet rendering its default matrix

The last solution that I want to talk about is a GeoGebra applet simply titled 'Visualizing Linear Transformations'[11]. This applet has input and output vectors, original and transformed grid lines, a unit circle, and the letter N. It allows the user to define a matrix as 4 numbers and view the aforementioned N (which the user can translate to anywhere on the grid), the unit circle, the input/output vectors, and the grid lines. It also has the input vector snapping to integer coordinates, but that's a standard part of GeoGebra.

I've already talked about most of these features but the thing I wanted to talk about here is the N. I don't particularly want the letter N to be a prominent part of my own app, but I really like the idea of being able to define a custom polygon and see how that polygon gets transformed by a given transformation. I think that would really help with building intuition and it shouldn't be too hard to implement.

## 1.4 Essential features

The primary aim of this application is to visualize linear transformations, so this will obviously be the centre of the app and an essential feature. I will have a widget which can render a background grid and a second version of the grid, transformed according to a user-defined matrix expression. This is necessary because it is the entire purpose of the app. It's designed to visualize linear transformations and would be completely useless without this visual component. I will give the user the ability to render a custom matrix expression containing matrices they have previously defined, as well as reset the canvas to the default identity matrix transformation. This will obviously require an input box to enter the expression, a render button, a reset button, and various dialog boxes to define matrices in different ways. I want the user to be able to define a matrix as a set of 4 numbers, and by dragging the basis vectors  $i$  and  $j$ . These dialogs will allow the user to define new matrices to be used in expressions, and having multiple ways to do it will make it easier, and will aid learning.

Another essential feature is animation. I want the user to be able to smoothly animate between matrices. I see two options for how this could work. If  $\mathbf{C}$  is the matrix for the currently displayed transformation, and  $\mathbf{T}$  is the matrix for the target transformation, then we could either animate from  $\mathbf{C}$  to  $\mathbf{T}$  or we could animate from  $\mathbf{C}$  to  $\mathbf{TC}$ . I would probably call these transitional and applicative animation respectively. Perhaps I'll give the user the option to choose which animation method they want to use. I might even have an option for sequential animation, where the user can define a sequence of matrices, perhaps separated with commas or semicolons, and the app will animate through the sequence, applying one at a time. Sequential animation would be nice, but is not crucial.

Either way, animation is used in most of the alternative solutions that I found, and it's a great way to build intuition, by allowing students to watch the transformation happen in real time. Compared to simply rendering the transformations, animating them would profoundly benefit learning, and since that's the main aim of the project, I think animation is a necessary part of the app.

Something that I thought was a big problem in every alternative solution I found was the fact that the user could only visualize a single matrix at once. I see this as a fatal flaw and I will allow the user to define 25 different matrices (all capital letters except  $\mathbf{I}$  for the identity matrix) and use all of them in expressions. This will allow teachers to define multiple matrices and then just change the expression to demonstrate different concepts rather than redefine a new transformation every time. It will also make things easier for students as it will allow them to visualize compositions of different matrix transformations without having to do any computations themselves.

Additionally, being able to show information on the currently displayed matrix is an essential tool for learning. Rendering things like the determinant parallelogram and the invariant lines of the transformation will greatly assist with learning and building understanding, so I think that having the option to render these attributes of the currently displayed transformation is necessary for success.

## 1.5 Limitations

The main limitation in this app is likely to be drawing grid lines. Most transformations will be fine but in some cases, the app will be required to draw potentially thousands of grid lines on the canvas and this will probably cause noticeable lag, especially in the animations. I will have to artificially limit the number of grid lines that can be drawn on the screen. This won't look fantastic, because it means that the grid lines will only extend a certain distance from the origin, but it's an inherent limitation of computers. Perhaps if I was using a faster, compiled language like C++ rather than Python, this processing would happen faster and I could render more grid lines, but it's impossible to render all the grid lines and any implementation of this idea must limit them for performance.

An interesting limitation is that I don't think I'll implement panning. I suspect that I'll have to convert between coordinate systems and having the origin in the centre of the canvas will probably make the code much simpler. Also, linear transformations always leave the origin fixed, so always having it in the centre of the canvas seems thematically appropriate. Panning is certainly an option - the Desmos solution in §1.3.3 and GeoGebra solution in §1.3.4 both allow panning as a default part



of Desmos and GeoGebra respectively, for example - but I don't think I'll implement it myself. I just don't think it's worth it.

I'm also not going to do any work with 3D linear transformations. 3D transformations are often harder to visualize and thus it would make sense to target them in an app like this, designed to help with learning and intuition, but 3D transformations are also harder to code. I would have to use a full graphics package rather than a simple widget, and I think it would be too much work for this project and I wouldn't be able to do it in the time frame. It's definitely a good idea, but I'm currently incapable of creating an app like that.

There are other limitations inherent to matrices. For instance, it's impossible to take an inverse of a singular matrix. There's nothing I can do about that without rewriting most of mathematics. Matrices can also only represent linear transformations. There's definitely a market for an app that could render any arbitrary transformation from  $\mathbb{R}^2 \rightarrow \mathbb{R}^2$  - I know I'd want an app like that - but matrices can only represent linear transformations, so those are the only kind of transformations that I'll be looking at with this project.

## 1.6 Hardware and software requirements

### 1.6.1 Hardware

Hardware requirements for the project are the same between the release and development environments and they're quite simple. I expect the app to require a processor with at least 1 GHz clock speed, \$BINARY\_SIZE free disk space, and about 1 GB of available RAM. The processor and RAM requirements are needed by the Python runtime and mainly by Qt5 - the GUI library I'll be using. The \$BINARY\_SIZE disk space is just for the executable binary that I'll compile for the public release. The code itself is less than 1 MB, but the compiled binary has to package all the dependencies and the entire CPython runtime to allow it to run on systems that don't have that, so the file size is much bigger.

I will also require that the user has a monitor that is at least  $1920 \times 1080$  pixels in resolution. This isn't necessarily required, because the app will likely run in a smaller window, but a HD monitor is highly recommended. This allows the user to go fullscreen if they want to, and it gives them enough resolution to easily see everything in the app. A large, wall-mounted screen is also highly recommended for use in the classroom, although this is common among schools.

I will also require a keyboard with all standard Latin alphabet characters. This is because the matrices are defined as uppercase Latin letters. Any UK or US keyboard will suffice for this. The app will also require a mouse with at least one button. I don't intend to have right click do anything, so only the primary mouse button is required, although getting a single button mouse to actually work on modern computers is probably quite a challenge. A separate mouse is not strictly required - a laptop trackpad is equally sufficient.

### 1.6.2 Software

Software requirements differ slightly between release and development, although everything that the release environment requires is also required by the development environment. I will require a modern operating system - namely Windows 10 or later, macOS 10.9 'Mavericks'<sup>1</sup> or later, or any modern Linux distro<sup>2</sup>. Basically, it just requires an operating system that is compatible with Python 3.8 or higher as well as Qt5, since I'll be using these in the project. Of course, Qt5 will need to be installed on the user's computer, although it's standard pretty much everywhere these days.

---

<sup>1</sup>Python 3.8 or higher won't compile on any earlier versions of macOS[18]

<sup>2</sup>Specifying a Linux version is practically impossible. Python 3.8 or higher is available in many package repositories, but all modern Python versions will compile on any modern distro. Qt5 is available in many package repositories and can be compiled on any x86 or x86\_64 generic Linux machine with gcc version 5 or later[19]

Python won't actually be required for the end user, because I will be compiling the app into a stand-alone binary executable for release, and this binary will contain the required Python runtime and dependencies. However, if the user wishes to download and run the source code themselves, then they will need Python 3.8 or higher and the package dependencies: `numpy`, `nptyping`, and `pyqt5`. These can be automatically installed with the command `python -m pip install -r requirements.txt` from the root of the repository, although the whole project will be an installable Python package, so using `pip install -e .` will be preferred.

`numpy` is a maths library that allows for fast matrix maths; `nptyping` is used by `mypy` for type-checking and isn't actually a runtime dependency but the imports in the `typing` module fail if it's not installed at runtime<sup>3</sup>; and `pyqt5` is a library that just allows interop between Python and Qt5, which is originally a C++ library.

In the development environment, I use PyCharm for actually writing my code, and I use a virtual environment to isolate my project dependencies. There are also some development dependencies listed in the file `dev_requirements.txt`. They are: `mypy`, `pyqt5-stubs`, `flake8`, `pycodestyle`, `pydocstyle`, and `pytest`. `mypy` is a static type checker<sup>4</sup>; `pyqt5-stubs` is a collection of type annotations for the PyQt5 API for `mypy` to use; `flake8`, `pycodestyle`, and `pydocstyle` are all linters; and `pytest` is a unit testing framework. I use these libraries to make sure my code is good quality and actually working properly during development.

## 1.7 Success criteria

The main aim of the app is to help teach students about linear transformations. As such, the primary measure of success will be letting teachers get to grips with the app and then asking if they would use it in the classroom or recommend it to students to use at home.

Additionally, the app must fulfil some basic requirements:

1. It must allow the user to define multiple matrices in at least two different ways (numerically and visually)
2. It must be able to validate arbitrary matrix expressions
3. It must be able to render any valid matrix expression
4. It must be able to animate any valid matrix expression
5. It must be able to apply a matrix expression to the current scene and animate this (animate from **C** to **TC**, and perhaps do sequential animation)
6. It must be able to display information about the currently rendered transformation (determinant, eigenlines, etc.)
7. It must be able to save and load sessions (defined matrices, display settings, etc.)
8. It must allow the user to define and transform arbitrary polygons

Defining multiple matrices is a feature that I thought was lacking from every other solution I researched, and I think it would make the app much easier to use, so I think it's necessary for success. Validating matrix expressions is necessary because if the user tries to render an expression that doesn't make sense, has an undefined matrix, or contains the inverse of a singular matrix, then we have to disallow that or else the app will crash.

Visualizing matrix expressions as linear transformations is the core part of the app, so basic rendering of them is definitely a requirement for success. Animating these expressions is also a pretty crucial part of the app, so I would consider this necessary for success. Displaying the information of a matrix

---

<sup>3</sup>These `nptyping` imports are needed for type annotations all over the code base, so factoring them out is not feasible

<sup>4</sup>Python has weak, dynamic typing with optional type annotations but `mypy` enforces these static type annotations

transformation is also very useful for building understanding, so I would consider this needed to succeed.

Saving and loading isn't strictly necessary for success, but it is a standard part of many apps, so will likely be expected by users, and it will benefit the app by allowing teachers to plan lessons in advance and save the matrices they've defined for that lesson to be loaded later.

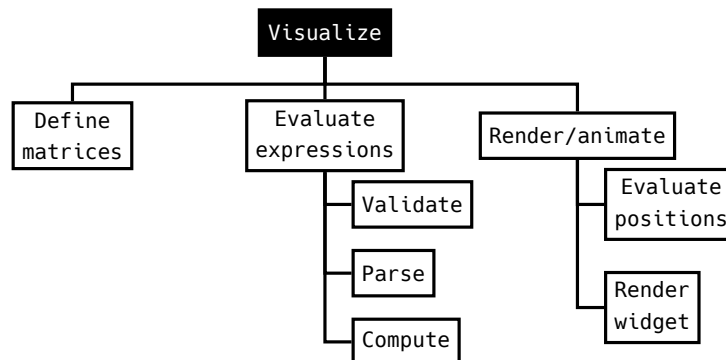
Transforming polygons is the lowest priority item on this list and will likely be implemented last, but it would definitely benefit learning. I wouldn't consider it necessary for success, but it would be very good to include, and it's certainly a feature that I want to have.

If the majority of teachers would use and/or recommend the app and it meets all of these points, then I will consider the app as a whole to be a success.

## 2 Design

### 2.1 Problem decomposition

I have decomposed the problem of visualization as follows:



Defining matrices is key to visualization because we need to have matrices to actually visualize. This is a key part of the app, and the user will be able to define multiple separate matrices numerically and visually using the GUI.

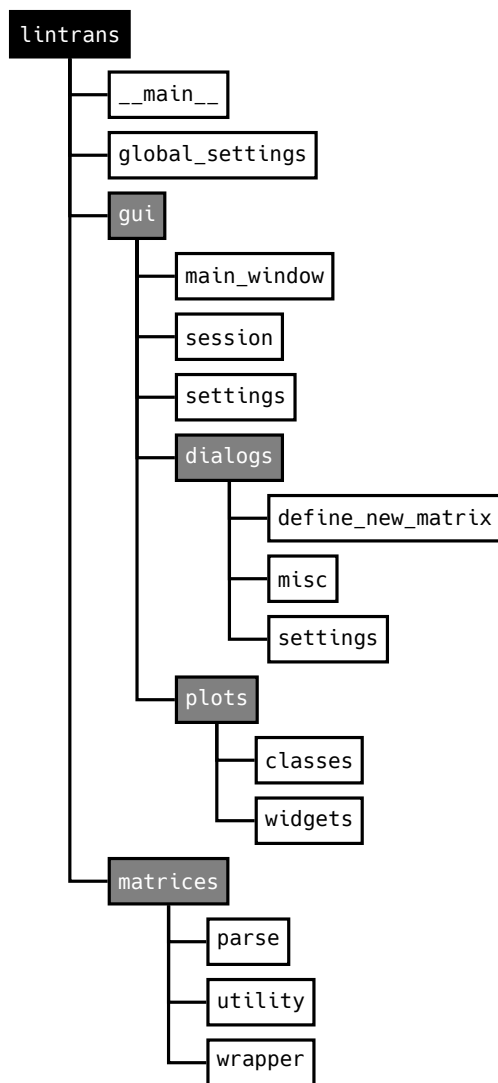
Evaluating expressions is another key part of the app and can be further broken down into validating, parsing, and computing the value. Validating an expression simply consists of checking that it adheres to a set of syntax rules for matrix expressions, and that it only contains matrices which have already been defined. Parsing consists of breaking an expression down into tokens, which are then much easier to evaluate. Computing the expression with these tokens is then just a series of simple operations, which will produce a final matrix at the end.

Rendering and animating will likely be the largest part in reality, but I've only decomposed it into simple blocks here. Evaluating positions involves evaluating the matrix expression that the user has input and using the columns of the resultant matrix to find the new positions of the basis vectors, and then extrapolating this for the rest of the plane. Rendering onto the widget is likely to be quite complicated and framework-dependent, so I've abstracted away the details for brevity here. Rendering will involve using the previously calculated values to render grid lines and vectors. Animating will probably be a `for` loop which just renders slightly different matrices onto the widget and sleeps momentarily between frames.

I have deliberately broken this problem down into parts that can be easily translated into modules in my eventual coded solution. This is simply to ease the design and development process, since now I already know my basic project structure. This problem could've been broken down into the parts that the user will directly interact with, but that would be less useful to me when actually starting development, since I would then have to decompose the problem differently to write the actual code.

### 2.2 Structure of the solution

I have decomposed my solution like so:



The `lintrans` node is simply the root of the whole project. `__main__` is the Python way to make the project executable as `python -m lintrans` on the command line. For release, I will package it into a standalone binary executable, using this module as the entry point.

The `global_settings` module will define a `GlobalSettings` singleton class. This class will manage global settings and variables - things like where to save sessions by default, etc. I'm not entirely sure what I want to put in here, but I expect that I'll want global settings in the future. Having this class will allow me to easily read and write these settings to a file to have them persist between sessions.

`matrices` is the package that will allow the user to define, validate, parse, evaluate, and use matrices. The `matrices.parse` module will contain functions to validate matrix expressions - likely using regular expressions - and functions to parse matrix expressions. It will not know which matrices are defined, so validation will be naïve and evaluation will be in the `matrices.wrapper` module. This `wrapper` module will contain a `MatrixWrapper` class, which will hold a dictionary of matrix names and values. It is this class which will have aware validation - making sure that all the matrices used in an expression are actually defined in the wrapper - as well the ability to evaluate matrix expressions, in addition to its basic behaviour of setting and getting matrices by name. There will also be a `matrices.utility` module, which will contain some simple functions for simple functionality. Functions like `create_rotation_matrix()`, which will generate a rotation matrix from an angle using the formula  $\begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix}$ .

`gui` is the package that will contain all the frontend code for everything GUI-related. `gui.main_window` is the module that will define the `LintransMainWindow` class, which will act as the main window of the application and have an instance of `MatrixWrapper` to keep track of which matrices are defined and allow for evaluation of matrix expressions. It will also have methods for rendering and animating matrix expressions, which will be connected to buttons in the GUI. The most important part of the main window is the viewport, which will be discussed shortly. This module will also contain a simple `main()` function to instantiate and launch the application GUI.

The `gui.session` module will contain functions to save and load a session from a file. A session will consist of the `MatrixWrapper`, along with perhaps the display settings and maybe some other things. I know that saving the wrapper will be essential, but I'll see what else should be saved as the project evolves.

The `gui.settings` module will contain a `DisplaySettings` dataclass<sup>5</sup> that will represent the settings for visualizing transformations. The viewport class will have an instance of this class and check against it when rendering things. The user will be able to open a dialog to change these display settings, which will update the main window's instance of this class.

The `gui.dialogs` subpackage will contain modules with different dialog classes. It will have a `gui.dialogs.define_new_matrices` module, which will have a `DefinedDialog` abstract superclass. It will then contain classes that inherit from this superclass and provide dialogs for defining new matrices visually,

<sup>5</sup>This is the Python equivalent of a struct or record in other languages

numerically, and as an expression in terms of other matrices. Additionally, it will contain a `gui.dialogs.settings` module, which will provide a `SettingsDialog` superclass and a `DisplaySettingsDialog` class, which will allow the user to configure the aforementioned display settings. It may also have a `GlobalSettingsDialog` class in the future, which would similarly allow the user to configure the app's global settings through a dialog. This will only be implemented once I've actually got global settings to configure.

The `gui.dialogs.misc` module will contain small miscellaneous dialog boxes - things like the about box which are very simple and don't need a dedicated module.

The `gui.plots` subpackage will have a `gui.plots.classes` module and a `gui.plots.widgets` module. The `classes` module will have the abstract superclasses `BackgroundPlot` and `VectorGridPlot`. The former will provide helper methods to convert between coordinate systems and draw the background grid, while the latter will provide helper methods to draw transformations and their components. It will have `point_i` and `point_j` attributes and will provide methods to draw the transformed version of the grid, the vectors and their arrowheads, the eigenlines of the transformation, etc. These methods can then be called from the Qt5 `paintEvent` handler which will be declared abstract and must therefore be implemented by all subclasses.

The `gui.plots.widgets` module will have the classes `VisualizeTransformationWidget` and `DefineVisuallyWidget`, which will both inherit from `VectorGridPlot`. They will both implement their own `paintEvent` handler to actually draw the respective widgets, and `DefineVisuallyWidget` will also implement handlers for mouse events, allowing the user to drag around the basis vectors.

I also want the user to be able to define arbitrary polygons and view their transformations. I imagine this polygon definition will happen in a separate dialog, but I don't know where that's going to fit just yet. I'll probably have the widget in `gui.plots.widgets`, but possibly elsewhere.

## 2.3 Algorithm design

The project will have many algorithms but a lot of them will be related to drawing transformations on the canvas itself, and almost all of the algorithms will evolve over time. In this section, I will present pseudocode for some of the most interesting parts of the project. My pseudocode is actually Python, purely to allow for syntax highlighting.

The `lintrans.matrices.utility` module will look like this:

```
1 import numpy as np
2
3 def create_rotation_matrix(angle: float, *, degrees: bool = True) -> MatrixType:
4     """Create a matrix representing a rotation (anticlockwise) by the given angle."""
5     rad = np.deg2rad(angle % 360) if degrees else angle % (2 * np.pi)
6     return np.array([
7         [np.cos(rad), -1 * np.sin(rad)],
8         [np.sin(rad), np.cos(rad)]
9     ])
```

And the `lintrans.matrices.wrapper` module will look like this:

```
1 import re
2 import numpy as np
3
4 # The `utility` syntax means that the utility module is next to this one in the tree
5 from .utility import create_rotation_matrix
6
7 class MatrixWrapper:
8     def __init__(self):
9         # This dictionary maps all letters of the alphabet to an optional matrix
10         self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
11             'A': None, 'B': None, 'C': None, 'D': None,
```

```

12         'E': None, 'F': None, 'G': None, 'H': None,
13         'I': np.eye(2), # I is always defined as the identity matrix
14         'J': None, 'K': None, 'L': None, 'M': None,
15         'N': None, 'O': None, 'P': None, 'Q': None,
16         'R': None, 'S': None, 'T': None, 'U': None,
17         'V': None, 'W': None, 'X': None, 'Y': None,
18         'Z': None
19     }
20
21     def __getitem__(self, name: str) -> Optional[MatrixType]:
22         """Get the matrix with the given name.
23
24         If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)`, with
25         a given angle in degrees, then we return a new matrix representing a rotation by that angle.
26
27         Using ``__getitem__` here allows for syntax like ``wrapper['A']` as if it was a dictionary.
28         """
29         # Return a new rotation matrix
30         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
31             return create_rotation_matrix(float(match.group(1)))
32
33         if name not in self._matrices:
34             raise NameError(f'Unrecognised matrix name "{name}"')
35
36         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
37         matrix = copy(self._matrices[name])
38
39         return matrix
40
41     def __setitem__(self, name: str, new_matrix: Optional[MatrixType]) -> None:
42         """Set the value of matrix ``name`` with the new_matrix.
43
44         If ``new_matrix`` is None, then that effectively unsets the matrix name.
45
46         Using ``__getitem__` here allows for syntax like ``wrapper['A'] = matrix`` as if it was a dictionary.
47         """
48         if not (name in self._matrices and name != 'I'):
49             raise NameError('Matrix name is illegal')
50
51         if new_matrix is None:
52             self._matrices[name] = None
53             return
54
55         if not is_matrix_type(new_matrix):
56             raise TypeError('Matrix must be a 2x2 NumPy array')
57
58         # All matrices must have float entries
59         a = float(new_matrix[0][0])
60         b = float(new_matrix[0][1])
61         c = float(new_matrix[1][0])
62         d = float(new_matrix[1][1])
63
64         self._matrices[name] = np.array([[a, b], [c, d]])

```

These modules handle the creation, storage, and use of matrices. Their implementations are deliberately simple, since they don't have to do much. I will eventually extend the `MatrixWrapper` class to allow strings as matrices, so they can be defined as expressions, but this is unnecessary for now. It will simply be more conditions in `__getitem__` and `__setitem__` and a method to evaluate expressions.

Parsing matrix expressions will be quite tricky and I don't really know how I'm going to do it. I think it will be possible with regular expressions, since I won't support nested expressions at first. But adding support for nested expressions may require something more complicated. I will have a function to validate a matrix expression, which can definitely be done with regular expressions, and I'll have another public function to parse matrix expressions, although this one may use some private functions to implement it properly.

I'm not sure on any algorithms yet, but here's the full BNF specification for matrix expressions (including nested expressions):

```

expression      ::= [ "-" ] matrices { ( "+" | "-" ) matrices };
matrices        ::= matrix { matrix };
matrix          ::= [ real_number ] matrix_identfier [ index ] | "(" expression ")";
matrix_identfier ::= "A" .. "Z" | "rot(" [ "-" ] real_number ")";
index           ::= "^{" index_content "}" | "^" index_content;
index_content    ::= [ "-" ] integer_not_zero | "T";

digit_no_zero   ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
digit           ::= "0" | digit_no_zero;
digits          ::= digit | digits digit;
integer_not_zero ::= digit_no_zero [ digits ];
real_number     ::= ( integer_not_zero [ "." digits ] | "0" "." digits );

```

Obviously the data structure returned by the parser is very important. I have decided to use `list[list[tuple[str, str, str]]]`. Each tuple represents a real number multiplier, a matrix identifier, and an index. The multiplier and index may be empty strings. These tuples are contained in lists which represent matrices to be multiplied together, in order. Those lists are contained in a top level list, which represents multiplication groups which should be summed.

This type makes the structure of the input clear, and makes it very easy for the `MatrixWrapper` to evaluate a parsed expression.

## 2.4 Usability features

My main concern in terms of usability is colour. In the 3blue1brown videos on linear algebra, red and green are used for the basis vectors, but these colours are often hard to distinguish in most common forms of colour blindness. The most common form is deuteranopia[28], which makes red and green look incredibly similar. I will use blue and red for my basis vectors. These colours are easy to distinguish for people with deuteranopia and protanopia - the two most common forms of colour blindness. Tritanopia makes it harder to distinguish blue and yellow, but my colour scheme is still be accessible for people with tritanopia, as red and blue are very distinct in this form of colour blindness.

I will probably use green for the eigenvectors and eigenlines, which will be hard to distinguish from the red basis vector for people with red-green colour blindness, but I think that the basis vectors and eigenvectors/eigenlines will look physically different enough from each other that the colour shouldn't be too much of a problem. Additionally, I will use a tool called Color Oracle[12] to make sure that my app is accessible to people with different forms of colour blindness<sup>6</sup>.

Another solution would be to have one default colour scheme, and allow the user to change the colour scheme to something more accessible for colour blind people, but I don't see the point in this. I think it's easier for colour blind people to just have the main colour scheme be accessible, and it's not really an inconvenience to non-colour blind people, so I think this is the best option.

The layout of my app will be self-consistent and follow standard conventions. I will have a menu bar at the top of the main window for actions like saving and loading, as well as accessing the tutorial (which will also be accessible by pressing `F1` at any point) and documentation. The dialogs will always have the confirm button in the bottom right and the cancel button just to the left of that. They will also have the matrix name drop-down on the left. This consistency will make the app easier to learn and understand.

I will also have hotkeys for everything that can have hotkeys - buttons, checkboxes, etc. This makes my life easier, since I'm used to having hotkeys for everything, and thus makes the app faster to test because I don't need to click everything. This also makes things easier for other people like me, who prefer to stay at the keyboard and not use the mouse. Obviously a mouse will be required for things

<sup>6</sup>I actually had to clone a fork of this project[1] to get it working on Ubuntu 20.04 and adapt it slightly to create a working jar file



like dragging basis vectors and polygon vertices, but hotkeys will be available wherever possible to help people who don't like using the mouse or find it difficult.

## 2.5 Variables and validation

The most important variables in the project will be instance attributes on the `LintransMainWindow` class. It will have a `MatrixWrapper` instance, a `DisplaySettings` instance, and most importantly, a `VisualizeTransformationWidget` instance. These will handle the matrices and various settings respectively. Having these as instance attributes allows them to be referenced from any method in the class, and Qt5 uses lots of slots (basically callback methods) and handlers, so it's good to be able to access the attributes I need right there rather than having to pass them around from method to method.

The `MatrixWrapper` class will have a dictionary of names and matrices. The names will be single letters<sup>7</sup> and the matrices will be of type `MatrixType`. This will be a custom type alias representing a  $2 \times 2$  numpy array of floats. When setting the values for these matrices, I will have to manually check the types. This is because Python has weak typing, and if we got, say, an integer in place of a matrix, then operations would fail when trying to evaluate a matrix expression, and the program would crash. To prevent this, we have to validate the type of every matrix when it's set. I have chosen to use a dictionary here because it makes accessing a matrix by its name easier. We don't have to check against a list of letters and another list of matrices, we just index into the dictionary.

The settings dataclasses will have instance attributes for each setting. Most of these will be booleans, since they will be simple binary options like *Show determinant*, which will be represented with checkboxes in the GUI. The `DisplaySettings` dataclass will also have an attribute of type `int` representing the time in milliseconds to pause during animations.

The `DefineDialog` superclass have a `MatrixWrapper` instance attribute, which will be a parameter in the constructor. When `LintransMainWindow` spawns a definition dialog (which subclasses `DefineDialog`), it will pass in a copy of its own `MatrixWrapper` and connect the `accepted` signal for the dialog. The slot (method) that this signal is connected to will get called when the dialog is closed with the *Confirm* button<sup>8</sup>. This allows the dialog to mutate its own `MatrixWrapper` object and then the main window can copy that mutated version back into its own instance attribute when the user confirms the change. This reduces coupling and makes everything easier to reason about and debug, as well as reducing the number of bugs, since the classes will be independent of each other. In another language, I could pass a pointer to the wrapper and let the dialog mutate it directly, but this is potentially dangerous, and Python doesn't have pointers anyway.

Validation will also play a very big role in the application. The user will be able to enter matrix expressions and these must be validated. I will define a BNF schema and either write my own RegEx or use that BNF to programmatically generate a RegEx. Every matrix expression input will be checked against it. This is to ensure that the matrix wrapper can actually evaluate the expression. If we didn't validate the expression, then the parsing would fail and the program could crash. I've chosen to use a RegEx here rather than any other option because it's the simplest. Creating a RegEx can be difficult, especially for complicated patterns, but it's then easier to use it. Also, Python can compile a RegEx pattern, which makes it much faster to match against, so I will compile the pattern at initialization time and just compare expressions against that pre-compiled pattern, since we know it won't change at runtime.

Additionally, the buttons to render and animate the current matrix expression will only be enabled when the expression is valid. Textboxes in Qt5 emit a `textChanged` signal, which can be connected to a slot. This is just a method that gets called whenever the text in the textbox is changed, so I can use this method to validate the input and update the buttons accordingly. An empty string will count as invalid, so the buttons will be disabled when the box is empty.

---

<sup>7</sup>I would make these char but Python only has a `str` type for strings

<sup>8</sup>Actually when the dialog calls `.accept()`. The *Confirm* button is actually connected to a method which first takes the info and updates the instance `MatrixWrapper`, and then calls `.accept()`

I will also apply this matrix expression validation to the textbox in the dialog which allows the user to define a matrix as an expression involving other matrices, and I will validate the input in the numeric definition dialog to make sure that all the inputs are floats. Again, this is to prevent crashes, since a matrix with non-number values in it will likely crash the program.

## 2.6 Iterative test data

In unit testing, I will test the validation, parsing, and generation of rotation matrices from an angle. I will also unit test the utility functions for the GUI, like `is_valid_float`, which is needed to verify input when defining a matrix visually.

For the validation of matrix expressions, I will have data like the following:

Valid	Invalid
"A"	" "
"AB"	"A^"
"-3.4A"	"rot( )" "
"A^2"	"A^{2" "
"A^T"	"^12" "
"A^{-1}"	"A^{3.2" "
"rot(45)"	"A^B" "
"3A^{12}"	".A" "
"2B^2+A^TC^{-1}"	"--A" "
"3.5A^{4}5.6rot(19.2^T-B^{-1})4.1C^5"	"A--B" "

This list is not exhaustive, mostly to save space and time, but the full unit testing code is included in appendix B.

The invalid expressions presented here have been chosen to be almost valid, but not quite. They are edge cases. I will also test blatantly invalid expressions like "This is a matrix expression" to make sure the validation works.

Here's an example of some test data for parsing:

Input	Expected
"A"	[[(" ", "A", " ")]]
"AB"	[[(" ", "A", " "), (" ", "B", " ")]]
"2A+B^2"	[[("2", "A", " "), (" ", "B", "2")]]
"3A^T2.4B^{-1}-C"	[[("3", "A", "T"), ("2.4", "B", "-1")], [("-1", "C", " ")]]

The parsing output is pretty verbose and this table doesn't have enough space for most of the more complicated inputs, so here's a monster one:

"2.14A^{3} 4.5rot(14.5)^{-1} + 8.5B^T 5.97C^{14} - 3.14D^{-1} 6.7E^T"

which should parse to give:

[[("2.14", "A", "3"), ("4.5", "rot(14.5)", "-1")], [("8.5", "B", "T"), ("5.97", "C", "14")], [("-3.14", "D", "-1"), ("6.7", "E", "T")]]

Any invalid expression will also raise a `MatrixParseError`, so I will check every invalid input previously mentioned and make sure it raises the appropriate error.

Again, this section is brief to save space and time. All unit tests are included in appendix B.

## 2.7 Post-development test data

This section will be completed later.

## 2.8 Issues with testing

Since `lintrans` is a graphical application about visualizing things, it will be mainly GUI focussed. Unfortunately, unit testing GUIs is a lot harder than unit testing library or API code. I don't think there's any way to easily and reliably unit test a graphical interface, so my unit tests will only cover the backend code for handling matrices. Testing the GUI will be entirely manual; mostly defining matrices, thinking about what I expect them to look like, and then making sure they look like that. I don't see a way around this limitation. I will make my backend unit tests very thorough, but testing the GUI can only be done manually.

### 3 Development

Please note, throughout this section, every code snippet will have two comments at the top. The first is the git commit hash that the snippet was taken from<sup>9</sup>. The second comment is the file name. The line numbers of the snippet reflect the line numbers of the file from where the snippet was taken. After a certain point, I introduced copyright comments at the top of every file. These are always omitted here.

#### 3.1 Matrices backend

##### 3.1.1 MatrixWrapper class

The first real part of development was creating the `MatrixWrapper` class. It needs a simple instance dictionary to be created in the constructor, and it needs a way of accessing the matrices. I decided to use Python's `__getitem__()` and `__setitem__()` special methods[17] to allow indexing into a `MatrixWrapper` object like `wrapper['M']`. This simplifies using the class.

```
# 29ec1fedbf307e3b7ca731c4a381535fec899b0b
# src/lintrans/matrices/wrapper.py

1  """A module containing a simple MatrixWrapper class to wrap matrices and context."""
2
3  import numpy as np
4
5  from lintrans.typing import MatrixType
6
7
8  class MatrixWrapper:
9      """A simple wrapper class to hold all possible matrices and allow access to them."""
10
11      def __init__(self):
12          """Initialise a MatrixWrapper object with a matrices dict."""
13          self._matrices: dict[str, MatrixType | None] = {
14              'A': None, 'B': None, 'C': None, 'D': None,
15              'E': None, 'F': None, 'G': None, 'H': None,
16              'I': np.eye(2), # I is always defined as the identity matrix
17              'J': None, 'K': None, 'L': None, 'M': None,
18              'N': None, 'O': None, 'P': None, 'Q': None,
19              'R': None, 'S': None, 'T': None, 'U': None,
20              'V': None, 'W': None, 'X': None, 'Y': None,
21              'Z': None
22          }
23
24      def __getitem__(self, name: str) -> MatrixType | None:
25          """Get the matrix with `name` from the dictionary.
26
27          Raises:
28              KeyError:
29                  If there is no matrix with the given name
30          """
31          return self._matrices[name]
32
33      def __setitem__(self, name: str, new_matrix: MatrixType) -> None:
34          """Set the value of matrix `name` with the new_matrix.
35
36          Raises:
37              ValueError:
38                  If `name` isn't a valid matrix name
39          """
40          name = name.upper()
41
42          if name == 'I' or name not in self._matrices:
43              raise NameError('Matrix name must be a capital letter and cannot be "I"')
```

<sup>9</sup>A history of all commits can be found in the GitHub repository[2]

```

44
45         self._matrices[name] = new_matrix

```

This code is very simple. The constructor (`__init__()`) creates a dictionary of matrices which all start out as having no value, except the identity matrix **I**. The `__getitem__()` and `__setitem__()` methods allow the user to easily get and set matrices just like a dictionary, and `__setitem__()` will raise an error if the name is invalid. This is a very early prototype, so it doesn't validate the type of whatever the user is trying to assign it to yet. This validation will come later.

I could make this class subclass `dict`, since it's basically just a dictionary at this point, but I want to extend it with much more functionality later, so I chose to handle the dictionary stuff myself.

I then had to write unit tests for this class, and I chose to do all my unit tests using a framework called `pytest`.

```

# 29ec1fedbf307e3b7ca731c4a381535fec899b0b
# tests/test_matrix_wrapper.py

1  """Test the MatrixWrapper class."""
2
3  import numpy as np
4  import pytest
5  from lintrans.matrices import MatrixWrapper
6
7  valid_matrix_names = 'ABCDEFGHJKLMNPOQRSTUVWXYZ'
8  test_matrix = np.array([[1, 2], [4, 3]])
9
10
11 @pytest.fixture
12 def wrapper() -> MatrixWrapper:
13     """Return a new MatrixWrapper object."""
14     return MatrixWrapper()
15
16
17 def test_get_matrix(wrapper) -> None:
18     """Test MatrixWrapper.__getitem__()."""
19     for name in valid_matrix_names:
20         assert wrapper[name] is None
21
22     assert (wrapper['I'] == np.array([[1, 0], [0, 1]])).all()
23
24
25 def test_get_name_error(wrapper) -> None:
26     """Test that MatrixWrapper.__getitem__() raises a KeyError if called with an invalid name."""
27     with pytest.raises(KeyError):
28         _ = wrapper['bad name']
29         _ = wrapper['123456']
30         _ = wrapper['Th15 Is an 1nV@l1D n@m3']
31         _ = wrapper['abc']
32
33
34 def test_set_matrix(wrapper) -> None:
35     """Test MatrixWrapper.__setitem__()."""
36     for name in valid_matrix_names:
37         wrapper[name] = test_matrix
38         assert (wrapper[name] == test_matrix).all()
39
40
41 def test_set_identity_error(wrapper) -> None:
42     """Test that MatrixWrapper.__setitem__() raises a NameError when trying to assign to I."""
43     with pytest.raises(NameError):
44         wrapper['I'] = test_matrix
45
46
47 def test_set_name_error(wrapper) -> None:
48     """Test that MatrixWrapper.__setitem__() raises a NameError when trying to assign to an invalid name."""
49     with pytest.raises(NameError):
50         wrapper['bad name'] = test_matrix
51         wrapper['123456'] = test_matrix

```

```

52     wrapper['Th15 Is an 1nV@11D n@m3'] = test_matrix
53     wrapper['abc'] = test_matrix

```

These tests are quite simple and just ensure that the expected behaviour works the way it should, and that the correct errors are raised when they should be. It verifies that matrices can be assigned, that every valid name works, and that the identity matrix **I** cannot be assigned to.

The function decorated with `@pytest.fixture` allows functions to use a parameter called `wrapper` and `pytest` will automatically call this function and pass it as that parameter. It just saves on code repetition.

### 3.1.2 Rudimentary parsing and evaluating

This first thing I did here was improve the `__setitem__()` and `__getitem__()` methods to validate input and easily get transposes and simple rotation matrices.

```

# f89fc9fd8d5917d07557fc50df3331123b55ad6b
# src/lintrans/matrices/wrapper.py

11 class MatrixWrapper:
...
60     def __setitem__(self, name: str, new_matrix: MatrixType) -> None:
61         """Set the value of matrix 'name' with the new_matrix.
62
63         :param str name: The name of the matrix to set the value of
64         :param MatrixType new_matrix: The value of the new matrix
65         :rtype: None
66
67         :raises NameError: If the name isn't a valid matrix name or is 'I'
68         """
69         if name not in self._matrices.keys():
70             raise NameError('Matrix name must be a single capital letter')
71
72         if name == 'I':
73             raise NameError('Matrix name cannot be "I"')
74
75         # All matrices must have float entries
76         a = float(new_matrix[0][0])
77         b = float(new_matrix[0][1])
78         c = float(new_matrix[1][0])
79         d = float(new_matrix[1][1])
80
81         self._matrices[name] = np.array([[a, b], [c, d]])

```

In this method, I'm now casting all the values to floats. This is very simple validation, since this cast will raise **ValueError** if it fails to cast the value to a float. I should've declared `:raises ValueError:` in the docstring, but this was an oversight at the time.

```

# f89fc9fd8d5917d07557fc50df3331123b55ad6b
# src/lintrans/matrices/wrapper.py

11 class MatrixWrapper:
...
27     def __getitem__(self, name: str) -> Optional[MatrixType]:
28         """Get the matrix with the given name.
29
30         If it is a simple name, it will just be fetched from the dictionary.
31         If the name is followed with a 't', then we will return the transpose of the named matrix.
32         If the name is 'rot()', with a given angle in degrees, then we return a new rotation matrix with that angle.
33
34         :param str name: The name of the matrix to get
35         :returns: The value of the matrix (may be none)
36         :rtype: Optional[MatrixType]

```

```

37
38         :raises NameError: If there is no matrix with the given name
39         """
40         # Return a new rotation matrix
41         match = re.match(r'rot\((\d+)\)', name)
42         if match is not None:
43             return create_rotation_matrix(float(match.group(1)))
44
45         # Return the transpose of this matrix
46         match = re.match(r'([A-Z])t', name)
47         if match is not None:
48             matrix = self[match.group(1)]
49
50             if matrix is not None:
51                 return matrix.T
52             else:
53                 return None
54
55         if name not in self._matrices:
56             raise NameError(f'Unrecognised matrix name "{name}"')
57
58         return self._matrices[name]
59

```

This `__getitem__()` method now allows for easily accessing transposes and rotation matrices by checking input with regular expressions. This makes getting matrices easier and thus makes evaluating full expressions simpler.

The `create_rotation_matrix()` method is also defined in this file and just uses the  $\begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix}$  formula from before:

```

# f89fc9fd8d5917d07557fc50df3331123b55ad6b
# src/lintrans/matrices/wrapper.py

158 def create_rotation_matrix(angle: float) -> MatrixType:
159     """Create a matrix representing a rotation by the given number of degrees anticlockwise.
160
161     :param float angle: The number of degrees to rotate by
162     :returns MatrixType: The resultant rotation matrix
163     """
164     rad = np.deg2rad(angle)
165     return np.array([
166         [np.cos(rad), -1 * np.sin(rad)],
167         [np.sin(rad), np.cos(rad)]
168     ])

```

At this stage, I also implemented a simple parser and evaluator using regular expressions. It's not great and it's not very flexible, but it can evaluate simple expressions.

```

# f89fc9fd8d5917d07557fc50df3331123b55ad6b
# src/lintrans/matrices/wrapper.py

11 class MatrixWrapper:
...
83     def parse_expression(self, expression: str) -> MatrixType:
84         """Parse a given expression and return the matrix for that expression.
85
86         Expressions are written with standard LaTeX notation for exponents. All whitespace is ignored.
87
88         Here is documentation on syntax:
89         A single matrix is written as 'A'.
90         Matrix A multiplied by matrix B is written as 'AB'
91         Matrix A plus matrix B is written as 'A+B'
92         Matrix A minus matrix B is written as 'A-B'
93         Matrix A squared is written as 'A^2'
94         Matrix A to the power of 10 is written as 'A^10' or 'A^{10}'
95         The inverse of matrix A is written as 'A^-1' or 'A^{-1}'

```

```

96         The transpose of matrix A is written as 'A^T' or 'At'
97
98     :param str expression: The expression to be parsed
99     :returns MatrixType: The matrix result of the expression
100
101     :raises ValueError: If the expression is invalid, such as an empty string
102     """
103     if expression == '':
104         raise ValueError('The expression cannot be an empty string')
105
106     match = re.search(r'^[-+A-Z^{*}\d.]', expression)
107     if match is not None:
108         raise ValueError(f'Invalid character "{match.group(0)}"')
109
110     # Remove all whitespace in the expression
111     expression = re.sub(r'\s', '', expression)
112
113     # Wrap all exponents and transposition powers with {}
114     expression = re.sub(r'(<=^)(-?\d+|T)(?=[^}]|$)', r'{\g<0>}', expression)
115
116     # Replace all subtractions with additions, multiplied by -1
117     expression = re.sub(r'(<=.)-(<=[A-Z])', '+-1', expression)
118
119     # Replace a possible leading minus sign with -1
120     expression = re.sub(r'^-(<=[A-Z])', '-1', expression)
121
122     # Change all transposition exponents into lowercase
123     expression = expression.replace('^T', 't')
124
125     # Split the expression into groups to be multiplied, and then we add those groups at the end
126     # We also have to filter out the empty strings to reduce errors
127     multiplication_groups = [x for x in expression.split('+') if x != '']
128
129     # Start with the 0 matrix and add each group on
130     matrix_sum: MatrixType = np.array([[0., 0.], [0., 0.]])
131
132     for group in multiplication_groups:
133         # Generate a list of tuples, each representing a matrix
134         # These tuples are (the multiplier, the matrix (with optional
135         # 't' at the end to indicate a transpose), the exponent)
136         string_matrices: list[tuple[str, str, str]]
137
138         # The generate tuple is (multiplier, matrix, full exponent, stripped exponent)
139         # The full exponent contains ^{}, so we ignore it
140         # The multiplier and exponent might be '', so we have to set them to '1'
141         string_matrices = [(t[0] if t[0] != '' else '1', t[1], t[3] if t[3] != '' else '1')
142                             for t in re.findall(r'(-?\d*\.\d*)([A-Z]?|rot\(\d+\))(\^((-?\d+|T)))?', group)]
143
144         # This list is a list of tuple, where each tuple is (a float multiplier,
145         # the matrix (gotten from the wrapper's __getitem__()), the integer power)
146         matrices: list[tuple[float, MatrixType, int]]
147         matrices = [(float(t[0]), self[t[1]], int(t[2])) for t in string_matrices]
148
149         # Process the matrices and make actual MatrixType objects
150         processed_matrices: list[MatrixType] = [t[0] * np.linalg.matrix_power(t[1], t[2]) for t in matrices]
151
152         # Add this matrix product to the sum total
153         matrix_sum += reduce(lambda m, n: m @ n, processed_matrices)
154
155     return matrix_sum

```

I think the comments in the code speak for themselves, but we basically split the expression up into groups to be added, and then for each group, we multiply every matrix in that group to get its value, and then add all these values together at the end.

This code is objectively bad. At the time of writing, it's now quite old, so I can say that. This code has no real error handling, and line 127 introduces the glaring error that 'A++B' is now a valid expression because we disregard empty strings. Not to mention the fact that the method is called `parse_expression()` but actually evaluates an expression. All these issues will be fixed in the future, but this was the first implementation of matrix evaluation, and it does the job decently well.



I then implemented several tests for this parsing.

```
# 60e0c713b244e097bab8ee0f71142b709fde1a8b
# tests/test_matrix_wrapper_parse_expression.py

1  """Test the MatrixWrapper parse_expression() method."""
2
3  import numpy as np
4  from numpy import linalg as la
5  import pytest
6  from lintrans.matrices import MatrixWrapper
7
8
9  @pytest.fixture
10 def wrapper() -> MatrixWrapper:
11     """Return a new MatrixWrapper object with some preset values."""
12     wrapper = MatrixWrapper()
13
14     root_two_over_two = np.sqrt(2) / 2
15
16     wrapper['A'] = np.array([[1, 2], [3, 4]])
17     wrapper['B'] = np.array([[6, 4], [12, 9]])
18     wrapper['C'] = np.array([[-1, -3], [4, -12]])
19     wrapper['D'] = np.array([[13.2, 9.4], [-3.4, -1.8]])
20     wrapper['E'] = np.array([
21         [root_two_over_two, -1 * root_two_over_two],
22         [root_two_over_two, root_two_over_two]
23     ])
24     wrapper['F'] = np.array([[-1, 0], [0, 1]])
25     wrapper['G'] = np.array([[np.pi, np.e], [1729, 743.631]])
26
27     return wrapper
28
29
30 def test_simple_matrix_addition(wrapper: MatrixWrapper) -> None:
31     """Test simple addition and subtraction of two matrices."""
32
33     # NOTE: We assert that all of these values are not None just to stop mypy complaining
34     # These values will never actually be None because they're set in the wrapper() fixture
35     # There's probably a better way do this, because this method is a bit of a bodge, but this works for now
36     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
37         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
38         wrapper['G'] is not None
39
40     assert (wrapper.parse_expression('A+B') == wrapper['A'] + wrapper['B']).all()
41     assert (wrapper.parse_expression('E+F') == wrapper['E'] + wrapper['F']).all()
42     assert (wrapper.parse_expression('G+D') == wrapper['G'] + wrapper['D']).all()
43     assert (wrapper.parse_expression('C+C') == wrapper['C'] + wrapper['C']).all()
44     assert (wrapper.parse_expression('D+A') == wrapper['D'] + wrapper['A']).all()
45     assert (wrapper.parse_expression('B+C') == wrapper['B'] + wrapper['C']).all()
46
47
48 def test_simple_two_matrix_multiplication(wrapper: MatrixWrapper) -> None:
49     """Test simple multiplication of two matrices."""
50     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
51         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
52         wrapper['G'] is not None
53
54     assert (wrapper.parse_expression('AB') == wrapper['A'] @ wrapper['B']).all()
55     assert (wrapper.parse_expression('BA') == wrapper['B'] @ wrapper['A']).all()
56     assert (wrapper.parse_expression('AC') == wrapper['A'] @ wrapper['C']).all()
57     assert (wrapper.parse_expression('DA') == wrapper['D'] @ wrapper['A']).all()
58     assert (wrapper.parse_expression('ED') == wrapper['E'] @ wrapper['D']).all()
59     assert (wrapper.parse_expression('FD') == wrapper['F'] @ wrapper['D']).all()
60     assert (wrapper.parse_expression('GA') == wrapper['G'] @ wrapper['A']).all()
61     assert (wrapper.parse_expression('CF') == wrapper['C'] @ wrapper['F']).all()
62     assert (wrapper.parse_expression('AG') == wrapper['A'] @ wrapper['G']).all()
63
64
65 def test_identity_multiplication(wrapper: MatrixWrapper) -> None:
66     """Test that multiplying by the identity doesn't change the value of a matrix."""
67     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
```

```

68         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
69         wrapper['G'] is not None
70
71     assert (wrapper.parse_expression('I') == wrapper['I']).all()
72     assert (wrapper.parse_expression('AI') == wrapper['A']).all()
73     assert (wrapper.parse_expression('IA') == wrapper['A']).all()
74     assert (wrapper.parse_expression('GI') == wrapper['G']).all()
75     assert (wrapper.parse_expression('IG') == wrapper['G']).all()
76
77     assert (wrapper.parse_expression('EID') == wrapper['E'] @ wrapper['D']).all()
78     assert (wrapper.parse_expression('IED') == wrapper['E'] @ wrapper['D']).all()
79     assert (wrapper.parse_expression('EDI') == wrapper['E'] @ wrapper['D']).all()
80     assert (wrapper.parse_expression('IEIDI') == wrapper['E'] @ wrapper['D']).all()
81     assert (wrapper.parse_expression('EI^3D') == wrapper['E'] @ wrapper['D']).all()
82
83
84 def test_simple_three_matrix_multiplication(wrapper: MatrixWrapper) -> None:
85     """Test simple multiplication of two matrices."""
86     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
87         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
88         wrapper['G'] is not None
89
90     assert (wrapper.parse_expression('ABC') == wrapper['A'] @ wrapper['B'] @ wrapper['C']).all()
91     assert (wrapper.parse_expression('ACB') == wrapper['A'] @ wrapper['C'] @ wrapper['B']).all()
92     assert (wrapper.parse_expression('BAC') == wrapper['B'] @ wrapper['A'] @ wrapper['C']).all()
93     assert (wrapper.parse_expression('EFG') == wrapper['E'] @ wrapper['F'] @ wrapper['G']).all()
94     assert (wrapper.parse_expression('DAC') == wrapper['D'] @ wrapper['A'] @ wrapper['C']).all()
95     assert (wrapper.parse_expression('GAE') == wrapper['G'] @ wrapper['A'] @ wrapper['E']).all()
96     assert (wrapper.parse_expression('FAG') == wrapper['F'] @ wrapper['A'] @ wrapper['G']).all()
97     assert (wrapper.parse_expression('GAF') == wrapper['G'] @ wrapper['A'] @ wrapper['F']).all()
98
99
100 def test_matrix_inverses(wrapper: MatrixWrapper) -> None:
101     """Test the inverses of single matrices."""
102     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
103         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
104         wrapper['G'] is not None
105
106     assert (wrapper.parse_expression('A^{-1}') == la.inv(wrapper['A'])).all()
107     assert (wrapper.parse_expression('B^{-1}') == la.inv(wrapper['B'])).all()
108     assert (wrapper.parse_expression('C^{-1}') == la.inv(wrapper['C'])).all()
109     assert (wrapper.parse_expression('D^{-1}') == la.inv(wrapper['D'])).all()
110     assert (wrapper.parse_expression('E^{-1}') == la.inv(wrapper['E'])).all()
111     assert (wrapper.parse_expression('F^{-1}') == la.inv(wrapper['F'])).all()
112     assert (wrapper.parse_expression('G^{-1}') == la.inv(wrapper['G'])).all()
113
114     assert (wrapper.parse_expression('A^{-1}') == la.inv(wrapper['A'])).all()
115     assert (wrapper.parse_expression('B^{-1}') == la.inv(wrapper['B'])).all()
116     assert (wrapper.parse_expression('C^{-1}') == la.inv(wrapper['C'])).all()
117     assert (wrapper.parse_expression('D^{-1}') == la.inv(wrapper['D'])).all()
118     assert (wrapper.parse_expression('E^{-1}') == la.inv(wrapper['E'])).all()
119     assert (wrapper.parse_expression('F^{-1}') == la.inv(wrapper['F'])).all()
120     assert (wrapper.parse_expression('G^{-1}') == la.inv(wrapper['G'])).all()
121
122
123 def test_matrix_powers(wrapper: MatrixWrapper) -> None:
124     """Test that matrices can be raised to integer powers."""
125     assert wrapper['A'] is not None and wrapper['B'] is not None and wrapper['C'] is not None and \
126         wrapper['D'] is not None and wrapper['E'] is not None and wrapper['F'] is not None and \
127         wrapper['G'] is not None
128
129     assert (wrapper.parse_expression('A^2') == la.matrix_power(wrapper['A'], 2)).all()
130     assert (wrapper.parse_expression('B^4') == la.matrix_power(wrapper['B'], 4)).all()
131     assert (wrapper.parse_expression('C^{12}') == la.matrix_power(wrapper['C'], 12)).all()
132     assert (wrapper.parse_expression('D^{12}') == la.matrix_power(wrapper['D'], 12)).all()
133     assert (wrapper.parse_expression('E^8') == la.matrix_power(wrapper['E'], 8)).all()
134     assert (wrapper.parse_expression('F^{-6}') == la.matrix_power(wrapper['F'], -6)).all()
135     assert (wrapper.parse_expression('G^{-2}') == la.matrix_power(wrapper['G'], -2)).all()

```

These test lots of simple expressions, but don't test any more complicated expressions, nor do they test any validation, mostly because validation doesn't really exist at this point. 'A++B' is still a valid

expression and is equivalent to 'A+B'.

### 3.1.3 Simple matrix expression validation

My next major step was to implement proper parsing, but I procrastinated for a while and first implemented proper validation.

```
# 39b918651f60bc72bc19d2018075b24a6fc3af17
# src/lintrans/_parse/matrices.py

9 def compile_valid_expression_pattern() -> Pattern[str]:
10     """Compile the single regular expression that will match a valid matrix expression."""
11     digit_no_zero = '[123456789]'
12     digits = '\\d+'
13     integer_no_zero = '-?' + digit_no_zero + '(' + digits + ')?'
14     real_number = f'({integer_no_zero}(\\.\\{digits}\\)?|-?0?\\.\\{digits}\\)'
15
16     index_content = f'({integer_no_zero}|T)'
17     index = f'\\^\\{\\{index_content\\}\\}\\^\\{index_content\\}|t)'
18     matrix_identifier = f'([A-Z]|rot\\(\\{real_number\\}\\))'
19     matrix = '(' + real_number + '?' + matrix_identifier + index + ')?'
20     expression = f'{matrix}+((\\+|-){matrix}+)*'
21
22     return re.compile(expression)
23
24
25 # This is an expensive pattern to compile, so we compile it when this module is initialized
26 valid_expression_pattern = compile_valid_expression_pattern()
27
28
29 def validate_matrix_expression(expression: str) -> bool:
30     """Validate the given matrix expression.
31
32     This function simply checks the expression against a BNF schema. It is not
33     aware of which matrices are actually defined in a wrapper. For an aware
34     version of this function, use the MatrixWrapper().is_valid_expression() method.
35
36     Here is the schema for a valid expression given in a version of BNF:
37
38         expression      ::= matrices { ( "+" | "-" ) matrices };
39         matrices        ::= matrix { matrix };
40         matrix          ::= [ real_number ] matrix_identifier [ index ];
41         matrix_identifier ::= "A" .. "Z" | "rot(" real_number ")";
42         index           ::= "^{" index_content "}" | "^" index_content | "t";
43         index_content   ::= integer_not_zero | "T";
44
45         digit_no_zero   ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
46         digit           ::= "0" | digit_no_zero;
47         digits          ::= digit | digits digit;
48         integer_not_zero ::= [ "-" ] digit_no_zero [ digits ];
49         real_number     ::= ( integer_not_zero [ "." digits ] | [ "-" ] [ "0" ] "." digits );
50
51     :param str expression: The expression to be validated
52     :returns bool: Whether the expression is valid according to the schema
53     """
54     match = valid_expression_pattern.match(expression)
55     return expression == match.group(0) if match is not None else False
```

Here, I'm using a BNF schema to programmatically generate a regular expression. I use a function to generate this pattern and assign it to a variable when the module is initialized. This is because the pattern compilation is expensive and it's more efficient to compile the pattern once and then just use it in the `validate_matrix_expression()` function.

I also created a method `is_valid_expression()` in `MatrixWrapper`, which just validates a given expression. It uses the aforementioned `validate_matrix_expression()` and also checks that every matrix referenced in the expression is defined in the wrapper.

```

# 39b918651f60bc72bc19d2018075b24a6fc3af17
# src/lintrans/matrices/wrapper.py

12 class MatrixWrapper:
13 ...
14 def is_valid_expression(self, expression: str) -> bool:
15     """Check if the given expression is valid, using the context of the wrapper.
16
17     This method calls _parse.validate_matrix_expression(), but also ensures
18     that all the matrices in the expression are defined in the wrapper.
19
20     :param str expression: The expression to validate
21     :returns bool: Whether the expression is valid according the schema
22     """
23     # Get rid of the transposes to check all capital letters
24     expression = re.sub(r'\^T', 't', expression)
25     expression = re.sub(r'\^{T}', 't', expression)
26
27     # Make sure all the referenced matrices are defined
28     for matrix in {x for x in expression if re.match('[A-Z]', x)}:
29         if self[matrix] is None:
30             return False
31
32     return _parse.validate_matrix_expression(expression)

```

I then implemented some simple tests to make sure the function works with valid and invalid expressions.

```

# a0fb029f7da995803c24ee36e7e8078e5621f676
# tests/_parse/test_parse_and_validate_expression.py

1 """Test the _parse.matrices module validation and parsing."""
2
3 import pytest
4 from lintrans._parse import validate_matrix_expression
5
6 valid_inputs: list[str] = [
7     'A', 'AB', '3A', '1.2A', '-3.4A', 'A^2', 'A^-1', 'A^{ -1}',
8     'A^12', 'A^T', 'A^{5}', 'A^{T}', '4.3A^7', '9.2A^{18}',
9
10     'rot(45)', 'rot(12.5)', '3rot(90)',
11     'rot(135)^3', 'rot(51)^T', 'rot(-34)^-1',
12
13     'A+B', 'A+2B', '4.3A+9B', 'A^2+B^T', '3A^7+0.8B^{16}',
14     'A-B', '3A-4B', '3.2A^3-16.79B^T', '4.752A^{17}-3.32B^{36}',
15     'A--1B', '-A', '--1A'
16
17     '3A4B', 'A^TB', 'A^{T}B', '4A^6B^3',
18     '2A^{3}4B^5', '4rot(90)^3', 'rot(45)rot(13)',
19     'Arot(90)', 'AB^2', 'A^2B^2', '8.36A^T3.4B^12',
20
21     '3.5A^{4}5.6rot(19.2)^T-B^{ -1}4.1C^5',
22 ]
23
24 invalid_inputs: list[str] = [
25     '', 'rot()', 'A', 'A^1.2', 'A^{3.4}', '1,2A', 'ro(12)', '5', '12^2',
26     '^T', '^12', 'A^{13}', 'A^3', 'A^A', '^2', 'A--B', '--A'
27
28     'This is 100% a valid matrix expression, I swear'
29 ]
30
31
32 @pytest.mark.parametrize('inputs,output', [(valid_inputs, True), (invalid_inputs, False)])
33 def test_validate_matrix_expression(inputs: list[str], output: bool) -> None:
34     """Test the validate_matrix_expression() function."""
35     for inp in inputs:
36         assert validate_matrix_expression(inp) == output

```

Here, we test some valid data, some definitely invalid data, and some edge cases. At this stage, 'A--1B' was considered a valid expression. This was a quirk of the validator at the time, but I fixed it

later. This should obviously be an invalid expression, especially since 'A--B' is considered invalid, but 'A--1B' is valid.

The `@pytest.mark.parametrize` decorator on line 32 means that `pytest` will run one test for valid inputs, and then another test for invalid inputs, and these will count as different tests. This makes it easier to see which tests failed and then debug the app.

### 3.1.4 Parsing matrix expressions

Parsing is quite an interesting problem and something I didn't feel able to tackle head-on, so I wrote the unit tests first. I had a basic idea of what I wanted the parser to return, but no real idea of how to implement that. My unit tests looked like this:

```
# e9f7a81892278fe70684562052f330fb3a02bf9b
# tests/_parse/test_parse_and_validate_expression.py

40 expressions_and_parsed_expressions: list[tuple[str, MatrixParseList]] = [
41     # Simple expressions
42     ('A', [((' ', 'A', ' ')]]),
43     ('A^2', [((' ', 'A', '2')]]),
44     ('A{2}', [((' ', 'A', '2')]]),
45     ('3A', [(('3', 'A', ' ')]]),
46     ('1.4A^3', [(('1.4', 'A', '3')]]),
47
48     # Multiplications
49     ('4A{3} 6B^2', [(('4', 'A', '3'), ('6', 'B', '2')]]),
50     ('4.2A{T} 6.1B^-1', [(('4.2', 'A', 'T'), ('6.1', 'B', '-1')]]),
51     ('-1.2A^2 rot(45)^2', [(('1.2', 'A', '2'), (' ', 'rot(45)', '2')]]),
52     ('3.2A^T 4.5B{5} 9.6rot(121.3)', [(('3.2', 'A', 'T'), ('4.5', 'B', '5'), ('9.6', 'rot(121.3)', ' ')]]),
53     ('-1.18A{-2} 0.1B{2} 9rot(34.6)^-1', [(('1.18', 'A', '-2'), ('0.1', 'B', '2'), ('9', 'rot(34.6)', '-1')]]),
54
55     # Additions
56     ('A + B', [((' ', 'A', ' '), (' ', 'B', ' ')]]),
57     ('A + B - C', [((' ', 'A', ' '), (' ', 'B', ' '), ('-1', 'C', ' ')]]),
58     ('2A^3 + 8B^T - 3C^-1', [(('2', 'A', '3'), ('8', 'B', 'T'), ('-3', 'C', '-1')]]),
59
60     # Additions with multiplication
61     ('2.14A{3} 4.5rot(14.5)^-1 + 8B^T - 3C^-1', [(('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'),
62                                                     [ ('8', 'B', 'T'), ('-3', 'C', '-1') ] ]),
63     ('2.14A{3} 4.5rot(14.5)^-1 + 8.5B^T 5.97C^4 - 3.14D{-1} 6.7E^T',
64      [(('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'), ('8.5', 'B', 'T'), ('5.97', 'C', '4'),
65        [ ('-3.14', 'D', '-1'), ('6.7', 'E', 'T') ] ]),
66 ]
67
68
69 @pytest.mark.skip(reason='parse_matrix_expression() not implemented')
70 def test_parse_matrix_expression() -> None:
71     """Test the parse_matrix_expression() function."""
72     for expression, parsed_expression in expressions_and_parsed_expressions:
73         # Test it with and without whitespace
74         assert parse_matrix_expression(expression) == parsed_expression
75         assert parse_matrix_expression(expression.replace(' ', '')) == parsed_expression
```

I just had example inputs and what I expected as output. I also wanted the parser to ignore whitespace. The decorator on line 69 just skips the test because the parser wasn't implemented yet.

When implementing the parser, I first had to tighten up validation to remove anomalies like 'A--1B' being valid. I did this by factoring out the optional minus signs from being part of a number, to being optionally in front of a number. This eliminated this kind of repetition and made 'A--1B' invalid, as it should be.

```
# fd80d8d3b0e975e92dcc7c10f1f0f1276879f408
# src/lintrans/_parse/matrices.py
```

```

32 def compile_valid_expression_pattern() -> Pattern[str]:
33     """Compile the single regular expression that will match a valid matrix expression."""
34     digit_no_zero = '[123456789]'
35     digits = '\\d+'
36     integer_no_zero = digit_no_zero + '(' + digits + ')?'
37     real_number = f'({integer_no_zero}(\\.\\{digits}\\{0?\\.\\{digits}\\})'
38
39     index_content = f'(-?{integer_no_zero}|T)'
40     index = f'(^\\^\\{index_content\\}\\}\\^\\{index_content\\}|t)'
41     matrix_identifier = f'([A-Z]|rot\\(-?{real_number}\\})'
42     matrix = '(' + real_number + '?' + matrix_identifier + index + ')?'
43     expression = f'-?{matrix}+((\\+|\\-){matrix}+)*'
44
45     return re.compile(expression)

```

The code can be a bit hard to read with all the RegEx stuff, but the BNF illustrates these changes nicely.

Compare the old version:

```

# 39b918651f60bc72bc19d2018075b24a6fc3af17
# src/lintrans/_parse/matrices.py

29 def validate_matrix_expression(expression: str) -> bool:
...
36     Here is the schema for a valid expression given in a version of BNF:
...
38     expression      ::= matrices { ( "+" | "-" ) matrices };
39     matrices        ::= matrix { matrix };
40     matrix          ::= [ real_number ] matrix_identifier [ index ];
41     matrix_identifier ::= "A" .. "Z" | "rot(" real_number ")";
42     index           ::= "^{" index_content "}" | "^" index_content | "t";
43     index_content   ::= integer_not_zero | "T";
44
45     digit_no_zero    ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
46     digit           ::= "0" | digit_no_zero;
47     digits          ::= digit | digits digit;
48     integer_not_zero ::= [ "-" ] digit_no_zero [ digits ];
49     real_number      ::= ( integer_not_zero [ "." digits ] | [ "-" ] [ "0" ] "." digits );

```

to the new version:

```

# fd80d8d3b0e975e92dcc7c10f1f0f1276879f408
# src/lintrans/_parse/matrices.py

52 def validate_matrix_expression(expression: str) -> bool:
...
59     Here is the schema for a valid expression given in a version of BNF:
...
61     expression      ::= [ "-" ] matrices { ( "+" | "-" ) matrices };
62     matrices        ::= matrix { matrix };
63     matrix          ::= [ real_number ] matrix_identifier [ index ];
64     matrix_identifier ::= "A" .. "Z" | "rot(" [ "-" ] real_number ")";
65     index           ::= "^{" index_content "}" | "^" index_content | "t";
66     index_content   ::= [ "-" ] integer_not_zero | "T";
67
68     digit_no_zero    ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
69     digit           ::= "0" | digit_no_zero;
70     digits          ::= digit | digits digit;
71     integer_not_zero ::= digit_no_zero [ digits ];
72     real_number      ::= ( integer_not_zero [ "." digits ] | [ "-" ] [ "0" ] "." digits );

```

Then once I'd fixed the validation, I could implement the parser itself.

```

# fd80d8d3b0e975e92dcc7c10f1f0f1276879f408
# src/lintrans/_parse/matrices.py

```

```

86 def parse_matrix_expression(expression: str) -> MatrixParseList:
87     """Parse the matrix expression and return a list of results.
88
89     The return value is a list of results. This results list contains lists of tuples.
90     The top list is the expressions that should be added together, and each sublist
91     is expressions that should be multiplied together. These expressions to be
92     multiplied are tuples, where each tuple is (multiplier, matrix identifier, index).
93     The multiplier can be any real number, the matrix identifier is either a named
94     matrix or a new rotation matrix declared with 'rot()', and the index is an
95     integer or 'T' for transpose.
96
97     :param str expression: The expression to be parsed
98     :returns MatrixParseTuple: A list of results
99     """
100     # Remove all whitespace
101     expression = re.sub(r'\s', '', expression)
102
103     # Check if it's valid
104     if not validate_matrix_expression(expression):
105         raise MatrixParseError('Invalid expression')
106
107     # Wrap all exponents and transposition powers with {}
108     expression = re.sub(r'(?<=\^)(-?\d+|T)(?=[^}]|$\)', r'{\g<0>}', expression)
109
110     # Remove any standalone minuses
111     expression = re.sub(r'-(?=[A-Z])', '-1', expression)
112
113     # Replace subtractions with additions
114     expression = re.sub(r'-(?=\d+\.?\d*([A-Z]|rot))', '+-', expression)
115
116     # Get rid of a potential leading + introduced by the last step
117     expression = re.sub(r'^+', '', expression)
118
119     return [
120         [
121             # The tuple returned by re.findall is (multiplier, matrix identifier, full index, stripped index),
122             # so we have to remove the full index, which contains the {}
123             (t[0], t[1], t[3])
124             for t in re.findall(r'(-?\d+\.?\d*)?([A-Z]|rot\(-?\d+\.?\d*\))(\^{\(-?\d+|T\)})?', group)
125         ]
126         # We just split the expression by '+' to have separate groups
127         for group in expression.split('+')
128     ]

```

It works similarly to the old `MatrixWrapper.parse_expression()` method in §3.1.2 but with a powerful list comprehension at the end. It splits the expression up into groups and then uses some RegEx magic to find all the matrices in these groups as a tuple.

This method passes all the unit tests, as expected.

My next step was then to rewrite the evaluation to use this new parser, like so (method name and docstring removed):

```

# a453774bcd824676461f9b9b441d7b94969ea55
# src/lintrans/matrices/wrapper.py

22 class MatrixWrapper:
...
147     def evaluate_expression(self, expression: str) -> MatrixType:
...
168         if not self.is_valid_expression(expression):
169             raise ValueError('The expression is invalid')
170
171         parsed_result = _parse.parse_matrix_expression(expression)
172         final_groups: list[list[MatrixType]] = []
173
174         for group in parsed_result:
175             f_group: list[MatrixType] = []
176

```

```
177     for matrix in group:
178         if matrix[2] == 'T':
179             m = self[matrix[1]]
180             assert m is not None
181             matrix_value = m.T
182         else:
183             matrix_value = np.linalg.matrix_power(self[matrix[1]],
184                                                    1 if (index := matrix[2]) == '1' else int(index))
185
186         matrix_value *= 1 if (multiplier := matrix[0]) == '1' else float(multiplier)
187         f_group.append(matrix_value)
188
189     final_groups.append(f_group)
190
191     return reduce(add, [reduce(matmul, group) for group in final_groups])
```

Here, we go through the list of tuples and evaluate the matrix represented by each tuple, putting this together in a list as we go. Then at the end, we simply reduce the sublists and then reduce these new matrices using a list comprehension in the `reduce()` call using `add` and `matmul` from the `operator` library. It's written in a functional programming style, and it passes all the previous tests.



## 3.2 Initial GUI

### 3.2.1 First basic GUI

The discrepancy in all the GUI code between `snake_case` and `camelCase` is because Qt5 was originally a C++ framework that was adapted into PyQt5 for Python. All the Qt API is in `camelCase`, but my Python code is in `snake_case`.

```
# 93ce763f7b993439fc0da89fad39456d8cc4b52c
# src/lintrans/gui/main_window.py

1  """The module to provide the main window as a QMainWindow object."""
2
3  import sys
4
5  from PyQt5 import QtCore, QtGui, QtWidgets
6  from PyQt5.QtWidgets import QApplication, QHBoxLayout, QMainWindow, QVBoxLayout
7
8  from lintrans.matrices import MatrixWrapper
9
10
11 class LintransMainWindow(QMainWindow):
12     """The class for the main window in the lintrans GUI."""
13
14     def __init__(self):
15         """Create the main window object, creating every widget in it."""
16         super().__init__()
17
18         self.matrix_wrapper = MatrixWrapper()
19
20         self.setWindowTitle('Linear Transformations')
21         self.setMinimumWidth(750)
22
23         # === Create widgets
24
25         # Left layout: the plot and input box
26
27         # NOTE: This QGraphicsView is only temporary
28         self.plot = QtWidgets.QGraphicsView(self)
29
30         self.text_input_expression = QtWidgets.QLineEdit(self)
31         self.text_input_expression.setPlaceholderText('Input matrix expression...')
32         self.text_input_expression.textChanged.connect(self.update_render_buttons)
33
34         # Right layout: all the buttons
35
36         # Misc buttons
37
38         self.button_create_polygon = QtWidgets.QPushButton(self)
39         self.button_create_polygon.setText('Create polygon')
40         # TODO: Implement create_polygon()
41         # self.button_create_polygon.clicked.connect(self.create_polygon)
42         self.button_create_polygon.setToolTip('Define a new polygon to view the transformation of')
43
44         self.button_change_display_settings = QtWidgets.QPushButton(self)
45         self.button_change_display_settings.setText('Change\ndisplay settings')
46         # TODO: Implement change_display_settings()
47         # self.button_change_display_settings.clicked.connect(self.change_display_settings)
48         self.button_change_display_settings.setToolTip('Change which things are rendered on the plot')
49
50         # Define new matrix buttons
51
52         self.label_define_new_matrix = QtWidgets.QLabel(self)
53         self.label_define_new_matrix.setText('Define a\nnew matrix')
54         self.label_define_new_matrix.setAlignment(QtCore.Qt.AlignCenter)
55
56         # TODO: Implement defining a new matrix visually, numerically, as a rotation, and as an expression
57
58         self.button_define_visually = QtWidgets.QPushButton(self)
59         self.button_define_visually.setText('Visually')
```

```

60     self.button_define_visually.setToolTip('Drag the basis vectors')
61
62     self.button_define_numerically = QtWidgets.QPushButton(self)
63     self.button_define_numerically.setText('Numerically')
64     self.button_define_numerically.setToolTip('Define a matrix just with numbers')
65
66     self.button_define_as_rotation = QtWidgets.QPushButton(self)
67     self.button_define_as_rotation.setText('As a rotation')
68     self.button_define_as_rotation.setToolTip('Define an angle to rotate by')
69
70     self.button_define_as_expression = QtWidgets.QPushButton(self)
71     self.button_define_as_expression.setText('As an expression')
72     self.button_define_as_expression.setToolTip('Define a matrix in terms of other matrices')
73
74     # Render buttons
75
76     self.button_render = QtWidgets.QPushButton(self)
77     self.button_render.setText('Render')
78     self.button_render.setEnabled(False)
79     self.button_render.clicked.connect(self.render_expression)
80     self.button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
81
82     self.button_render_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self)
83     self.button_render_shortcut.activated.connect(self.button_render.click)
84
85     self.button_animate = QtWidgets.QPushButton(self)
86     self.button_animate.setText('Animate')
87     self.button_animate.setEnabled(False)
88     self.button_animate.clicked.connect(self.animate_expression)
89     self.button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
90
91     self.button_animate_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Shift+Return'), self)
92     self.button_animate_shortcut.activated.connect(self.button_animate.click)
93
94     # === Arrange widgets
95
96     self.setContentsMargins(10, 10, 10, 10)
97
98     self.vlay_left = QVBoxLayout()
99     self.vlay_left.addWidget(self.plot)
100    self.vlay_left.addWidget(self.text_input_expression)
101
102    self.vlay_misc_buttons = QVBoxLayout()
103    self.vlay_misc_buttons.setSpacing(20)
104    self.vlay_misc_buttons.addWidget(self.button_create_polygon)
105    self.vlay_misc_buttons.addWidget(self.button_change_display_settings)
106
107    self.vlay_define_new_matrix = QVBoxLayout()
108    self.vlay_define_new_matrix.setSpacing(20)
109    self.vlay_define_new_matrix.addWidget(self.label_define_new_matrix)
110    self.vlay_define_new_matrix.addWidget(self.button_define_visually)
111    self.vlay_define_new_matrix.addWidget(self.button_define_numerically)
112    self.vlay_define_new_matrix.addWidget(self.button_define_as_rotation)
113    self.vlay_define_new_matrix.addWidget(self.button_define_as_expression)
114
115    self.vlay_render = QVBoxLayout()
116    self.vlay_render.setSpacing(20)
117    self.vlay_render.addWidget(self.button_animate)
118    self.vlay_render.addWidget(self.button_render)
119
120    self.vlay_right = QVBoxLayout()
121    self.vlay_right.setSpacing(50)
122    self.vlay_right.addLayout(self.vlay_misc_buttons)
123    self.vlay_right.addLayout(self.vlay_define_new_matrix)
124    self.vlay_right.addLayout(self.vlay_render)
125
126    self.hlay_all = QHBoxLayout()
127    self.hlay_all.setSpacing(15)
128    self.hlay_all.addLayout(self.vlay_left)
129    self.hlay_all.addLayout(self.vlay_right)
130
131    self.central_widget = QtWidgets.QWidget()
132    self.central_widget.setLayout(self.hlay_all)

```

```

133         self.setCentralWidget(self.central_widget)
134
135     def update_render_buttons(self) -> None:
136         """Enable or disable the render and animate buttons according to the validity of the matrix expression."""
137         valid = self.matrix_wrapper.is_valid_expression(self.text_input_expression.text())
138         self.button_render.setEnabled(valid)
139         self.button_animate.setEnabled(valid)
140
141     def render_expression(self) -> None:
142         """Render the expression in the input box, and then clear the box."""
143         # TODO: Render the expression
144         self.text_input_expression.setText('')
145
146     def animate_expression(self) -> None:
147         """Animate the expression in the input box, and then clear the box."""
148         # TODO: Animate the expression
149         self.text_input_expression.setText('')
150
151
152 def main() -> None:
153     """Run the GUI."""
154     app = QApplication(sys.argv)
155     window = LintransMainWindow()
156     window.show()
157     sys.exit(app.exec_())
158
159
160 if __name__ == '__main__':
161     main()

```

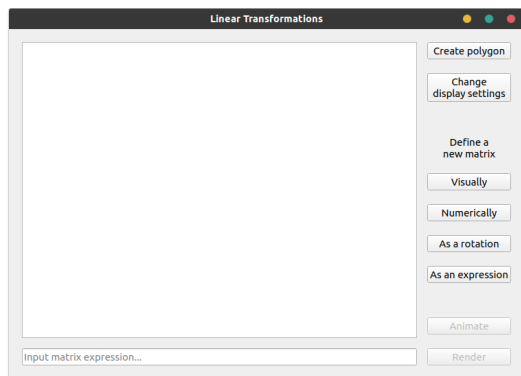


Figure 3.1: The first version of the GUI

A lot of the methods here don't have implementations yet, but they will. This version is just a very early prototype to get a rough draft of the GUI.

I create the widgets and layouts in the constructor as well as configuring all of them. The most important non-constructor method is `update_render_buttons()`. It gets called whenever the text in `text_input_expression` is changed. This happens because we connect it to the `textChanged` signal on line 32.

The big white box here will eventually be replaced with an actual viewport. This is just a prototype.

### 3.2.2 Numerical definition dialog

My next major addition was a dialog that would allow the user to define a matrix numerically.

```

# cedbd3ed126a1183f197c27adf6dabb4e5d301c7
# src/lintrans/gui/dialogs/define_new_matrix.py

1 """The module to provide dialogs for defining new matrices."""
2
3 from numpy import array
4 from PyQt5 import QtGui, QtWidgets
5 from PyQt5.QtWidgets import QDialog, QGridLayout, QHBoxLayout, QVBoxLayout
6
7 from lintrans.matrices import MatrixWrapper
8
9 ALPHABET_NO_I = 'ABCDEFGHJKLMNPOQRSTUVWXYZ'
10
11
12 def is_float(string: str) -> bool:
13     """Check if a string is a float."""

```

```
14     try:
15         float(string)
16         return True
17     except ValueError:
18         return False
19
20
21 class DefineNumericallyDialog(QDialog):
22     """The dialog class that allows the user to define a new matrix numerically."""
23
24     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
25         """Create the dialog, but don't run it yet.
26
27         :param matrix_wrapper: The MatrixWrapper that this dialog will mutate
28         :type matrix_wrapper: MatrixWrapper
29         """
30         super().__init__(*args, **kwargs)
31
32         self.matrix_wrapper = matrix_wrapper
33         self.setWindowTitle('Define a matrix')
34
35         # === Create the widgets
36
37         self.button_confirm = QtWidgets.QPushButton(self)
38         self.button_confirm.setText('Confirm')
39         self.button_confirm.setEnabled(False)
40         self.button_confirm.clicked.connect(self.confirm_matrix)
41         self.button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
42
43         QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
44
45         self.button_cancel = QtWidgets.QPushButton(self)
46         self.button_cancel.setText('Cancel')
47         self.button_cancel.clicked.connect(self.close)
48         self.button_cancel.setToolTip('Cancel this definition<br><b>(Ctrl + Q)</b>')
49
50         QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Q'), self).activated.connect(self.button_cancel.click)
51
52         self.element_tl = QtWidgets.QLineEdit(self)
53         self.element_tl.textChanged.connect(self.update_confirm_button)
54
55         self.element_tr = QtWidgets.QLineEdit(self)
56         self.element_tr.textChanged.connect(self.update_confirm_button)
57
58         self.element_bl = QtWidgets.QLineEdit(self)
59         self.element_bl.textChanged.connect(self.update_confirm_button)
60
61         self.element_br = QtWidgets.QLineEdit(self)
62         self.element_br.textChanged.connect(self.update_confirm_button)
63
64         self.matrix_elements = (self.element_tl, self.element_tr, self.element_bl, self.element_br)
65
66         self.letter_combo_box = QtWidgets.QComboBox(self)
67
68         # Everything except I, because that's the identity
69         for letter in ALPHABET_NO_I:
70             self.letter_combo_box.addItem(letter)
71
72         self.letter_combo_box.activated.connect(self.load_matrix)
73
74         # === Arrange the widgets
75
76         self.setContentsMargins(10, 10, 10, 10)
77
78         self.grid_matrix = QGridLayout()
79         self.grid_matrix.setSpacing(20)
80         self.grid_matrix.addWidget(self.element_tl, 0, 0)
81         self.grid_matrix.addWidget(self.element_tr, 0, 1)
82         self.grid_matrix.addWidget(self.element_bl, 1, 0)
83         self.grid_matrix.addWidget(self.element_br, 1, 1)
84
85         self.hlay_buttons = QHBoxLayout()
86         self.hlay_buttons.setSpacing(20)
```

```

87     self.hlay_buttons.addWidget(self.button_cancel)
88     self.hlay_buttons.addWidget(self.button_confirm)
89
90     self.vlay_right = QVBoxLayout()
91     self.vlay_right.setSpacing(20)
92     self.vlay_right.addLayout(self.grid_matrix)
93     self.vlay_right.addLayout(self.hlay_buttons)
94
95     self.hlay_all = QHBoxLayout()
96     self.hlay_all.setSpacing(20)
97     self.hlay_all.addWidget(self.letter_combo_box)
98     self.hlay_all.addLayout(self.vlay_right)
99
100    self.setLayout(self.hlay_all)
101
102    # Finally, we load the default matrix A into the boxes
103    self.load_matrix(0)
104
105    def update_confirm_button(self) -> None:
106        """Enable the confirm button if there are numbers in every box."""
107        for elem in self.matrix_elements:
108            if elem.text() == '' or not is_float(elem.text()):
109                # If they're not all numbers, then we can't confirm it
110                self.button_confirm.setEnabled(False)
111                return
112
113        # If we didn't find anything invalid
114        self.button_confirm.setEnabled(True)
115
116    def load_matrix(self, index: int) -> None:
117        """If the selected matrix is defined, load it into the boxes."""
118        matrix = self.matrix_wrapper[ALPHABET_NO_I[index]]
119
120        if matrix is None:
121            for elem in self.matrix_elements:
122                elem.setText('')
123
124        else:
125            self.element_tl.setText(str(matrix[0][0]))
126            self.element_tr.setText(str(matrix[0][1]))
127            self.element_bl.setText(str(matrix[1][0]))
128            self.element_br.setText(str(matrix[1][1]))
129
130        self.update_confirm_button()
131
132    def confirm_matrix(self) -> None:
133        """Confirm the inputted matrix and assign it to the name."""
134        letter = self.letter_combo_box.currentText()
135        matrix = array([
136            [float(self.element_tl.text()), float(self.element_tr.text())],
137            [float(self.element_bl.text()), float(self.element_br.text())]
138        ])
139
140        self.matrix_wrapper[letter] = matrix
141        self.close()

```

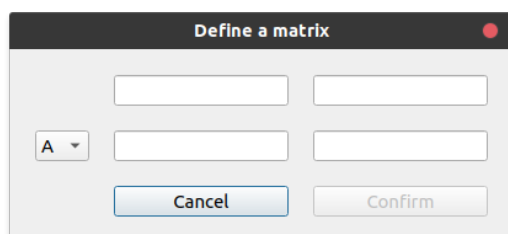


Figure 3.2: The first version of the numerical definition dialog

When I add more definition dialogs, I will factor out a superclass, but this is just a prototype to make sure it all works as intended.

Hopefully the methods are relatively self explanatory, but they're just utility methods to update the GUI when things are changed. We connect the QLineEdit widgets to the `update_confirm_button()` slot to make sure the confirm button is always up to date.

The `confirm_matrix()` method just updates the instance's matrix wrapper with the new matrix. We

pass a reference to the `LintransMainWindow` instance's matrix wrapper when we open the dialog, so we're just updating the referenced object directly.

In the `LintransMainWindow` class, we're just connecting a lambda slot to the button so that it opens the dialog, as seen here:

```
# cedbd3ed126a1183f197c27adf6dabb4e5d301c7
# src/lintrans/gui/main_window.py

12 class LintransMainWindow(QMainWindow):
13 ...
14
15     def __init__(self):
16 ...
17
18         self.button_define_numerically.clicked.connect(
19             lambda: DefineNumericallyDialog(self.matrix_wrapper, self).exec()
20         )
21
22
```

### 3.2.3 More definition dialogs

I then factored out the constructor into a `DefineDialog` superclass so that I could easily create other definition dialogs.

```
# 5d04fb7233a03d0cd8fa0768f6387c6678da9df3
# src/lintrans/gui/dialogs/define_new_matrix.py

22 class DefineDialog(QDialog):
23     """A superclass for definitions dialogs."""
24
25     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
26         """Create the dialog, but don't run it yet.
27
28         :param matrix_wrapper: The MatrixWrapper that this dialog will mutate
29         :type matrix_wrapper: MatrixWrapper
30         """
31         super().__init__(*args, **kwargs)
32
33         self.matrix_wrapper = matrix_wrapper
34         self.setWindowTitle('Define a matrix')
35
36         # === Create the widgets
37
38         self.button_confirm = QtWidgets.QPushButton(self)
39         self.button_confirm.setText('Confirm')
40         self.button_confirm.setEnabled(False)
41         self.button_confirm.clicked.connect(self.confirm_matrix)
42         self.button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
43         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
44
45         self.button_cancel = QtWidgets.QPushButton(self)
46         self.button_cancel.setText('Cancel')
47         self.button_cancel.clicked.connect(self.close)
48         self.button_cancel.setToolTip('Cancel this definition<br><b>(Ctrl + Q)</b>')
49         QShortcut(QKeySequence('Ctrl+Q'), self).activated.connect(self.button_cancel.click)
50
51         self.label_equals = QtWidgets.QLabel()
52         self.label_equals.setText('=')
53
54         self.letter_combo_box = QtWidgets.QComboBox(self)
55
56         # Everything except I, because that's the identity
57         for letter in ALPHABET_NO_I:
58             self.letter_combo_box.addItem(letter)
59
60         self.letter_combo_box.activated.connect(self.load_matrix)
61
```

This superclass just has a constructor that subclasses can use. When I added the `DefineAsARotationDialog`

class, I also moved the cancel and confirm buttons into the constructor and added abstract methods that all dialog subclasses must implement.

```
# 0d534c35c6a4451e317d41a0d2b3ecb17827b45f
# src/lintrans/gui/dialogs/define_new_matrix.py
```

```
24 class DefineDialog(QDialog):
...
27     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
...
61         # === Arrange the widgets
62
63         self.setContentsMargins(10, 10, 10, 10)
64
65         self.horizontal_spacer = QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum)
66
67         self.hlay_buttons = QHBoxLayout()
68         self.hlay_buttons.setSpacing(20)
69         self.hlay_buttons.addItem(self.horizontal_spacer)
70         self.hlay_buttons.addWidget(self.button_cancel)
71         self.hlay_buttons.addWidget(self.button_confirm)
72
73     @property
74     def selected_letter(self) -> str:
75         """The letter currently selected in the combo box."""
76         return self.letter_combo_box.currentText()
77
78     @abc.abstractmethod
79     def update_confirm_button(self) -> None:
80         """Enable the confirm button if it should be enabled."""
81         ...
82
83     @abc.abstractmethod
84     def confirm_matrix(self) -> None:
85         """Confirm the inputted matrix and assign it.
86
87         This should mutate self.matrix_wrapper and then call self.accept().
88         """
89         ...
```

I then added the class for the rotation definition dialog.

```
# 0d534c35c6a4451e317d41a0d2b3ecb17827b45f
# src/lintrans/gui/dialogs/define_new_matrix.py
```

```
182 class DefineAsARotationDialog(DefineDialog):
183     """The dialog that allows the user to define a new matrix as a rotation."""
184
185     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
186         """Create the dialog, but don't run it yet."""
187         super().__init__(matrix_wrapper, *args, **kwargs)
188
189         # === Create the widgets
190
191         self.label_equals.setText('= rot(')
192
193         self.text_angle = QtWidgets.QLineEdit(self)
194         self.text_angle.setPlaceholderText('angle')
195         self.text_angle.textChanged.connect(self.update_confirm_button)
196
197         self.label_close_paren = QtWidgets.QLabel(self)
198         self.label_close_paren.setText(')')
199
200         self.checkbox_radians = QtWidgets.QCheckBox(self)
201         self.checkbox_radians.setText('Radians')
202
203         # === Arrange the widgets
204
205         self.hlay_checkbox_and_buttons = QHBoxLayout()
206         self.hlay_checkbox_and_buttons.setSpacing(20)
```

```

207     self.hlay_checkbox_and_buttons.addWidget(self.checkbox_radians)
208     self.hlay_checkbox_and_buttons.addItem(self.horizontal_spacer)
209     self.hlay_checkbox_and_buttons.addLayout(self.hlay_buttons)
210
211     self.hlay_definition = QHBoxLayout()
212     self.hlay_definition.addWidget(self.letter_combo_box)
213     self.hlay_definition.addWidget(self.label_equals)
214     self.hlay_definition.addWidget(self.text_angle)
215     self.hlay_definition.addWidget(self.label_close_paren)
216
217     self.vlay_all = QVBoxLayout()
218     self.vlay_all.setSpacing(20)
219     self.vlay_all.addLayout(self.hlay_definition)
220     self.vlay_all.addLayout(self.hlay_checkbox_and_buttons)
221
222     self.setLayout(self.vlay_all)
223
224     def update_confirm_button(self) -> None:
225         """Enable the confirm button if there is a valid float in the angle box."""
226         self.button_confirm.setEnabled(is_float(self.text_angle.text()))
227
228     def confirm_matrix(self) -> None:
229         """Confirm the inputted matrix and assign it."""
230         self.matrix_wrapper[self.selected_letter] = create_rotation_matrix(
231             float(self.text_angle.text()),
232             degrees=not self.checkbox_radians.isChecked()
233         )
234         self.accept()

```

This dialog class just overrides the abstract methods of the superclass with its own implementations. This will be the pattern that all of the definition dialogs will follow.

It has a checkbox for radians, since this is supported in `create_rotation_matrix()`, but the textbox only supports numbers, so the user would have to calculate some multiple of  $\pi$  and paste in several decimal places. I expect people to only use degrees, because these are easier to use.

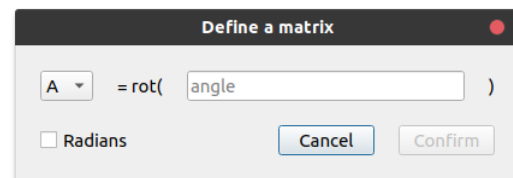


Figure 3.3: The first version of the rotation definition dialog

Additionally, I created a helper method in `LintransMainWindow`. Rather than connecting the clicked signal of the buttons to lambdas that instantiate an instance of the `DefineDialog` subclass and call `.exec()` on it, I now connect the clicked signal of the buttons to lambdas that call `self.dialog_define_matrix()` with the specific subclass.

```

# 6269e04d453df7be2d2f9c7ee176e83406ccc139
# src/lintrans/gui/main_window.py

17 class LintransMainWindow(QMainWindow):
18     ...
19
20     def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
21         """Open a generic definition dialog to define a new matrix.
22
23         The class for the desired dialog is passed as an argument. We create an
24         instance of this class and the dialog is opened asynchronously and modally
25         (meaning it blocks interaction with the main window) with the proper method
26         connected to the ``dialog.finished`` slot.
27
28         .. note::
29             ``dialog_class`` must subclass :class:`lintrans.gui.dialogs.define_new_matrix.DefineDialog`.
30
31         :param dialog_class: The dialog class to instantiate
32         :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineDialog]
33         """
34         # We create a dialog with a deepcopy of the current matrix_wrapper
35         # This avoids the dialog mutating this one

```



```

186         dialog = dialog_class(deepcopy(self.matrix_wrapper), self)
187
188         # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
189         dialog.open()
190
191         # So we have to use the finished slot to call a method when the user accepts the dialog
192         # If the user rejects the dialog, this matrix_wrapper will be the same as the current one, because we copied
193         ↪ it
194         # So we don't care, we just assign the wrapper anyway
195         dialog.finished.connect(lambda: self._assign_matrix_wrapper(dialog.matrix_wrapper))
196
197     def _assign_matrix_wrapper(self, matrix_wrapper: MatrixWrapper) -> None:
198         """Assign a new value to self.matrix_wrapper.
199
200         This is a little utility function that only exists because a lambda
201         callback can't directly assign a value to a class attribute.
202
203         :param matrix_wrapper: The new value of the matrix wrapper to assign
204         :type matrix_wrapper: MatrixWrapper
205         """
206         self.matrix_wrapper = matrix_wrapper

```

I also then implemented a simple DefineAsAnExpressionDialog, which evaluates a given expression in the current MatrixWrapper context and assigns the result to the given matrix name.

```

# d5f930e15c3c8798d4990486532da46e926a6cb9
# src/lintrans/gui/dialogs/define_new_matrix.py

241 class DefineAsAnExpressionDialog(DefinedDialog):
242     """The dialog that allows the user to define a matrix as an expression."""
243
244     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
245         """Create the dialog, but don't run it yet."""
246         super().__init__(matrix_wrapper, *args, **kwargs)
247
248         self.setMinimumWidth(450)
249
250         # === Create the widgets
251
252         self.text_box_expression = QtWidgets.QLineEdit(self)
253         self.text_box_expression.setPlaceholderText('Enter matrix expression...')
254         self.text_box_expression.textChanged.connect(self.update_confirm_button)
255
256         # === Arrange the widgets
257
258         self.hlay_definition.addWidget(self.text_box_expression)
259
260         self.vlay_all = QVBoxLayout()
261         self.vlay_all.setSpacing(20)
262         self.vlay_all.addLayout(self.hlay_definition)
263         self.vlay_all.addLayout(self.hlay_buttons)
264
265         self.setLayout(self.vlay_all)
266
267     def update_confirm_button(self) -> None:
268         """Enable the confirm button if the expression is valid."""
269         self.button_confirm.setEnabled(
270             self.matrix_wrapper.is_valid_expression(self.text_box_expression.text())
271         )
272
273     def confirm_matrix(self) -> None:
274         """Evaluate the matrix expression and assign its value to the chosen matrix."""
275         self.matrix_wrapper[self.selected_letter] = \
276             self.matrix_wrapper.evaluate_expression(self.text_box_expression.text())
277         self.accept()

```

My next dialog that I wanted to implement was a visual definition dialog, which would allow the user to drag around the basis vectors to define a transformation. However, I would first need to create the lintrans.gui.plots package to allow for actually visualizing matrices and transformations.

### 3.3 Visualizing matrices

#### 3.3.1 Asking strangers on the internet for help

After creating most of the GUI skeleton, I wanted to build the viewport. Unfortunately, I had no idea what I was doing.

While looking through the PyQt5 docs, I found a pretty comprehensive explanation of the Qt5 ‘Graphics View Framework’[16], which seemed pretty good, but not really what I was looking for. I wanted a way to easily draw lots of straight, parallel lines. This framework seemed more focussed on manipulating objects on a canvas, almost like sprites. I knew of a different Python library called `matplotlib`, which has various backends available. I learned that it could be embedded in a standard PyQt5 GUI, so I started doing some research.

I didn’t get very far with `matplotlib`. I hadn’t used it much before and it’s designed for visualizing data. It can draw manually defined straight lines on a canvas, but that’s not what it’s designed for and it’s not very good at it. Thankfully, my horrific `matplotlib` code has been lost to time. I used the `Qt5Agg` backend from `matplotlib` to create a custom PyQt5 widget for the GUI and I could graph randomly generated data with it after following a tutorial[15].

I realised that I wasn’t going to get very far with `matplotlib`, but I didn’t know what else to do. I couldn’t find any relevant examples on the internet, so I decided to post a question on a forum myself. I’d had experience with StackOverflow and its unfriendly community before, so I decided to ask the `r/learnpython` subreddit[3].

I only got one response, but it was incredibly helpful. The person told me that if I couldn’t find an easy way to do what I wanted, I could write a custom PyQt5 widget. I knew this was possible with a class that just inherited from `QWidget`, but had no idea how to actually make something useful. Thankfully, this person provided a link to a GitLab repository of theirs, where they had multiple examples of custom widgets with PyQt5[4].

When looking through this repo, I found out how to draw on a widget like a simple canvas. All I have to do is override the `paintEvent()` method and use a `QPainter` object to draw on the widget. I used this knowledge to start creating the actual viewport for the GUI, starting with the background axes.

#### 3.3.2 Creating the plots package

Initially, the `lintrans.gui.plots` package just has some classes for widgets. `TransformationPlotWidget` acts as a base class and then `ViewTransformationWidget` acts as a wrapper. I will expand this class in the future.

```
# 4af63072b383dc9cef9adbb8900323aa007e7f26
# src/lintrans/gui/plots/plot_widget.py

1 """This module provides the basic classes for plotting transformations."""
2
3 from __future__ import annotations
4
5 from PyQt5.QtCore import Qt
6 from PyQt5.QtGui import QColor, QPainter, QPaintEvent, QPen
7 from PyQt5.QtWidgets import QWidget
8
9
10 class TransformationPlotWidget(QWidget):
11     """An abstract superclass for plot widgets.
12
13     This class provides a background (untransformed) plane, and all the backend
14     details for a Qt application, but does not provide useful functionality. To
15     be useful, this class must be subclassed and behaviour must be implemented
16     by the subclass.
```

```

17
18 .. warning:: This class should never be directly instantiated, only subclassed.
19
20 .. note::
21     I would make this class have ``metaclass=abc.ABCMeta``, but I can't because it subclasses ``QWidget``,
22     and a every superclass of a class must have the same metaclass, and ``QWidget`` is not an abstract class.
23     """
24
25 def __init__(self, *args, **kwargs):
26     """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor (``QWidget``)."""
27     super().__init__(*args, **kwargs)
28
29     self.setAutoFillBackground(True)
30
31     # Set the background to white
32     palette = self.palette()
33     palette.setColor(self.backgroundRole(), Qt.white)
34     self.setPalette(palette)
35
36     # Set the grid colour to grey and the axes colour to black
37     self.grid_colour = QColor(128, 128, 128)
38     self.axes_colour = QColor(0, 0, 0)
39
40     self.grid_spacing: int = 50
41     self.line_width: float = 0.4
42
43 @property
44 def w(self) -> int:
45     """Return the width of the widget."""
46     return self.size().width()
47
48 @property
49 def h(self) -> int:
50     """Return the height of the widget."""
51     return self.size().height()
52
53 def paintEvent(self, e: QPaintEvent):
54     """Handle a ``QPaintEvent`` by drawing the widget."""
55     qp = QPainter()
56     qp.begin(self)
57     self.draw_widget(qp)
58     qp.end()
59
60 def draw_widget(self, qp: QPainter):
61     """Draw the grid and axes in the widget."""
62     qp.setRenderHint(QPainter.Antialiasing)
63     qp.setBrush(Qt.NoBrush)
64
65     # Draw the grid
66     qp.setPen(QPen(self.grid_colour, self.line_width))
67
68     # We draw the background grid, centered in the middle
69     # We deliberately exclude the axes - these are drawn separately
70     for x in range(self.w // 2 + self.grid_spacing, self.w, self.grid_spacing):
71         qp.drawLine(x, 0, x, self.h)
72         qp.drawLine(self.w - x, 0, self.w - x, self.h)
73
74     for y in range(self.h // 2 + self.grid_spacing, self.h, self.grid_spacing):
75         qp.drawLine(0, y, self.w, y)
76         qp.drawLine(0, self.h - y, self.w, self.h - y)
77
78     # Now draw the axes
79     qp.setPen(QPen(self.axes_colour, self.line_width))
80     qp.drawLine(self.w // 2, 0, self.w // 2, self.h)
81     qp.drawLine(0, self.h // 2, self.w, self.h // 2)
82
83
84 class ViewTransformationWidget(TransformationPlotWidget):
85     """This class is used to visualise matrices as transformations."""
86
87     def __init__(self, *args, **kwargs):
88         """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor."""
89         super().__init__(*args, **kwargs)

```

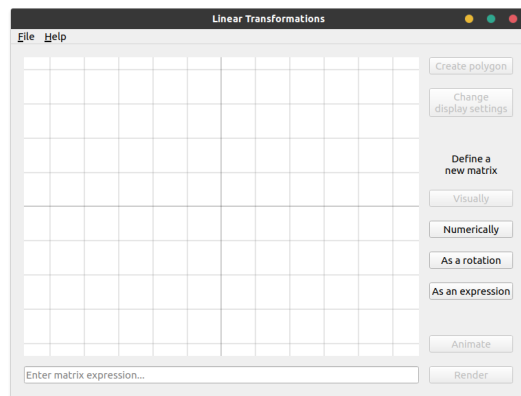


Figure 3.4: The GUI with background axes

The meat of this class is the `draw_widget()` method. Right now, this method only draws the background axes. My next step is to implement basis vector attributes and draw them in `draw_widget()`. After changing the the plot attribute in `LintransMainWindow` to an instance of `ViewTransformationWidget`, the plot was visible in the GUI.

I then refactored the code slightly to rename `draw_widget()` to `draw_background()` and then call it from the `paintEvent()` method in `ViewTransformationWidget`.

### 3.3.3 Implementing basis vectors

My first step in implementing basis vectors was to add some utility methods to convert between coordinate systems. The matrices are using Cartesian coordinates with (0,0) in the middle, positive  $x$  going to the right, and positive  $y$  going up. However, Qt5 is using standard computer graphics coordinates, with (0,0) in the top left, positive  $x$  going to the right, and positive  $y$  going down. I needed a way to convert Cartesian 'grid' coordinates to Qt5 'canvas' coordinates, so I wrote some little utility methods.

```
# 1fa7e1c61d61cb6aeff773b9698541f82fee39ea
# src/lintrans/gui/plots/plot_widget.py
```

```
12 class TransformationPlotWidget(QWidget):
...
45     @property
46     def origin(self) -> tuple[int, int]:
47         """Return the canvas coords of the origin."""
48         return self.width() // 2, self.height() // 2
49
50     def trans_x(self, x: float) -> int:
51         """Transform an x coordinate from grid coords to canvas coords."""
52         return int(self.origin[0] + x * self.grid_spacing)
53
54     def trans_y(self, y: float) -> int:
55         """Transform a y coordinate from grid coords to canvas coords."""
56         return int(self.origin[1] - y * self.grid_spacing)
57
58     def trans_coords(self, x: float, y: float) -> tuple[int, int]:
59         """Transform a coordinate in grid coords to canvas coords."""
60         return self.trans_x(x), self.trans_y(y)
```

Once I had a way to convert coordinates, I could add the basis vectors themselves. I did this by creating attributes for the points in the constructor and creating a `transform_by_matrix()` method to change these point attributes accordingly.

```
# 37e7c208a33d7cbbc8e0bb6c94cd889e2918c605
# src/lintrans/gui/plots/plot_widget.py
```

```
92 class ViewTransformationWidget(TransformationPlotWidget):
93     """This class is used to visualise matrices as transformations."""
94
95     def __init__(self, *args, **kwargs):
96         """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor."""
97         super().__init__(*args, **kwargs)
98
99         self.point_i: tuple[float, float] = (1., 0.)
100        self.point_j: tuple[float, float] = (0., 1.)
```

```

101
102     self.colour_i = QColor(37, 244, 15)
103     self.colour_j = QColor(8, 8, 216)
104
105     self.width_vector_line = 1
106     self.width_transformed_grid = 0.6
107
108     def transform_by_matrix(self, matrix: MatrixType) -> None:
109         """Transform the plane by the given matrix."""
110         self.point_i = (matrix[0][0], matrix[1][0])
111         self.point_j = (matrix[0][1], matrix[1][1])
112         self.update()

```

I also created a `draw_transformed_grid()` method which gets called in `paintEvent()`.

```

# 37e7c208a33d7cbbc8e0bb6c94cd889e2918c605
# src/lintrans/gui/plots/plot_widget.py

92 class ViewTransformationWidget(TransformationPlotWidget):
...
122     def draw_transformed_grid(self, painter: QPainter) -> None:
123         """Draw the transformed version of the grid, given by the unit vectors."""
124         # Draw the unit vectors
125         painter.setPen(QPen(self.colour_i, self.width_vector_line))
126         painter.drawLine(*self.origin, *self.trans_coords(*self.point_i))
127         painter.setPen(QPen(self.colour_j, self.width_vector_line))
128         painter.drawLine(*self.origin, *self.trans_coords(*self.point_j))

```

I then changed the `render_expression()` method in `LintransMainWindow` to call this new `transform_by_matrix()` method.

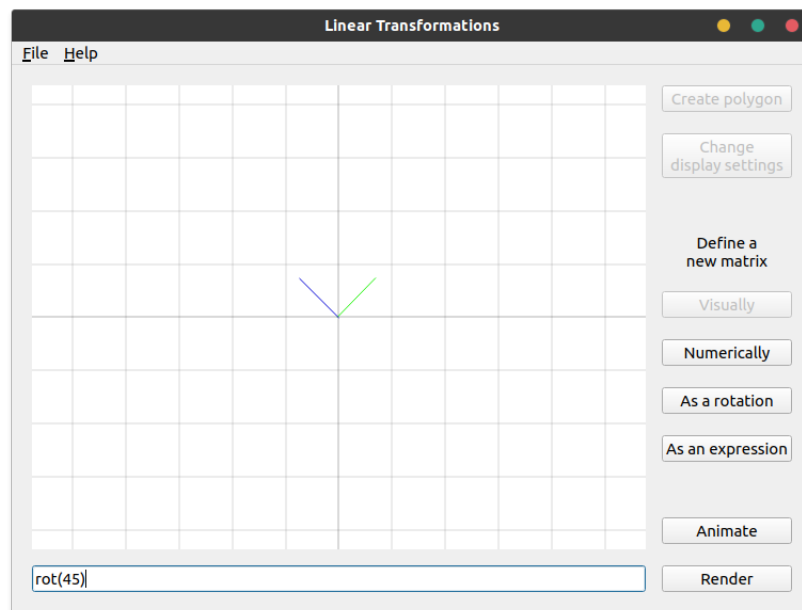
```

# 37e7c208a33d7cbbc8e0bb6c94cd889e2918c605
# src/lintrans/gui/main_window.py

19 class LintransMainWindow(QMainWindow):
...
229     def render_expression(self) -> None:
230         """Render the expression in the input box, and then clear the box."""
231         self.plot.transform_by_matrix(
232             self.matrix_wrapper.evaluate_expression(
233                 self.lineedit_expression_box.text()
234             )
235         )

```

Testing this new code shows that it works well.

Figure 3.5: Basis vectors drawn for a  $45^\circ$  rotation

### 3.3.4 Drawing the transformed grid

After drawing the basis vectors, I wanted to draw the transformed version of the grid. I first created a `grid_corner()` utility method to return the grid coordinates of the top right corner of the canvas. This allows me to find the bounding box in which to draw the grid lines.

```
# 2ade98ac28d1c3f6691e4afa819142a3ab8e9fd9
# src/lintrans/gui/plots/plot_widget.py
```

```
14 class TransformationPlotWidget(QWidget):
...
64     def grid_corner(self) -> tuple[float, float]:
65         """Return the grid coords of the top right corner."""
66         return self.width() / (2 * self.grid_spacing), self.height() / (2 * self.grid_spacing)
```

I then created a `draw_parallel_lines()` method that would fill the bounding box with a set of lines parallel to a given vector with spacing defined by the intersection with a given point.

```
# 2ade98ac28d1c3f6691e4afa819142a3ab8e9fd9
# src/lintrans/gui/plots/plot_widget.py
```

```
96 class ViewTransformationWidget(TransformationPlotWidget):
...
126     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
    ↪ None:
127         """Draw a set of grid lines parallel to ``vector`` intersecting ``point``."""
128         max_x, max_y = self.grid_corner()
129         vector_x, vector_y = vector
130         point_x, point_y = point
131
132         if vector_x == 0:
133             painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
134
135         for i in range(int(max_x / point_x)):
136             painter.drawLine(
137                 self.trans_x((i + 1) * point_x),
138                 0,
139                 self.trans_x((i + 1) * point_x),
```

```

140         self.height()
141     )
142     painter.drawLine(
143         self.trans_x(-1 * (i + 1) * point_x),
144         0,
145         self.trans_x(-1 * (i + 1) * point_x),
146         self.height()
147     )
148
149     elif vector_y == 0:
150         painter.drawLine(0, self.trans_y(0), self.width(), self.trans_y(0))
151
152     for i in range(int(max_y / point_y)):
153         painter.drawLine(
154             0,
155             self.trans_y((i + 1) * point_y),
156             self.width(),
157             self.trans_y((i + 1) * point_y)
158         )
159         painter.drawLine(
160             0,
161             self.trans_y(-1 * (i + 1) * point_y),
162             self.width(),
163             self.trans_y(-1 * (i + 1) * point_y)
164         )

```

I then called this method from `draw_transformed_grid()`.

```

# 2ade98ac28d1c3f6691e4afa819142a3ab8e9fd9
# src/lintrans/gui/plots/plot_widget.py

```

```

96 class ViewTransformationWidget(TransformationPlotWidget):
97     ...
166     def draw_transformed_grid(self, painter: QPainter) -> None:
167         """Draw the transformed version of the grid, given by the unit vectors."""
168         # Draw the unit vectors
169         painter.setPen(QPen(self.colour_i, self.width_vector_line))
170         painter.drawLine(*self.origin, *self.trans_coords(*self.point_i))
171         painter.setPen(QPen(self.colour_j, self.width_vector_line))
172         painter.drawLine(*self.origin, *self.trans_coords(*self.point_j))
173
174         # Draw all the parallel lines
175         painter.setPen(QPen(self.colour_i, self.width_transformed_grid))
176         self.draw_parallel_lines(painter, self.point_i, self.point_j)
177         painter.setPen(QPen(self.colour_j, self.width_transformed_grid))
178         self.draw_parallel_lines(painter, self.point_j, self.point_i)

```

This worked quite well when the matrix involved no rotation, as seen on the right, but this didn't work with rotation. When trying `'rot(45)'` for example, it looked the same as in Figure 3.5.

Also, the vectors aren't particularly clear. They'd be much better with arrowheads on their tips, but this is just a prototype. The arrowheads will come later.

My next step was to make the transformed grid lines work with rotations.

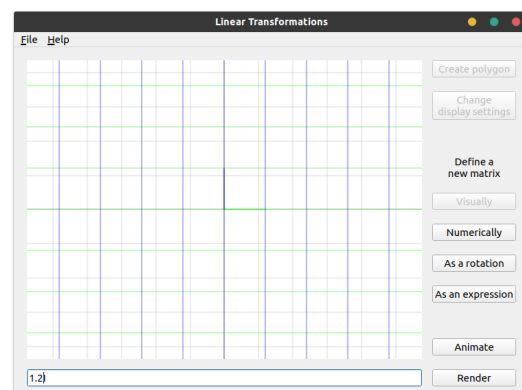


Figure 3.6: Parallel lines being drawn for matrix 1.2

```

# 7dfe1e24729562501e2fd88a839dca6b653a3375
# src/lintrans/gui/plots/plot_widget.py

```

```
96 class ViewTransformationWidget(TransformationPlotWidget):
97 ...
126 def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
    ↪ None:
127     """Draw a set of grid lines parallel to ``vector`` intersecting ``point``."""
128     max_x, max_y = self.grid_corner()
129     vector_x, vector_y = vector
130     point_x, point_y = point
131
132     print(max_x, max_y, vector_x, vector_y, point_x, point_y)
133
134     # We want to use  $y = mx + c$  but  $m = y / x$  and if either of those are 0, then this
135     # equation is harder to work with, so we deal with these edge cases first
136     if abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
137         # If both components of the vector are practically 0, then we can't render any grid lines
138         return
139
140     elif abs(vector_x) < 1e-12:
141         painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
142
143         for i in range(abs(int(max_x / point_x))):
144             painter.drawLine(
145                 self.trans_x((i + 1) * point_x),
146                 0,
147                 self.trans_x((i + 1) * point_x),
148                 self.height()
149             )
150             painter.drawLine(
151                 self.trans_x(-1 * (i + 1) * point_x),
152                 0,
153                 self.trans_x(-1 * (i + 1) * point_x),
154                 self.height()
155             )
156
157     elif abs(vector_y) < 1e-12:
158         painter.drawLine(0, self.trans_y(0), self.width(), self.trans_y(0))
159
160         for i in range(abs(int(max_y / point_y))):
161             painter.drawLine(
162                 0,
163                 self.trans_y((i + 1) * point_y),
164                 self.width(),
165                 self.trans_y((i + 1) * point_y)
166             )
167             painter.drawLine(
168                 0,
169                 self.trans_y(-1 * (i + 1) * point_y),
170                 self.width(),
171                 self.trans_y(-1 * (i + 1) * point_y)
172             )
173
174     else: # If the line is not horizontal or vertical, then we can use  $y = mx + c$ 
175         m = vector_y / vector_x
176         c = point_y - m * point_x
177
178         # For  $c = 0$ 
179         painter.drawLine(
180             *self.trans_coords(
181                 -1 * max_x,
182                 m * -1 * max_x
183             ),
184             *self.trans_coords(
185                 max_x,
186                 m * max_x
187             )
188         )
189
190         # Count up how many multiples of c we can have without wasting time rendering lines off screen
191         multiples_of_c: int = 0
192         ii: int = 1
193         while True:
194             y1 = m * max_x + ii * c
```



```

195         y2 = -1 * m * max_x + ii * c
196
197     if y1 < max_y or y2 < max_y:
198         multiples_of_c += 1
199         ii += 1
200
201     else:
202         break
203
204     # Once we know how many lines we can draw, we just draw them all
205     for i in range(1, multiples_of_c + 1):
206         painter.drawLine(
207             *self.trans_coords(
208                 -1 * max_x,
209                 m * -1 * max_x + i * c
210             ),
211             *self.trans_coords(
212                 max_x,
213                 m * max_x + i * c
214             )
215         )
216         painter.drawLine(
217             *self.trans_coords(
218                 -1 * max_x,
219                 m * -1 * max_x - i * c
220             ),
221             *self.trans_coords(
222                 max_x,
223                 m * max_x - i * c
224             )
225         )

```

This code checks if  $x$  or  $y$  is zero<sup>10</sup> and if they're not, then we have to use the standard straight line equation  $y = mx + c$  to create parallel lines. We find our value of  $m$  and then iterate through all the values of  $c$  that keep the line within the bounding box.

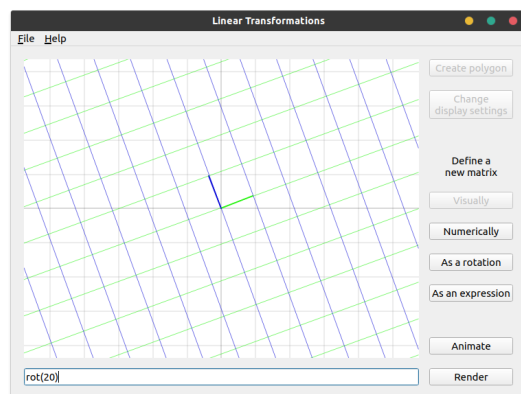


Figure 3.7: An example of a 20° rotation

### 3.3.5 Implementing animation

Now that I had a very crude renderer, I could create a method to animate a matrix. Eventually I want to be able to apply a given matrix to the currently rendered scene and animate between them. However, I wanted to start simple by animating from the identity to the given matrix.

```

# 829a130af5aee9819bf0269c03ecfb20bec1a108
# src/lintrans/gui/main_window.py

```

```

20 class LintransMainWindow(QMainWindow):

```

<sup>10</sup>We actually check if they're less than  $10^{-12}$  to allow for floating point errors

There are some serious logical errors in this code. It works fine for things like `'3rot(45)'` or `'0.5rot(20)'`, but something like `'rot(115)'` will leave the program hanging indefinitely.

In fact, this code only works for rotations between  $0^\circ$  and  $90^\circ$ , and will hang forever when given a matrix like  $\begin{pmatrix} 12 & 4 \\ -2 & 3 \end{pmatrix}$ , because it's just not very good.

I will fix these issues in the future, but it works somewhat decently, so I decided to do animation next, because that sounded more fun.

```

...
238 def animate_expression(self) -> None:
239     """Animate the expression in the input box, and then clear the box."""
240     self.button_render.setEnabled(False)
241     self.button_animate.setEnabled(False)
242
243     matrix = self.matrix_wrapper.evaluate_expression(self.lineEdit_expression_box.text())
244     matrix_move = matrix - self.matrix_wrapper['I']
245     steps: int = 100
246
247     for i in range(0, steps + 1):
248         self.plot.visualize_matrix_transformation(
249             self.matrix_wrapper['I'] + (i / steps) * matrix_move
250         )
251
252         self.update()
253         self.repaint()
254
255         time.sleep(0.01)
256
257     self.button_render.setEnabled(False)
258     self.button_animate.setEnabled(False)

```

This code creates the `matrix_move` variable and adds scaled versions of it to the identity matrix and renders that each frame. It's simple, but it works well for this simple use case. Unfortunately, it's very hard to show off an animation in a PDF, since all these images are static. The git commit hashes are included in the code snippets if you want to clone the repo[2], checkout this commit, and run it yourself if you want.

### 3.3.6 Preserving determinants

Ignoring the obvious flaw with not being able to render transformations with a more than 90° rotation, the animations don't respect determinants. When rotating 90°, the determinant changes during the animation, even though we're going from a determinant 1 matrix (the identity) to another determinant 1 matrix. This is because we're just moving each vector to its new position in a straight line. I want to animate in a way that smoothly transitions the determinant.

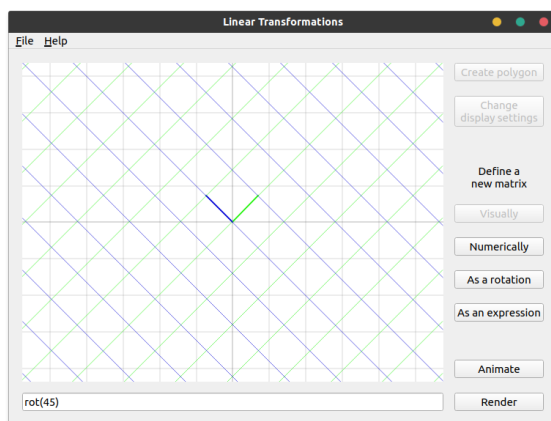


Figure 3.8: What we would expect halfway through a 90° rotation

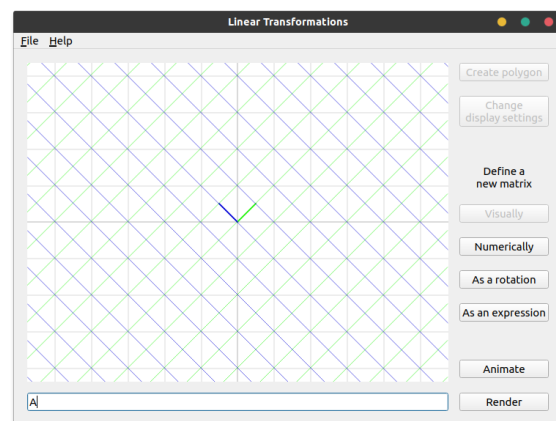


Figure 3.9: What we actually get halfway through a 90° rotation

In order to smoothly animate the determinant, I had to do some maths. I first defined the matrix **A** to be equivalent to the `matrix_move` variable from before - the target matrix minus the identity, scaled by the proportion. I then wanted to normalize **A** so that it had a determinant of 1 so that I could scale it up with the `proportion` variable through the animation.

I think I first tried just multiplying **A** by  $\frac{1}{\det(\mathbf{A})}$  but that didn't work, so I googled it. I found a

post[13] on ResearchGate about the topic, and thanks to a very helpful comment from Jeffrey L Stuart, I learned that for a  $2 \times 2$  matrix  $\mathbf{A}$  and a scalar  $c$ ,  $\det(c\mathbf{A}) = c^2 \det(\mathbf{A})$ .

I wanted a  $c$  such that  $\det(c\mathbf{A}) = 1$ . Therefore  $c = \frac{1}{\sqrt{|\det(\mathbf{A})|}}$ . I then defined matrix  $\mathbf{B}$  to be  $c\mathbf{A}$ .

Then I wanted to scale this normalized matrix  $\mathbf{B}$  to have the same determinant as the target matrix  $\mathbf{T}$  using some scalar  $d$ . We know that  $\det(d\mathbf{B}) = d^2 \det(\mathbf{B}) = \det(\mathbf{T})$ . We can just rearrange to find  $d$  and get  $d = \sqrt{\frac{\det(\mathbf{T})}{\det(\mathbf{B})}}$ . But  $\mathbf{B}$  is defined so that  $\det(\mathbf{B}) = 1$ , so we can get  $d = \sqrt{|\det(\mathbf{T})|}$ .

However, we want to scale this over time with our proportion variable  $p$ , so our final scalar  $s = 1 + p(\sqrt{|\det(\mathbf{T})|} - 1)$ . We define a matrix  $\mathbf{C} = s\mathbf{B}$  and render  $\mathbf{C}$  each frame. When in code form, this is the following:

```
# 6ff49450d8438ea2b2e7d2a97125dc518e648bc5
# src/lintrans/gui/main_window.py

22 class LintransMainWindow(QMainWindow):
...
240     def animate_expression(self) -> None:
...
245         # Get the target matrix and it's determinant
246         matrix_target = self.matrix_wrapper.evaluate_expression(self.linedit_expression_box.text())
247         det_target = linalg.det(matrix_target)
248
249         identity = self.matrix_wrapper['I']
250         steps: int = 100
251
252         for i in range(0, steps + 1):
253             # This proportion is how far we are through the loop
254             proportion = i / steps
255
256             # matrix_a is the identity plus some part of the target, scaled by the proportion
257             # If we just used matrix_a, then things would animate, but the determinants would be weird
258             matrix_a = identity + proportion * (matrix_target - identity)
259
260             # So to fix the determinant problem, we get the determinant of matrix_a and use it to normalise
261             det_a = linalg.det(matrix_a)
262
263             # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
264             # We want B = cA such that det(B) = 1, so then we can scale it with the animation
265             # So we get c^2 det(A) = 1 => c = sqrt(1 / abs(det(A)))
266             # Then we scale A down to get a determinant of 1, and call that matrix_b
267             if det_a == 0:
268                 c = 0
269             else:
270                 c = np.sqrt(1 / abs(det_a))
271
272             matrix_b = c * matrix_a
273
274             # matrix_c is the final matrix that we transform by
275             # It's B, but we scale it up over time to have the target determinant
276
277             # We want some C = dB such that det(C) is some target determinant T
278             # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
279             # But we defined B to have det 1, so we can ignore it there
280
281             # We're also subtracting 1 and multiplying by the proportion and then adding one
282             # This just scales the determinant along with the animation
283             scalar = 1 + proportion * (np.sqrt(abs(det_target)) - 1)
284
285             matrix_c = scalar * matrix_b
286
287             self.plot.visualize_matrix_transformation(matrix_c)
288
289             self.repaint()
290             time.sleep(0.01)
```

Unfortunately, the system I use to render matrices is still quite bad at its job. This makes it hard to test properly. But, transformations like '**2rot(90)**' work exactly as expected, which is very good.

## 3.4 Improving the GUI

### 3.4.1 Fixing rendering

Now that I had the basics of matrix visualization sorted, I wanted to make the GUI and UX better. My first step was overhauling the rendering code to make it actually work with rotations of more than 90°.

I narrowed down the issue with PyCharm's debugger and found that the loop in `VectorGridPlot.draw_parallel_lines()` was looping forever if it tried to do anything outside of the top right quadrant. To fix this, I decided to instead delegate this task of drawing a set of oblique lines to a separate method, and work on that instead.

```
# cf05e09e5ebb6ea7a96db8660d0d8de6b946490a
# src/lintrans/gui/plots/classes.py

118 class VectorGridPlot(BackgroundPlot):
119     ...
120     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
121         None:
122         ...
123         else: # If the line is not horizontal or vertical, then we can use  $y = mx + c$ 
124             m = vector_y / vector_x
125             c = point_y - m * point_x
126
127             # For  $c = 0$ 
128             painter.drawLine(
129                 *self.trans_coords(
130                     -1 * max_x,
131                     m * -1 * max_x
132                 ),
133                 *self.trans_coords(
134                     max_x,
135                     m * max_x
136                 )
137             )
138
139             # We keep looping and increasing the multiple of  $c$  until we stop drawing lines on the canvas
140             multiple_of_c = 1
141             while self.draw_pair_of_oblique_lines(painter, m, multiple_of_c * c):
142                 multiple_of_c += 1
```

This separation of functionality made designing and debugging this part of the solution much easier. The `draw_pair_of_oblique_lines()` method looked like this:

```
# cf05e09e5ebb6ea7a96db8660d0d8de6b946490a
# src/lintrans/gui/plots/classes.py

118 class VectorGridPlot(BackgroundPlot):
119     ...
120     def draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
121         """Draw a pair of oblique lines, using the equation  $y = mx + c$ .
122
123         This method just calls :meth:`draw_oblique_line` with ``c`` and ``-c``,
124         and returns True if either call returned True.
125
126         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
127         :param float m: The gradient of the lines to draw
128         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
129         :returns bool: Whether we were able to draw any lines on the canvas
130         """
131         return any([
132             self.draw_oblique_line(painter, m, c),
133             self.draw_oblique_line(painter, m, -c)
134         ])
135
136
137
138
139
```

```
240 def draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
241     """Draw an oblique line, using the equation  $y = mx + c$ .
242
243     We only draw the part of the line that fits within the canvas, returning True if
244     we were able to draw a line within the boundaries, and False if we couldn't draw a line
245
246     :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
247     :param float m: The gradient of the line to draw
248     :param float c: The y-intercept of the line to draw
249     :returns bool: Whether we were able to draw a line on the canvas
250     """
251     max_x, max_y = self.grid_corner()
252
253     # These variable names are shortened for convenience
254     # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
255     myi = (max_y - c) / m
256     mmyi = (-max_y - c) / m
257     mx_i = max_x * m + c
258     mmxi = -max_x * m + c
259
260     # The inner list here is a list of coords, or None
261     # If an intersection fits within the bounds, then we keep its coord,
262     # else it is None, and then gets discarded from the points list
263     # By the end, points is a list of two coords, or an empty list
264     points: list[tuple[float, float]] = [
265         x for x in [
266             (myi, max_y) if -max_x < myi < max_x else None,
267             (mmyi, -max_y) if -max_x < mmyi < max_x else None,
268             (max_x, mx_i) if -max_y < mx_i < max_y else None,
269             (-max_x, mmxi) if -max_y < mmxi < max_y else None
270         ] if x is not None
271     ]
272
273     # If no intersections fit on the canvas
274     if len(points) < 2:
275         return False
276
277     # If we can, then draw the line
278     else:
279         painter.drawLine(
280             *self.trans_coords(*points[0]),
281             *self.trans_coords(*points[1])
282         )
283         return True
```

To illustrate what this code is doing, I'll use a diagram.

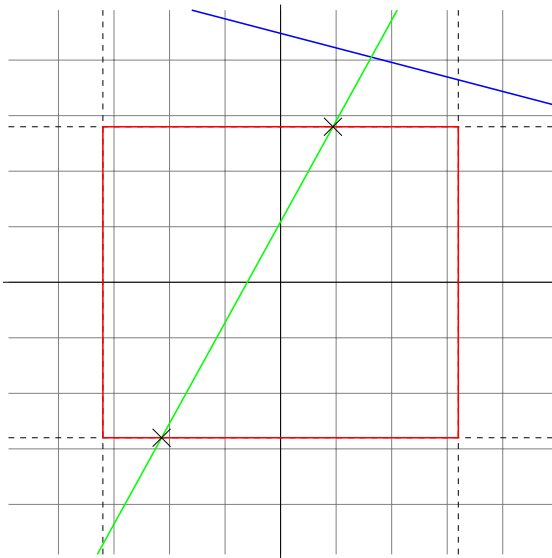


Figure 3.10: Two example lines and the viewport box

The red box represents the viewport of the GUI. The dashed lines represent the extensions of the red box. For a given line we want to draw, we first want to find where it intersects these orthogonal lines. Any oblique line will intersect each of these lines exactly once. This is what the `myi`, `myyi`, `mxi`, and `mmxi` variables represent. The value of `myi` is the  $x$  value where the line intersects the maximum  $y$  line, for example.

In the case of the blue line, all 4 intersection points are outside the bounds of the box, whereas the green line intersects with the box, as shown with the crosses. We use a list comprehension over a list of ternaries to get the `points` list. This list contains 0 or 2 coordinates, and we may or may not draw a line accordingly.

That's how the `draw_oblique_line()` method works, and the `draw_pair_of_oblique_lines()` method just calls it with positive and negative values of  $c$ .

### 3.4.2 Adding vector arrowheads

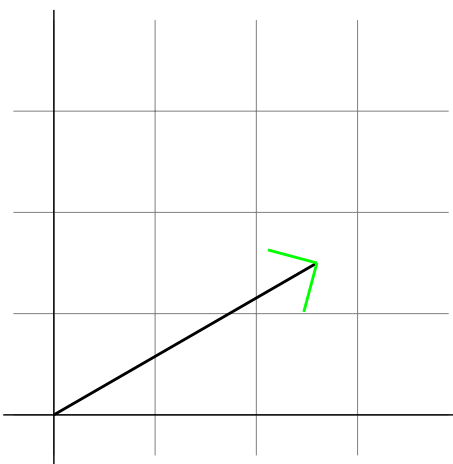


Figure 3.12: An example of a vector with the arrowheads highlighted in green

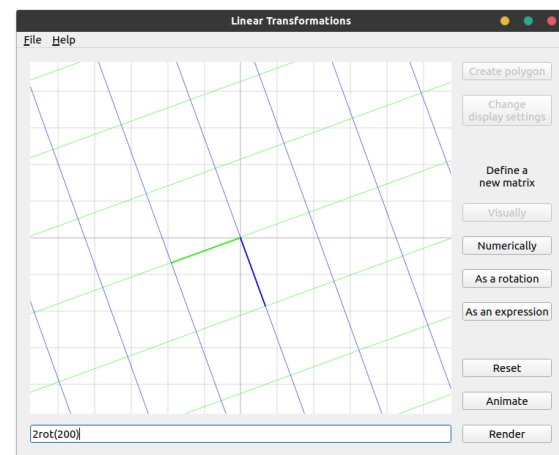


Figure 3.11: A demonstration of the new oblique lines system.

Now that I had a good renderer, I wanted to add arrowheads to the vectors to make them easier to see. They were already thicker than the gridlines, but adding arrowheads like in the 3blue1brown series would make them much easier to see. Unfortunately, I couldn't work out how to do this.

I wanted a function that would take a coordinate, treat it as a unit vector, and draw lines at  $45^\circ$  angles at the tip. This wasn't how I was conceptualising the problem at the time and because of that, I couldn't work out how to solve this problem. I could create this  $45^\circ$  lines in the top right quadrant, but none of my possible solutions worked for any arbitrary point.

So I started googling and found a very nice algorithm on [csharpshelper.com](https://csharpshelper.com)[26], which I adapted for Python.

```

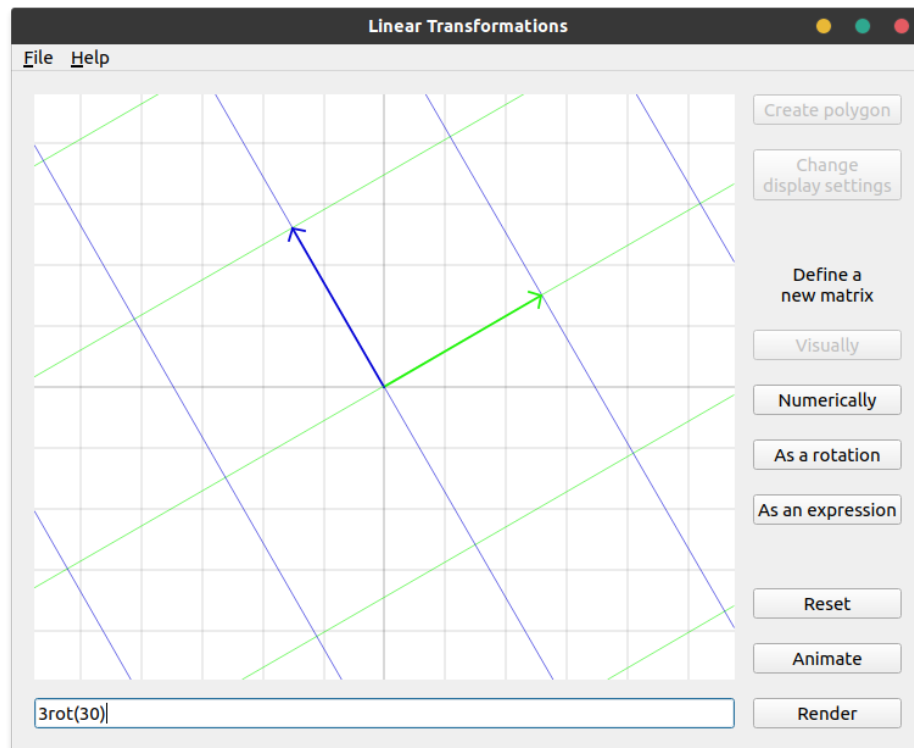
# 5373b1ad8040f6726147cccea523c0570251cf67
# src/lintrans/gui/plots/widgets.py

12 class VisualizeTransformationWidget(VectorGridPlot):
13     ...
52     def draw_arrowhead_away_from_origin(self, painter: QPainter, point: tuple[float, float]) -> None:
53         """Draw an arrowhead at ``point``, pointing away from the origin.
54
55         :param QPainter painter: The ``QPainter`` object to use to draw the arrowheads with
56         :param point: The point to draw the arrowhead at, given in grid coords
57         :type point: tuple[float, float]
58         """
59         # This algorithm was adapted from a C# algorithm found at
60         # http://csharpshelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
61
62         # Get the x and y coords of the point, and then normalize them
63         # We have to normalize them, or else the size of the arrowhead will
64         # scale with the distance of the point from the origin
65         x, y = point
66         nx = x / np.sqrt(x * x + y * y)
67         ny = y / np.sqrt(x * x + y * y)
68
69         # We choose a length and do some magic to find the steps in the x and y directions
70         length = 0.15
71         dx = length * (-nx - ny)
72         dy = length * (nx - ny)
73
74         # Then we just plot those lines
75         painter.drawLine(*self.trans_coords(x, y), *self.trans_coords(x + dx, y + dy))
76         painter.drawLine(*self.trans_coords(x, y), *self.trans_coords(x - dy, y + dx))
77
78     def draw_vector_arrowheads(self, painter: QPainter) -> None:
79         """Draw arrowheads at the tips of the basis vectors.
80
81         :param QPainter painter: The ``QPainter`` object to use to draw the arrowheads with
82         """
83         painter.setPen(QPen(self.colour_i, self.width_vector_line))
84         self.draw_arrowhead_away_from_origin(painter, self.point_i)
85         painter.setPen(QPen(self.colour_j, self.width_vector_line))
86         self.draw_arrowhead_away_from_origin(painter, self.point_j)

```

As the comments suggest, we get the  $x$  and  $y$  components of the normalised vector, and then do some magic with a chosen length and get some distance values, and then draw those lines. I don't really understand how this code works, but I'm happy that it does. All we have to do is call `draw_vector_arrowheads()` from `paintEvent()`.



Figure 3.13: An example of the  $i$  and  $j$  vectors with arrowheads

### 3.4.3 Implementing zoom

The next thing I wanted to do was add the ability to zoom in and out of the viewport, and I wanted a button to reset the zoom level as well. I added a `default_grid_spacing` class attribute in `BackgroundPlot` and used that as the `grid_spacing` instance attribute in `__init__()`.

```
# d944e86e1d0fdc2c4be4d63479bc6bc3a31568ef
# src/lintrans/gui/plots/classes.py

12 class BackgroundPlot(QWidget):
13 ...
27     default_grid_spacing: int = 50
28
29     def __init__(self, *args, **kwargs):
30         """Create the widget and setup backend stuff for rendering.
31
32         .. note:: ``*args`` and ``**kwargs`` are passed the superclass constructor (``QWidget``).
33         """
34         super().__init__(*args, **kwargs)
35
36         self.setAutoFillBackground(True)
37
38         # Set the background to white
39         palette = self.palette()
40         palette.setColor(self.backgroundRole(), Qt.white)
41         self.setPalette(palette)
42
43         # Set the grid colour to grey and the axes colour to black
44         self.colour_background_grid = QColor(128, 128, 128)
45         self.colour_background_axes = QColor(0, 0, 0)
46
47         self.grid_spacing = BackgroundPlot.default_grid_spacing
```

The reset button in `LintransMainWindow` simply sets `plot.grid_spacing` to the default.

To actually allow for zooming, I had to implement the `wheelEvent()` method in `BackgroundPlot` to listen for mouse wheel events. After reading through the docs for the `QWheelEvent` class[21], I learned how to handle this event.

```
# d944e86e1d0fdc2c4be4d63479bc6bc3a31568ef
# src/lintrans/gui/plots/classes.py

12 class BackgroundPlot(QWidget):
13     ...
119     def wheelEvent(self, event: QWheelEvent) -> None:
120         """Handle a ``QWheelEvent`` by zooming in or out of the grid."""
121         # angleDelta() returns a number of units equal to 8 times the number of degrees rotated
122         degrees = event.angleDelta() / 8
123
124         if degrees is not None:
125             self.grid_spacing = max(1, self.grid_spacing + degrees.y())
126
127         event.accept()
128         self.update()
```

All we do is get the amount that the user scrolled and add that to the current spacing, taking the max with 1, which acts as a minimum grid spacing. We need to use `degrees.y()` on line 125 because Qt5 allows for mice that can scroll in the  $x$  and  $y$  directions, and we only want the  $y$  component. Line 127 marks the event as accepted so that the parent widget doesn't try to act on it.

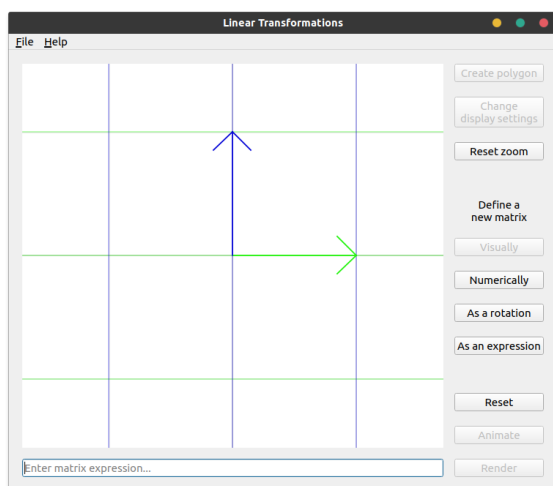


Figure 3.14: The GUI zoomed in a bit

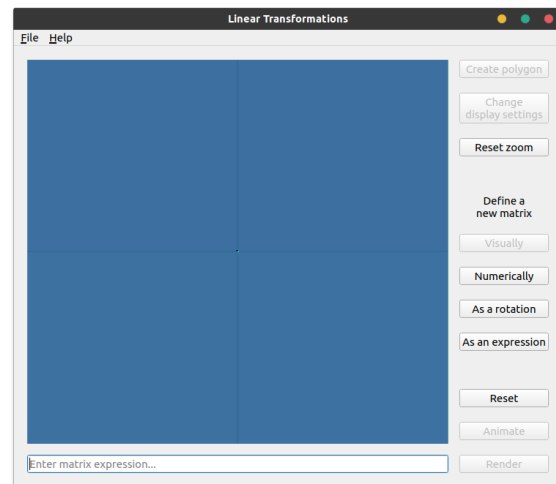


Figure 3.15: The GUI zoomed out as far as possible

There are two things I don't like here. Firstly, the minimum grid spacing is too small. The user can zoom out too far. Secondly, the arrowheads are too big in figure 3.14.

The first problem is minor and won't be fixed for quite a while, but I fixed the second problem quite quickly.

We want the arrowhead length to not just be 0.15, but to scale with the zoom level (the ratio between default grid spacing and current spacing).

This creates a slight issue when zoomed out all the way, because the arrowheads are then far larger than the vectors themselves, so we take the minimum of the scaled length and the vector length.

I factored out the default arrowhead length into the `arrowhead_length` instance attribute and initialize it in `__init__()`.

```
# 3d19a003368ae992ebb60049685bb04fde0836b5
# src/lintrans/gui/plots/widgets.py
```

```

12 class VisualizeTransformationWidget(VectorGridPlot):
...
54     def draw_arrowhead_away_from_origin(self, painter: QPainter, point: tuple[float, float]) -> None:
...
68         vector_length = np.sqrt(x * x + y * y)
69         nx = x / vector_length
70         ny = y / vector_length
71
72         # We choose a length and find the steps in the x and y directions
73         length = min(
74             self.arrowhead_length * self.default_grid_spacing / self.grid_spacing,
75             vector_length
76         )

```

This code results in arrowheads that stay the same length unless the user is zoomed out basically as far as possible.

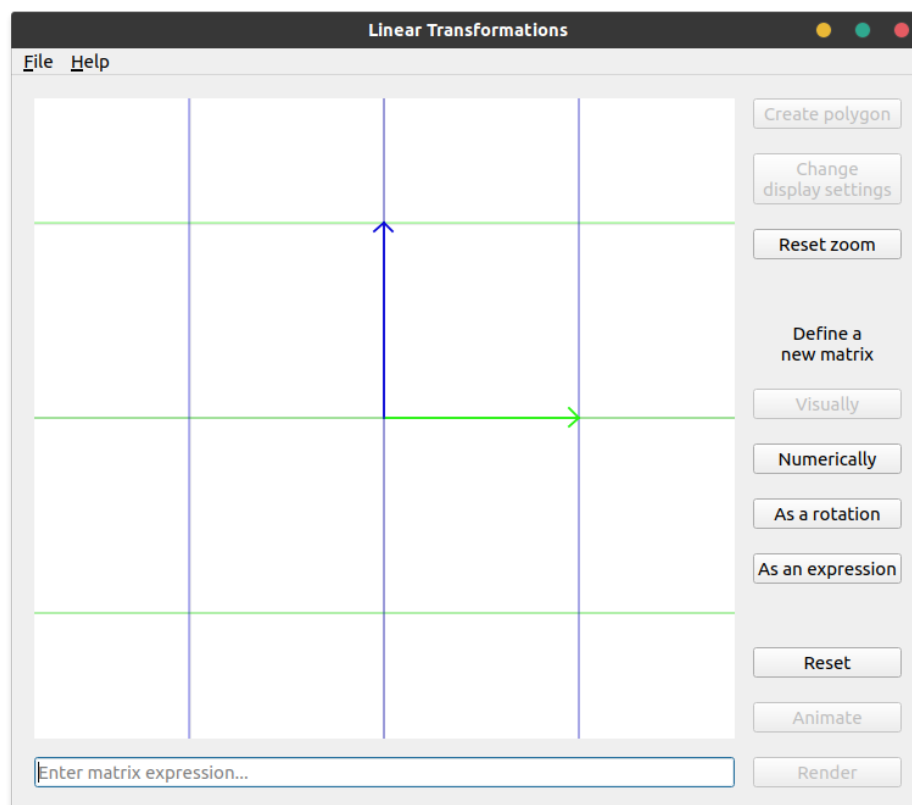


Figure 3.16: The arrowheads adjusted for zoom level

### 3.4.4 Animation blocks zooming

The biggest problem with this new zoom feature is that when animating between matrices, the user is unable to zoom. This is because when `LintransMainWindow.animate_expression()` is called, it uses Python's standard library `time.sleep()` function to delay each frame, which prevents Qt from handling user interaction while we're animating. This was a problem.

I did some googling and found a helpful post on StackOverflow[10] that gave me a nice solution. The user `ekhumoro` used the functions `QApplication.processEvents()` and `QThread.msleep()` to solve the problem, and I used these functions in my own app, with much success.

After reading 'The Event System' in the Qt5 documentation[27], I learned that Qt5 uses an event loop,

a lot like JavaScript. This means that events are scheduled to be executed on the next pass of the event loop. I also read the documentation for the `repaint()` and `update()` methods on the `QWidget` class[23, 24] and decided that it would be better to just queue a repaint by calling `update()` on the plot rather than immediately repaint with `repaint()`, and then call `QApplication.processEvents()` to process the pending events on the main thread. This is a nicer way of repainting, which reduces potential flickering issues, and using `QThread.msleep()` allows for asynchronous processing and therefore non-blocking animation.

### 3.4.5 Rank 1 transformations

The rank of a matrix is the dimension of its column space. This is the dimension of the span of its columns, which is to say the dimension of the output space. The rank of a matrix must be less than or equal to the dimension of the matrix, so we only need to worry about ranks 0, 1, and 2. There is only one rank 0 matrix, which is the **0** matrix itself. I've already covered this case by just not drawing any transformed grid lines.

Rank 2 matrices encompass most 2D matrices, and I've already covered this case in §3.3.4 and §3.4.1. A rank 1 matrix collapses all of 2D space onto a single line, so for this type of matrix, we should just draw this line.

This code is in `VectorGridPlot.draw_parallel_lines()`. We assemble the matrix  $\begin{pmatrix} \text{vector\_x} & \text{point\_x} \\ \text{vector\_y} & \text{point\_y} \end{pmatrix}$  (which is actually the matrix used to create the transformation we're trying to render lines for) and use this matrix to check determinant and rank.

```
# 677b38c87bb6722b16aaf35058cf3cef66e43c21
# src/lintrans/gui/plots/classes.py

132 class VectorGridPlot(BackgroundPlot):
133     ...
164     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
134         ↪ None:
135         ...
177         # If the determinant is 0
178         if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
179             rank = np.linalg.matrix_rank(
180                 np.array([
181                     [vector_x, point_x],
182                     [vector_y, point_y]
183                 ])
184             )
185
186         # If the matrix is rank 1, then we can draw the column space line
187         if rank == 1:
188             self.draw_oblique_line(painter, vector_y / vector_x, 0)
189
190         # If the rank is 0, then we don't draw any lines
191         else:
192             return
```

Additionally, there was a bug with animating these determinant 0 matrices, since we try to scale the determinant through the animation, as documented in §3.3.6, but when the determinant is 0, this causes issues. To fix this, we just check the `det_target` variable in `LintransMainWindow.animate_expression` and if it's 0, we use the non-scaled version of the matrix.

```
# b889b686d997c2b64124bee786bccba3fc4f6b08
# src/lintrans/gui/main_window.py

22 class LintransMainWindow(QMainWindow):
23     ...
262     def animate_expression(self) -> None:
263     ...
```

```

274         for i in range(0, steps + 1):
275             ...
307             # If we're animating towards a det 0 matrix, then we don't want to scale the
308             # determinant with the animation, because this makes the process not work
309             # I'm doing this here rather than wrapping the whole animation logic in an
310             # if block mainly because this looks nicer than an extra level of indentation
311             # The extra processing cost is negligible thanks to NumPy's optimizations
312             if det_target == 0:
313                 matrix_c = matrix_a
314             else:
315                 matrix_c = scalar * matrix_b

```

### 3.4.6 Matrices that are too big

One of my friends was playing around with the prototype and she discovered a bug. When trying to render really big matrices, we can get errors like `'OverflowError: argument 3 overflowed: value must be in the range -2147483648 to 2147483647'` because PyQt5 is a wrapper over Qt5, which is a C++ library that uses the C++ `int` type for the `painter.drawLine()` call. This type is a 32-bit integer. Python can store integers of arbitrary precision, but when PyQt5 calls the underlying C++ library code, this gets cast to a C++ `int` and we can get an `OverflowError`.

This isn't a problem with the gridlines, because we only draw them inside the viewport, as discussed in §3.4.1, and these calculations all happen in Python, so integer precision is not a concern. However, when drawing the basis vectors, we just draw them directly, so we'll have to check that they're within the limit.

I'd previously created a `LintransMainWindow.show_error_message()` method for telling the user when they try to take the inverse of a singular matrix<sup>11</sup>.

```

# 0f699dd95b6431e95b2311dcb03e7af49c19613f
# src/lintrans/gui/main_window.py

23 class LintransMainWindow(QMainWindow):
24     ...
378     def show_error_message(self, title: str, text: str, info: str | None = None) -> None:
379         """Show an error message in a dialog box.
380
381         :param str title: The window title of the dialog box
382         :param str text: The simple error message
383         :param info: The more informative error message
384         :type info: Optional[str]
385         """
386         dialog = QMessageBox(self)
387         dialog.setIcon(QMessageBox.Critical)
388         dialog.setWindowTitle(title)
389         dialog.setText(text)
390
391         if info is not None:
392             dialog.setInformativeText(info)
393
394         dialog.open()
395
396         dialog.finished.connect(self.update_render_buttons)

```

I then created the `is_matrix_too_big()` method to just check that the elements of the matrix are within the desired bounds. If it returns `True` when we try to render or animate, then we call `show_error_message()`.

```

# 4682a7b225747cfd77aca0fe3abccdd1397b7c5dd
# src/lintrans/gui/main_window.py

```

---

<sup>11</sup>This commit didn't get a standalone section in this write-up because it was so small

```

24 class LintransMainWindow(QMainWindow):
...
407     def is_matrix_too_big(self, matrix: MatrixType) -> bool:
408         """Check if the given matrix will actually fit onto the canvas.
409
410         Convert the elements of the matrix to canvas coords and make sure they fit within Qt's 32-bit integer limit.
411
412         :param MatrixType matrix: The matrix to check
413         :returns bool: Whether the matrix fits on the canvas
414         """
415         coords: list[tuple[int, int]] = [self.plot.trans_coords(*vector) for vector in matrix.T]
416
417         for x, y in coords:
418             if not (-2147483648 <= x <= 2147483647 and -2147483648 <= y <= 2147483647):
419                 return True
420
421         return False

```

### 3.4.7 Creating the DefineVisuallyDialog

Next, I wanted to allow the user to define a matrix visually by dragging the basis vectors. To do this, I obviously needed a new DefineDialog subclass for it.

```

# 16ca0229aab73b3f4a8fe752dee3608f3ed6ead5
# src/lintrans/gui/dialogs/define_new_matrix.py

135 class DefineVisuallyDialog(DefineDialog):
136     """The dialog class that allows the user to define a matrix visually."""
137
138     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
139         """Create the widgets and layout of the dialog.
140
141         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
142         """
143         super().__init__(matrix_wrapper, *args, **kwargs)
144
145         self.setMinimumSize(500, 450)
146
147         # === Create the widgets
148
149         self.combobox_letter.activated.connect(self.show_matrix)
150
151         self.plot = DefineVisuallyWidget(self)
152
153         # === Arrange the widgets
154
155         self.hlay_definition.addWidget(self.plot)
156         self.hlay_definition.setStretchFactor(self.plot, 1)
157
158         self.vlay_all = QVBoxLayout()
159         self.vlay_all.setSpacing(20)
160         self.vlay_all.addLayout(self.hlay_definition)
161         self.vlay_all.addLayout(self.hlay_buttons)
162
163         self.setLayout(self.vlay_all)
164
165         # We load the default matrix A into the plot
166         self.show_matrix(0)
167
168         # We also enable the confirm button, because any visually defined matrix is valid
169         self.button_confirm.setEnabled(True)
170
171     def update_confirm_button(self) -> None:
172         """Enable the confirm button.
173
174         .. note::
175             The confirm button is always enabled in this dialog and this method is never actually used,
176             so it's got an empty body. It's only here because we need to implement the abstract method.
177         """

```

```

178
179     def show_matrix(self, index: int) -> None:
180         """Show the selected matrix on the plot. If the matrix is None, show the identity."""
181         matrix = self.matrix_wrapper[ALPHABET_NO_I[index]]
182
183         if matrix is None:
184             matrix = self.matrix_wrapper['I']
185
186         self.plot.visualize_matrix_transformation(matrix)
187         self.plot.update()
188
189     def confirm_matrix(self) -> None:

```

This DefineVisuallyDialog class just implements the normal methods needed for a DefineDialog and has a plot attribute to handle drawing graphics and handling mouse movement. After creating the DefineVisuallyWidget as a skeleton and doing some more research in the Qt5 docs[22], I re-named the trans\_coords() methods to canvas\_coords() to make the intent more clear, and created a grid\_coords() method.

```

# 417aea6555029b049c470faff18df29f064f6101
# src/lintrans/gui/plots/classes.py

13 class BackgroundPlot(QWidget):
...
85     def grid_coords(self, x: int, y: int) -> tuple[float, float]:
86         """Convert a coordinate from canvas coords to grid coords.
87
88         :param int x: The x component of the canvas coordinate
89         :param int y: The y component of the canvas coordinate
90         :returns: The resultant grid coordinates
91         :rtype: tuple[float, float]
92         """
93         # We get the maximum grid coords and convert them into canvas coords
94         return (x - self.canvas_origin[0]) / self.grid_spacing, (-y + self.canvas_origin[1]) / self.grid_spacing

```

I then needed to implement the methods to handle mouse movement in the DefineVisuallyWidget class. Thankfully, Ross Wilson, the person who helped me learn about the QWidget.paintEvent() method in §3.3.1, also wrote an example of draggable points[5]. In my post, I had explained that I needed draggable points on my canvas, and Ross was helpful enough to create an example in their own time. I probably could've worked it out myself eventually, but this example allowed me to learn a lot quicker.

```

# 417aea6555029b049c470faff18df29f064f6101
# src/lintrans/gui/plots/widgets.py

56 class DefineVisuallyWidget(VisualizeTransformationWidget):
57     """This class is the widget that allows the user to visually define a matrix.
58
59     This is just the widget itself. If you want the dialog, use
60     :class:`lintrans.gui.dialogs.define_new_matrix.DefineVisuallyDialog`.
61     """
62
63     def __init__(self, *args, **kwargs):
64         """Create the widget and enable mouse tracking. ``*args`` and ``**kwargs`` are passed to ``super()``."""
65         super().__init__(*args, **kwargs)
66
67         # self.setMouseTracking(True)
68         self.dragged_point: tuple[float, float] | None = None
69
70         # This is the distance that the cursor needs to be from the point to drag it
71         self.epsilon: int = 5
72
73     def mousePressEvent(self, event: QMouseEvent) -> None:
74         """Handle a QMouseEvent when the user pressed a button."""
75         mx = event.x()
76         my = event.y()

```

```

77         button = event.button()
78
79         if button != Qt.LeftButton:
80             event.ignore()
81             return
82
83         for point in (self.point_i, self.point_j):
84             px, py = self.canvas_coords(*point)
85             if abs(px - mx) <= self.epsilon and abs(py - my) <= self.epsilon:
86                 self.dragged_point = point[0], point[1]
87
88         event.accept()
89
90     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
91         """Handle a QMouseEvent when the user release a button."""
92         if event.button() == Qt.LeftButton:
93             self.dragged_point = None
94             event.accept()
95         else:
96             event.ignore()
97
98     def mouseMoveEvent(self, event: QMouseEvent) -> None:
99         """Handle the mouse moving on the canvas."""
100         mx = event.x()
101         my = event.y()
102
103         if self.dragged_point is not None:
104             x, y = self.grid_coords(mx, my)
105
106             if self.dragged_point == self.point_i:
107                 self.point_i = x, y
108
109             elif self.dragged_point == self.point_j:
110                 self.point_j = x, y
111
112             self.dragged_point = x, y
113
114             self.update()
115
116             print(self.dragged_point)
117             print(self.point_i, self.point_j)
118
119             event.accept()
120
121         event.ignore()

```

This snippet has the line `self.setMouseTracking(True)` commented out. This line was in the example, but it turns out that I don't want it. Mouse tracking means that a widget will receive a `QMouseEvent` every time the mouse moves. But if it's disabled (the default), then the widget will only receive a `QMouseEvent` for mouse movement when a button is held down at the same time.

I've also left in some print statements on lines 116 and 117. These small oversights are there because I just forgot to remove them before I committed these changes. They were removed 3 commits later.

### 3.4.8 Fixing a division by zero bug

When drawing the rank line for a determinant 0, rank 1 matrix, we can encounter a division by zero error. I'm sure this originally manifested in a crash with a **ZeroDivisionError** at runtime, but now I can only get a **RuntimeWarning** when running the old code from commit [16ca0229aab73b3f4a8fe752dee3608f3ed6ead5](#).

Whether it crashes or just warns the user, there is a division by zero bug when trying to render  $\begin{pmatrix} k & 0 \\ 0 & 0 \end{pmatrix}$  or  $\begin{pmatrix} 0 & 0 \\ 0 & k \end{pmatrix}$ . To fix this, I just handled those cases separately in `VectorGridPlot.draw_parallel_lines()`.



```

# 40bee6461d477a5c767ed132359cd511c0051e3b
# src/lintrans/gui/plots/classes.py

140 class VectorGridPlot(BackgroundPlot):
141     ...
174     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
142         ↪ None:
143         ...
188         if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
144             ...
196             # If the matrix is rank 1, then we can draw the column space line
197             if rank == 1:
198                 if abs(vector_x) < 1e-12:
199                     painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
200                 elif abs(vector_y) < 1e-12:
201                     painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
202                 else:
203                     self.draw_oblique_line(painter, vector_y / vector_x, 0)
204             ...
205             # If the rank is 0, then we don't draw any lines
206             else:
207                 return

```

### 3.4.9 Implementing transitional animation

Currently, all animation animates from  $\mathbf{I}$  to the target matrix  $\mathbf{T}$ . This means it resets the plot at the start. I eventually want an applicative animation system, where the matrix in the box is applied to the current scene. But I also want an option for a transitional animation, where the program animates from the start matrix  $\mathbf{S}$  to the target matrix  $\mathbf{T}$ , and this seems easier to implement, so I'll do it first.

In LintransMainWindow, I created a new method called `animate_between_matrices()` and I call it from `animate_expression()`. The maths for smoothening determinants in §3.3.6 assumed the starting matrix had a determinant of 1, but when using transitional animation, this may not always be true.

If we let  $\mathbf{S}$  be the starting matrix, and  $\mathbf{A}$  be the matrix from the first stage of calculation as specified in §3.3.6, then we want a  $c$  such that  $\det(c\mathbf{A}) = \det(\mathbf{S})$ , so we get  $c = \sqrt{\left|\frac{\det(\mathbf{S})}{\det(\mathbf{A})}\right|}$  by the identity  $\det(c\mathbf{A}) = c^2 \det(\mathbf{A})$ .

Following the same logic as in §3.3.6, we can let  $\mathbf{B} = c\mathbf{A}$  and then scale it by  $d$  to get the same determinant as the target matrix  $\mathbf{T}$  and find that  $d = \sqrt{\left|\frac{\det(\mathbf{T})}{\det(\mathbf{B})}\right|}$ . Unlike previously,  $\det(\mathbf{B})$  could be any scalar, so we can't simplify our expression for  $d$ .

We then scale this with our proportion variable  $p$  to get a scalar  $s = 1 + p \left( \sqrt{\left|\frac{\det(\mathbf{T})}{\det(\mathbf{B})}\right|} - 1 \right)$  and render  $\mathbf{C} = s\mathbf{B}$  on each frame.

In code, that looks like this:

```

# 4017b84fbce67d8e041bc9ce84cefc0b6e65e1f
# src/lintrans/gui/main_window.py

25 class LintransMainWindow(QMainWindow):
26     ...
275     def animate_expression(self) -> None:
276         """Animate from the current matrix to the matrix in the expression box."""
277         self.button_render.setEnabled(False)
278         self.button_animate.setEnabled(False)
279         ...
280         # Get the target matrix and it's determinant
281         try:

```

```

282         matrix_target = self.matrix_wrapper.evaluate_expression(self.lineedit_expression_box.text())
283
284     except linalg.LinAlgError:
285         self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
286         return
287
288     matrix_start: MatrixType = np.array([
289         [self.plot.point_i[0], self.plot.point_j[0]],
290         [self.plot.point_i[1], self.plot.point_j[1]]
291     ])
292
293     self.animate_between_matrices(matrix_start, matrix_target)
294
295     self.button_render.setEnabled(True)
296     self.button_animate.setEnabled(True)
297
298     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
299     ↪ None:
300         """Animate from the start matrix to the target matrix."""
301         det_target = linalg.det(matrix_target)
302         det_start = linalg.det(matrix_start)
303
304         for i in range(0, steps + 1):
305             # This proportion is how far we are through the loop
306             proportion = i / steps
307
308             # matrix_a is the start matrix plus some part of the target, scaled by the proportion
309             # If we just used matrix_a, then things would animate, but the determinants would be weird
310             matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
311
312             # So to fix the determinant problem, we get the determinant of matrix_a and use it to normalise
313             det_a = linalg.det(matrix_a)
314
315             # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
316             # We want B = cA such that det(B) = det(S), where S is the start matrix,
317             # so then we can scale it with the animation, so we get
318             # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
319             # Then we scale A to get the determinant we want, and call that matrix_b
320             if det_a == 0:
321                 c = 0
322             else:
323                 c = np.sqrt(abs(det_start / det_a))
324
325             matrix_b = c * matrix_a
326             det_b = linalg.det(matrix_b)
327
328             # matrix_c is the final matrix that we then render for this frame
329             # It's B, but we scale it over time to have the target determinant
330
331             # We want some C = dB such that det(C) is some target determinant T
332             # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
333
334             # We're also subtracting 1 and multiplying by the proportion and then adding one
335             # This just scales the determinant along with the animation
336             scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
337
338             # If we're animating towards a det 0 matrix, then we don't want to scale the
339             # determinant with the animation, because this makes the process not work
340             # I'm doing this here rather than wrapping the whole animation logic in an
341             # if block mainly because this looks nicer than an extra level of indentation
342             # The extra processing cost is negligible thanks to NumPy's optimizations
343             if det_target == 0:
344                 matrix_c = matrix_a
345             else:
346                 matrix_c = scalar * matrix_b
347
348             if self.is_matrix_too_big(matrix_c):
349                 self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
350                 return
351
352             self.plot.visualize_matrix_transformation(matrix_c)
353
354             # We schedule the plot to be updated, tell the event loop to

```

```

354         # process events, and asynchronously sleep for 10ms
355         # This allows for other events to be processed while animating, like zooming in and out
356         self.plot.update()

```

This change results in an animation system that will transition from the current matrix to whatever the user types into the input box.

### 3.4.10 Allowing for sequential animation with commas

Applicative animation has two main forms. There's the version where a standard matrix expression gets applied to the current scene, and the kind where the user defines a sequence of matrices and we animate through the sequence, applying one at a time. Both of these are referenced in success criterion 5.

I want the user to be able to decide if they want applicative animation or transitional animation, so I'll need to create some form of display settings. However, transitional animation doesn't make much sense for sequential animation<sup>12</sup>, so I can implement this now.

Applicative animation is just animating from the matrix **C** representing the current scene to the composition **TC** with the target matrix **T**.

We use **TC** instead of **CT** because matrix multiplication can be thought of as applying successive transformations from right to left. **TC** is the same as starting with the identity **I**, applying **C** (to get to the current scene), and then applying **T**.

Doing this in code is very simple. We just split the expression on commas, and then apply each sub-expression to the current scene one by one, pausing on each comma.

```

# 60584d2559cacbf23479a1bebbb986a800a32331
# src/lintrans/gui/main_window.py

25 class LintransMainWindow(QMainWindow):
...
284     def animate_expression(self) -> None:
285         """Animate from the current matrix to the matrix in the expression box."""
286         self.button_render.setEnabled(False)
287         self.button_animate.setEnabled(False)
288
289         matrix_start: MatrixType = np.array([
290             [self.plot.point_i[0], self.plot.point_j[0]],
291             [self.plot.point_i[1], self.plot.point_j[1]]
292         ])
293
294         text = self.lineEdit_expression_box.text()
295
296         # If there's commas in the expression, then we want to animate each part at a time
297         if ',' in text:
298             current_matrix = matrix_start
299
300             # For each expression in the list, right multiply it by the current matrix,
301             # and animate from the current matrix to that new matrix
302             for expr in text.split(',')[::-1]:
303                 new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
304
305                 self.animate_between_matrices(current_matrix, new_matrix)
306                 current_matrix = new_matrix
307
308             # Here we just redraw and allow for other events to be handled while we pause
309             self.plot.update()
310             QApplication.processEvents()
311             QThread.sleep(500)

```

<sup>12</sup>I have since changed my thoughts on this, and I allowed sequential transitional animation much later, in commit 41907b81661f3878e435b794d9d719491ef14237

```

312
313     # If there's no commas, then just animate directly from the start to the target
314     else:
315         # Get the target matrix and it's determinant
316         try:
317             matrix_target = self.matrix_wrapper.evaluate_expression(text)
318
319         except linalg.LinAlgError:
320             self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
321             return
322
323         self.animate_between_matrices(matrix_start, matrix_target)
324
325     self.update_render_buttons()

```

We're deliberately not checking if the sub-expressions are valid here. We would normally validate the expression in `LintransMainWindow.update_render_buttons()` and only allow the user to render or animate an expression if it's valid. Now we have to check all the sub-expressions if the expression contains commas. Additionally, we can only animate these expressions with commas in them, so rendering should be disabled when the expression contains commas.

Compare the old code to the new code:

```

# 4017b84fbce67d8e041bc9ce84cefc0b6e65e1f
# src/lintrans/gui/main_window.py

25 class LintransMainWindow(QMainWindow):
...
243     def update_render_buttons(self) -> None:
244         """Enable or disable the render and animate buttons according to whether the matrix expression is valid."""
245         valid = self.matrix_wrapper.is_valid_expression(self.lineEdit_expression_box.text())
246         self.button_render.setEnabled(valid)
247         self.button_animate.setEnabled(valid)

# 60584d2559cacbf23479a1bebbb986a80a32331
# src/lintrans/gui/main_window.py

25 class LintransMainWindow(QMainWindow):
...
243     def update_render_buttons(self) -> None:
244         """Enable or disable the render and animate buttons according to whether the matrix expression is valid."""
245         text = self.lineEdit_expression_box.text()
246
247         if ',' in text:
248             self.button_render.setEnabled(False)
249
250         valid = all(self.matrix_wrapper.is_valid_expression(x) for x in text.split(','))
251         self.button_animate.setEnabled(valid)
252
253     else:
254         valid = self.matrix_wrapper.is_valid_expression(text)
255         self.button_render.setEnabled(valid)
256         self.button_animate.setEnabled(valid)

```

## 3.5 Adding display settings

### 3.5.1 Creating the dataclass (and implementing applicative animation)

The first step of adding display settings is creating a dataclass to hold all of the settings. This dataclass will hold attributes to manage how a matrix transformation is displayed. Things like whether to show eigenlines or the determinant parallelogram. It will also hold information for animation. We can factor out the code used to smoothen the determinant, as written in §3.3.6, and make it dependant on a `bool` attribute of the `DisplaySettings` dataclass.

This is a standard class rather than some form of singleton to allow different plots to have different display settings. For example, the user might want different settings for the main view and the visual definition dialog. Allowing each instance of a subclass of `VectorGridPlot` to have its own `DisplaySettings` attribute allows for separate settings for separate plots.

However, this class initially just contained attributes relevant to animation, so it was only an attribute on `LintransMainWindow`.

```
# 2041c7a24d963d8d142d6f0f20ec3828ba8257c6
# src/lintrans/gui/settings.py

1  """This module contains the :class:`DisplaySettings` class, which holds configuration for display."""
2
3  from dataclasses import dataclass
4
5
6  @dataclass
7  class DisplaySettings:
8      """This class simply holds some attributes to configure display."""
9
10     animate_determinant: bool = True
11     """This controls whether we want the determinant to change smoothly during the animation."""
12
13     applicative_animation: bool = True
14     """There are two types of simple animation, transitional and applicative.
15
16     Let ``C`` be the matrix representing the currently displayed transformation, and let ``T`` be the target matrix.
17     Transitional animation means that we animate directly from ``C`` from ``T``,
18     and applicative animation means that we animate from ``C`` to ``TC``, so we apply ``T`` to ``C``.
19     """
20
21     animation_pause_length: int = 400
22     """This is the number of milliseconds that we wait between animations when using comma syntax."""
```

Once I had the dataclass, I just had to add `from .settings import DisplaySettings` to the top of the file, and `self.display_settings = DisplaySettings()` to the constructor of `LintransMainWindow`. I could then use the attributes of this dataclass in `animate_expression()`.

```
# 2041c7a24d963d8d142d6f0f20ec3828ba8257c6
# src/lintrans/gui/main_window.py

26  class LintransMainWindow(QMainWindow):
27      ...
28
29      def animate_expression(self) -> None:
30          """Animate from the current matrix to the matrix in the expression box."""
31          self.button_render.setEnabled(False)
32          self.button_animate.setEnabled(False)
33
34          matrix_start: MatrixType = np.array([
35              [self.plot.point_i[0], self.plot.point_j[0]],
36              [self.plot.point_i[1], self.plot.point_j[1]]
37          ])
38
39          text = self.lineedit_expression_box.text()
```

```

298     # If there's commas in the expression, then we want to animate each part at a time
299     if ',' in text:
300         current_matrix = matrix_start
301
302         # For each expression in the list, right multiply it by the current matrix,
303         # and animate from the current matrix to that new matrix
304         for expr in text.split(',')[:-1]:
305             new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
306
307             self.animate_between_matrices(current_matrix, new_matrix)
308             current_matrix = new_matrix
309
310             # Here we just redraw and allow for other events to be handled while we pause
311             self.plot.update()
312             QApplication.processEvents()
313             QThread.sleep(self.display_settings.animation_pause_length)
314
315     # If there's no commas, then just animate directly from the start to the target
316     else:
317         # Get the target matrix and it's determinant
318         try:
319             matrix_target = self.matrix_wrapper.evaluate_expression(text)
320
321         except linalg.LinAlgError:
322             self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
323             return
324
325         # The concept of applicative animation is explained in /gui/settings.py
326         if self.display_settings.applicative_animation:
327             matrix_target = matrix_target @ matrix_start
328
329         self.animate_between_matrices(matrix_start, matrix_target)
330
331     self.update_render_buttons()

```

Lines 327 are very important here. I included applicative animation as an option in the display settings because once I'd implemented animating from one matrix to another, it was very easy to implement applicative animation.

The user will input whatever matrix they wanted to apply to the current scene. Let's call that target matrix **T**. The matrix representing the starting state of the viewport is **S**. Animating from **S** to **T** is a transitional animation, but an applicative animation is simply animating from **S** to **TS**, so we can just say `matrix_target = matrix_target @ matrix_start` on line 327 (where `@` is the matrix multiplication operator), and continue as normal.

I also wrapped the main logic of `animate_between_matrices()` in an `if` block to check if the user wants the determinant to be smoothed.

```

# 03e154e1326dc256ffc1a539e97d8ef5ec89f6fd
# src/lintrans/gui/main_window.py

26 class LintransMainWindow(QMainWindow):
...
333     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
        None:
334         """Animate from the start matrix to the target matrix."""
335         det_target = linalg.det(matrix_target)
336         det_start = linalg.det(matrix_start)
337
338         for i in range(0, steps + 1):
339             # This proportion is how far we are through the loop
340             proportion = i / steps
341
342             # matrix_a is the start matrix plus some part of the target, scaled by the proportion
343             # If we just used matrix_a, then things would animate, but the determinants would be weird
344             matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
345
346             if self.display_settings.animate_determinant and det_target != 0:
347                 # To fix the determinant problem, we get the determinant of matrix_a and use it to normalise

```

```

348     det_a = linalg.det(matrix_a)
349
350     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
351     # We want B = cA such that det(B) = det(S), where S is the start matrix,
352     # so then we can scale it with the animation, so we get
353     # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
354     # Then we scale A to get the determinant we want, and call that matrix_b
355     if det_a == 0:
356         c = 0
357     else:
358         c = np.sqrt(abs(det_start / det_a))
359
360     matrix_b = c * matrix_a
361     det_b = linalg.det(matrix_b)
362
363     # matrix_to_render is the final matrix that we then render for this frame
364     # It's B, but we scale it over time to have the target determinant
365
366     # We want some C = dB such that det(C) is some target determinant T
367     # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
368
369     # We're also subtracting 1 and multiplying by the proportion and then adding one
370     # This just scales the determinant along with the animation
371     scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
372     matrix_to_render = scalar * matrix_b
373
374     else:
375         matrix_to_render = matrix_a
376
377     if self.is_matrix_too_big(matrix_to_render):
378         self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
379         return
380
381     self.plot.visualize_matrix_transformation(matrix_to_render)
382
383     # We schedule the plot to be updated, tell the event loop to
384     # process events, and asynchronously sleep for 10ms
385     # This allows for other events to be processed while animating, like zooming in and out
386     self.plot.update()
387     QApplication.processEvents()
388     QThread.msleep(1000 // steps)

```

### 3.5.2 Creating the settings dialog

Display settings are good, but useless on their own. My next step was to add a settings dialog that would allow the user to edit these settings.

I first had to create the dialog class itself, so I created the `SettingsDialog` superclass first, so that I could use it for global settings in the future, as well as the specific `DisplaySettingsDialog` subclass now.

As far as I know, a dialog in Qt can't really return a value when it's closed<sup>13</sup>, so the dialog keeps a public instance attribute for the `DisplaySettings` class itself, and then the main window can copy that instance attribute when the dialog is closed.

```

# b1ba4adc3c7723c95b490e831e651a7781af7d99
# src/lintrans/gui/dialogs/settings.py

1  """This module provides dialogs to edit settings within the app."""
2
3  from __future__ import annotations
4
5  import abc

```

---

<sup>13</sup>This is because Qt uses a system of event loops, so the main window continues executing its main loop while the dialog is doing the same. That means that the main window can't wait around for the dialog to close, so nothing can be returned from it.

```
6 import copy
7
8 from PyQt5 import QtWidgets
9 from PyQt5.QtCore import Qt
10 from PyQt5.QtGui import QIntValidator, QKeySequence
11 from PyQt5.QtWidgets import QCheckBox, QDialog, QHBoxLayout, QShortcut, QSizePolicy, QSpacerItem, QVBoxLayout
12
13 from lintrans.gui.settings import DisplaySettings
14
15
16 class SettingsDialog(QDialog):
17     """An abstract superclass for other simple dialogs."""
18
19     def __init__(self, *args, **kwargs):
20         """Create the widgets and layout of the dialog, passing ``*args`` and ``**kwargs`` to super."""
21         super().__init__(*args, **kwargs)
22
23         # === Create the widgets
24
25         self.button_confirm = QtWidgets.QPushButton(self)
26         self.button_confirm.setText('Confirm')
27         self.button_confirm.clicked.connect(self.confirm_settings)
28         self.button_confirm.setToolTip('Confirm these new settings<br><b>(Ctrl + Enter)</b>')
29         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
30
31         self.button_cancel = QtWidgets.QPushButton(self)
32         self.button_cancel.setText('Cancel')
33         self.button_cancel.clicked.connect(self.reject)
34         self.button_cancel.setToolTip('Revert these settings<br><b>(Escape)</b>')
35
36         # === Arrange the widgets
37
38         self.setContentsMargins(10, 10, 10, 10)
39
40         self.hlay_buttons = QHBoxLayout()
41         self.hlay_buttons.setSpacing(20)
42         self.hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
43         self.hlay_buttons.addWidget(self.button_cancel)
44         self.hlay_buttons.addWidget(self.button_confirm)
45
46         self.vlay_options = QVBoxLayout()
47         self.vlay_options.setSpacing(20)
48
49         self.vlay_all = QVBoxLayout()
50         self.vlay_all.setSpacing(20)
51         self.vlay_all.addLayout(self.vlay_options)
52         self.vlay_all.addLayout(self.hlay_buttons)
53
54         self.setLayout(self.vlay_all)
55
56     @abc.abstractmethod
57     def load_settings(self) -> None:
58         """Load the current settings into the widgets."""
59
60     @abc.abstractmethod
61     def confirm_settings(self) -> None:
62         """Confirm the settings chosen in the dialog."""
63
64
65 class DisplaySettingsDialog(SettingsDialog):
66     """The dialog to allow the user to edit the display settings."""
67
68     def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
69         """Create the widgets and layout of the dialog.
70
71         :param DisplaySettings display_settings: The :class:`lintrans.gui.settings.DisplaySettings` object to mutate
72         """
73         super().__init__(*args, **kwargs)
74
75         self.display_settings = display_settings
76         self.setWindowTitle('Change display settings')
77
78         # === Create the widgets
```



```

79
80     font_label = self.font()
81     font_label.setUnderline(True)
82     font_label.setPointSize(int(font_label.pointSize() * 1.2))
83
84     self.label_animations = QtWidgets.QLabel(self)
85     self.label_animations.setText('Animations')
86     self.label_animations.setAlignment(Qt.AlignCenter)
87     self.label_animations.setFont(font_label)
88
89     self.checkbox_animate_determinant = QCheckBox(self)
90     self.checkbox_animate_determinant.setText('Animate determinant')
91     self.checkbox_animate_determinant.setToolTip('Smoothly animate the determinant during animation')
92
93     self.checkbox_applicative_animation = QCheckBox(self)
94     self.checkbox_applicative_animation.setText('Applicative animation')
95     self.checkbox_applicative_animation.setToolTip(
96         'Animate the new transformation applied to the current one,\n'
97         'rather than just that transformation on its own'
98     )
99
100    self.label_animation_pause_length = QtWidgets.QLabel(self)
101    self.label_animation_pause_length.setText('Animation pause length (ms)')
102    self.label_animation_pause_length.setToolTip(
103        'How many milliseconds to pause for in comma-separated animations'
104    )
105
106    self.lineedit_animation_pause_length = QtWidgets.QLineEdit(self)
107    self.lineedit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
108
109    # === Arrange the widgets
110
111    self.hlay_animation_pause_length = QHBoxLayout()
112    self.hlay_animation_pause_length.addWidget(self.label_animation_pause_length)
113    self.hlay_animation_pause_length.addWidget(self.lineedit_animation_pause_length)
114
115    self.vlay_options.addWidget(self.label_animations)
116    self.vlay_options.addWidget(self.checkbox_animate_determinant)
117    self.vlay_options.addWidget(self.checkbox_applicative_animation)
118    self.vlay_options.addLayout(self.hlay_animation_pause_length)
119
120    # Finally, we load the current settings
121    self.load_settings()
122
123    def load_settings(self) -> None:
124        """Load the current display settings into the widgets."""
125        self.checkbox_animate_determinant.setChecked(self.display_settings.animate_determinant)
126        self.checkbox_applicative_animation.setChecked(self.display_settings.applicative_animation)
127        self.lineedit_animation_pause_length.setText(str(self.display_settings.animation_pause_length))
128
129    def confirm_settings(self) -> None:
130        """Build a :class:`lintrans.gui.settings.DisplaySettings` object and assign it."""
131        self.display_settings.animate_determinant = self.checkbox_animate_determinant.isChecked()
132        self.display_settings.applicative_animation = self.checkbox_applicative_animation.isChecked()
133        self.display_settings.animation_pause_length = int(self.lineedit_animation_pause_length.text())
134
135    self.accept()

```

I then just had to enable the button in the main GUI and implement the method to open the new dialog. I have to use a lambda to capture the local dialog variable, but a separate method to actually assign its display settings, since Python doesn't allow assignments in lambda expressions.

```

# b1ba4adc3c7723c95b490e831e651a7781af7d99
# src/lintrans/gui/main_window.py

```

```

27 class LintransMainWindow(QMainWindow):
...
436     def dialog_change_display_settings(self) -> None:
437         """Open the dialog to change the display settings."""
438         dialog = DisplaySettingsDialog(self.display_settings, self)

```

```

439     dialog.open()
440     dialog.finished.connect(lambda: self._assign_display_settings(dialog.display_settings))
441
442     def _assign_display_settings(self, display_settings: DisplaySettings) -> None:
443         """Assign a new value to `self.display_settings`."""
444         self.display_settings = display_settings

```

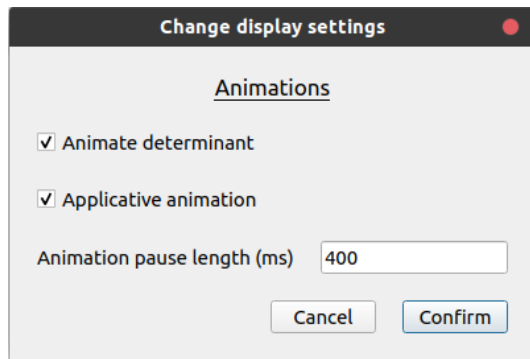


Figure 3.17: The display settings dialog

The `dialog.finished` signal on line 440 should really be `dialog.accepted`. Currently, we re-assign the display settings whenever the dialog is closed in any way. Really, we should only re-assign them when the user hits the confirm button, but trying to cancel the changes will currently save them. This was a silly mistake and I fixed it along with some similar signal-related bugs a few weeks later.

### 3.5.3 Fixing a bug with transitional animation

While playing around with these new display settings, I encountered a bug with transitional animation. When you animate an expression with transitional animation and then animate the same thing again, nothing happens. This is because the app tries to transition from the starting position to the target position, but they are the same position, so nothing moves.

To fix this, I had to check if the start and target matrices were the same (within floating point error), and then reset the viewport to the identity first, before animating to the target as requested.

```

# fa4a65540749e84b750ddea8abfd36a86c224b47
# src/lintrans/gui/main_window.py

27 class LintransMainWindow(QMainWindow):
...
285     def animate_expression(self) -> None:
...
315     else:
...
328         # If we want a transitional animation and we're animating the same matrix, then restart the animation
329         # We use this check rather than equality because of small floating point errors
330         elif (matrix_start - matrix_target < 1e-12).all():
331             matrix_start = self.matrix_wrapper['I']
332
333         # We pause here for 200 ms to make the animation look a bit nicer
334         self.plot.visualize_matrix_transformation(matrix_start)
335         self.plot.update()
336         QApplication.processEvents()
337         QThread.sleep(200)

```

I later found a bug on line 330. If we subtract the start and target matrices and get a matrix of all negative numbers (rather than all zeroes, which is what I wanted to check for), then the if condition will still be true. That means that some completely different matrices can be considered the same, and the viewport will reset before animating them. To fix this, I can simply take the absolute value.

```

# 3c490c48a0f4017ab8ee9cf471a65c251817b00e
# src/lintrans/gui/main_window.py

333     elif (abs(matrix_start - matrix_target) < 1e-12).all():

```

### 3.5.4 Adding the determinant parallelogram

The determinant can be represented as the area of the parallelogram formed by the basis vectors. This would be good to visualize in the app.

To do that, I had to add a setting to the display settings, create a function to actually draw it in `VectorGridPlot`, and call that function from `paintEvent()`.

```
# e9e76c1d4f28452efc6ae18afb936616006fd04a
# src/lintrans/gui/settings.py

9 class DisplaySettings:
...
26     draw_determinant_parallelogram: bool = False
27     """This controls whether or not we should shade the parallelogram representing the determinant of the matrix."""

# e9e76c1d4f28452efc6ae18afb936616006fd04a
# src/lintrans/gui/plots/classes.py

140 class VectorGridPlot(BackgroundPlot):
...
385     def draw_determinant_parallelogram(self, painter: QPainter) -> None:
386         """Draw the parallelogram of the determinant of the matrix."""
387         path = QPainterPath()
388         path.moveTo(*self.canvas_origin)
389         path.lineTo(*self.canvas_coords(*self.point_i))
390         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
391         path.lineTo(*self.canvas_coords(*self.point_j))
392
393         brush = QBrush(QColor(16, 235, 253, alpha=128), Qt.SolidPattern)
394         painter.fillPath(path, brush)

# e9e76c1d4f28452efc6ae18afb936616006fd04a
# src/lintrans/gui/plots/widgets.py

13 class VisualizeTransformationWidget(VectorGridPlot):
...
42     def paintEvent(self, event: QPaintEvent) -> None:
43         """Handle a ``QPaintEvent`` by drawing the background grid and the transformed grid.
44
45         The transformed grid is defined by the basis vectors i and j, which can
46         be controlled with the :meth:`visualize_matrix_transformation` method.
47         """
48         painter = QPainter()
49         painter.begin(self)
50
51         painter.setRenderHint(QPainter.Antialiasing)
52         painter.setBrush(Qt.NoBrush)
53
54         self.draw_background(painter)
55         self.draw_transformed_grid(painter)
56         self.draw_vector_arrowheads(painter)
57
58         if self.display_settings.draw_determinant_parallelogram:
59             self.draw_determinant_parallelogram(painter)
60
61         painter.end()
62         event.accept()
```

I then wanted to change the determinant parallelogram to be blue when it's positive and red when it's negative. I did this by just checking the sign of the determinant and changing the colour accordingly.

```
# cc75c7dc85e941540f7e98fe027d0657ad5462b8
# src/lintrans/gui/plots/classes.py

140 class VectorGridPlot(BackgroundPlot):
```

```

...
385     def draw_determinant_parallelogram(self, painter: QPainter) -> None:
386         """Draw the parallelogram of the determinant of the matrix."""
387         det = np.linalg.det(np.array([
388             [self.point_i[0], self.point_j[0]],
389             [self.point_i[1], self.point_j[1]]
390         ]))
391
392         if det == 0:
393             return
394
395         path = QPainterPath()
396         path.moveTo(*self.canvas_origin)
397         path.lineTo(*self.canvas_coords(*self.point_i))
398         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
399         path.lineTo(*self.canvas_coords(*self.point_j))
400
401         color = (16, 235, 253) if det > 0 else (253, 34, 16)
402         brush = QBrush(QColor(*color, alpha=128), Qt.SolidPattern)
403
404         painter.fillPath(path, brush)

```

I then had the determinant parallelogram for positive and negative determinants.

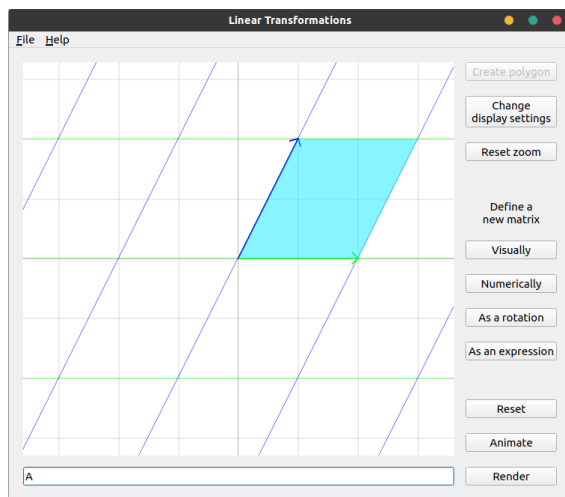


Figure 3.18: The blue parallelogram

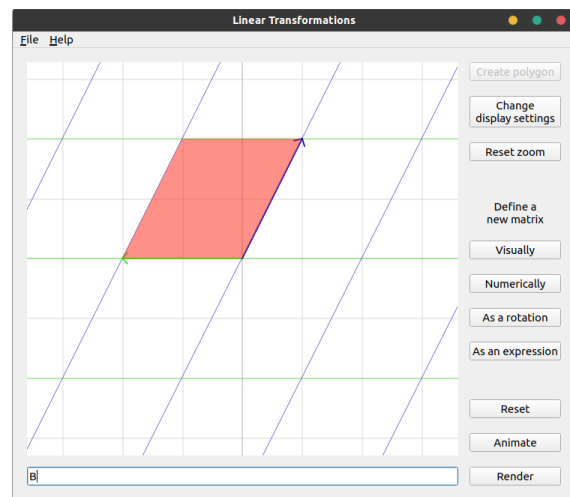


Figure 3.19: The red parallelogram

### 3.5.5 Adding the determinant text

Seeing the determinant as a shape is one thing, but knowing its exact value is also often very useful. To do this, I had to add a variable in the `DisplaySettings` for it, add a checkbox in the `DisplaySettingsDialog`, and create a method to actually draw the text in the right place, which I can call from `paintEvent()`.

```

# e344e50eccfd87c0834cfbdf459f0dd1d555fcd6
# src/lintrans/gui/settings.py

9  class DisplaySettings:
...
35     draw_determinant_text: bool = True
36     """This controls whether we should write the text value of the determinant.
37
38     The text only gets draw if :attr:`draw_determinant_parallelogram` is also True.
39     """

# e344e50eccfd87c0834cfbdf459f0dd1d555fcd6
# src/lintrans/gui/dialogs/settings.py

```

```

63 class DisplaySettingsDialog(SettingsDialog):
64     ...
65     def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
66         ...
108         self.checkbox_draw_determinant_text = QCheckBox(self)
109         self.checkbox_draw_determinant_text.setText('Draw determinant text')
110         self.checkbox_draw_determinant_text.setToolTip(
111             'Write the text value of the determinant inside the parallelogram'
112         )

# e344e50eccfd87c0834cfbdf459f0dd1d555fcd6
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
143     ...
146     def draw_determinant_text(self, painter: QPainter) -> None:
147         """Write the string value of the determinant in the middle of the parallelogram."""
148         painter.setPen(QPen(QColor(0, 0, 0), self.width_vector_line))
149         painter.drawText(
150             *self.canvas_coords(
151                 (self.point_i[0] + self.point_j[0]) / 2,
152                 (self.point_i[1] + self.point_j[1]) / 2
153             ),
154             f'{self.det:.2f}'
155         )

```

It doesn't make much sense to show the text without also showing the parallelogram, so we should only show the text when the parallelogram is also being shown, and the checkbox for the text should only be clickable when the parallelogram is enabled.

To do this, I created an `update_gui()` method which gets called when the parallelogram checkbox is clicked. This method will enable or disable the text checkbox appropriately.

```

# e344e50eccfd87c0834cfbdf459f0dd1d555fcd6
# src/lintrans/gui/plots/widgets.py

13 class VisualizeTransformationWidget(VectorGridPlot):
14     ...
42     def paintEvent(self, event: QPaintEvent) -> None:
15         ...
58         if self.display_settings.draw_determinant_parallelogram:
59             self.draw_determinant_parallelogram(painter)
60
61         if self.display_settings.draw_determinant_text:
62             self.draw_determinant_text(painter)

# 517773e1ace0dc4485c425134cd36ba482ba65df
# src/lintrans/gui/dialogs/settings.py

63 class DisplaySettingsDialog(SettingsDialog):
64     ...
66     def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
67         ...
107         self.checkbox_draw_determinant_parallelogram.clicked.connect(self.update_gui)
108
109     def update_gui(self) -> None:
110         """Update the GUI according to other widgets in the GUI.
111
112         For example, this method updates which checkboxes are enabled based on the values of other checkboxes.
113         """
114         self.checkbox_draw_determinant_text.setEnabled(self.checkbox_draw_determinant_parallelogram.isChecked())

```

## 3.6 Fixing bugs and adding polish

### 3.6.1 Fixing an animation crash

The scaling logic in 3.3.6 creates a matrix **A** which is the start matrix plus some proportion of the difference between the target and start matrices. It then defines matrix **B** to be the matrix **A** normalised to have a determinant of 1. We then divide by  $\det(\mathbf{B})$  to get matrix **C**, which we then render.

This works very well for most matrices, but if we're animating from **I** to  $-\mathbf{I}$  for example, then we can get the following problem:

When we're halfway through the animation,  $p = \frac{1}{2}$ .

$$\begin{aligned}\mathbf{A} &= \mathbf{S} + p(\mathbf{T} - \mathbf{S}) \\ &= \mathbf{I} + \frac{1}{2}(-\mathbf{I} - \mathbf{I}) \\ &= \mathbf{I} + \frac{-1}{2}\mathbf{I} \\ &= \mathbf{I} - \mathbf{I} = \mathbf{0}\end{aligned}$$

I'm using **I** as an example here, but this can happen with the right  $p$  for many matrix pairs. Since  $\mathbf{A} = \mathbf{0}$ ,  $\det(\mathbf{A}) = 0$ . We check for this case already when we find  $c$ :

```
# f7a91cdc35695f8fb9269b17bc103e42578072bd
# src/lintrans/gui/main_window.py

367         if det_a == 0:
368             c = 0
369         else:
370             c = np.sqrt(abs(det_start / det_a))
```

But if  $\det(\mathbf{A}) = 0$ , then  $c = 0$  and  $\det(\mathbf{B}) = 0$ , so we also need to check that before we divide by it.

Old:

```
# f7a91cdc35695f8fb9269b17bc103e42578072bd
# src/lintrans/gui/main_window.py

383         scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
384         matrix_to_render = scalar * matrix_b
```

New:

```
# 4383808a4cc29d192c55aca56161d8affda8c9a7
# src/lintrans/gui/main_window.py

384         # That is all of course, if we can do that
385         # We'll crash if we try to do this with det(B) == 0
386         if det_b != 0:
387             scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
388             matrix_to_render = scalar * matrix_b
389
390         else:
391             matrix_to_render = matrix_a
```

This change fixes a division by zero bug, which eliminates a possible crash here.

### 3.6.2 Limiting parallel lines

If you try to render a matrix like `0.01Irot(45)`, then the app ends up drawing as many parallel lines as it can physically fit in the viewport. This leads to a lot of lag, especially when zoomed out far. To fix this, I just introduced a maximum number of parallel lines. I chose 150 as a number that was big enough to have enough parallel lines for matrices that need a lot, while also causing virtually no lag.

```
# bd9aaa2e3037214f65d0fc1d12d67db35af0e5ec
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
...
151     def __init__(self, *args, **kwargs):
...
169         self.max_parallel_lines = 150

# bd9aaa2e3037214f65d0fc1d12d67db35af0e5ec
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
...
191     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
        ↪ None:
...
230         # Draw vertical lines
231         elif abs(vector_x) < 1e-12:
232             painter.drawLine(self.canvas_x(0), 0, self.canvas_x(0), self.height())
233
234             for i in range(max(abs(int(max_x / point_x)), self.max_parallel_lines)):
235                 painter.drawLine(
236                     self.canvas_x((i + 1) * point_x),
237                     0,
238                     self.canvas_x((i + 1) * point_x),
239                     self.height()
240                 )
241                 painter.drawLine(
242                     self.canvas_x(-1 * (i + 1) * point_x),
243                     0,
244                     self.canvas_x(-1 * (i + 1) * point_x),
245                     self.height()
246                 )
247
248         # Draw horizontal lines
249         elif abs(vector_y) < 1e-12:
250             painter.drawLine(0, self.canvas_y(0), self.width(), self.canvas_y(0))
251
252             for i in range(max(abs(int(max_y / point_y)), self.max_parallel_lines)):
253                 painter.drawLine(
254                     0,
255                     self.canvas_y((i + 1) * point_y),
256                     self.width(),
257                     self.canvas_y((i + 1) * point_y)
258                 )
259                 painter.drawLine(
260                     0,
261                     self.canvas_y(-1 * (i + 1) * point_y),
262                     self.width(),
263                     self.canvas_y(-1 * (i + 1) * point_y)
264                 )
265
266         # If the line is oblique, then we can use y = mx + c
267         else:
268             m = vector_y / vector_x
269             c = point_y - m * point_x
270
271             self.draw_oblique_line(painter, m, 0)
272
273         # We don't want to overshoot the max number of parallel lines,
274         # but we should also stop looping as soon as we can't draw any more lines
```

```

275         for i in range(1, self.max_parallel_lines + 1):
276             if not self.draw_pair_of_oblique_lines(painter, m, i * c):
277                 break

```

The idea behind this code is just to limit the maximum number of parallel lines that get drawn. It works perfectly for oblique lines, but there's a small bug for orthogonal lines that I never noticed. I just forgot to test it.

On lines 234 and 252, I call the built-in `max()` function with the maximum number of parallel lines and the total number of lines that could fit in the viewport. This should be a call to `min()` instead. I fixed this before releasing it for my end users, but it took an embarrassingly long time to notice something this simple.

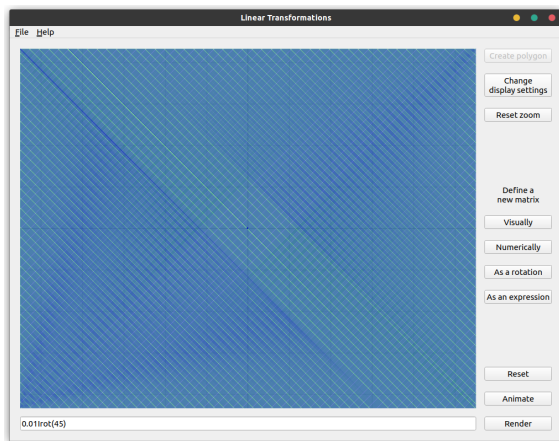


Figure 3.20: The old version with too many parallel lines.

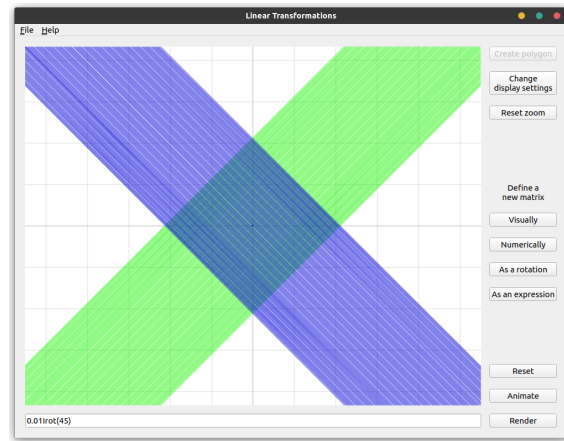


Figure 3.21: The fixed version with a maximum number of parallel lines.

### 3.6.3 Giving focus to the expression box

It would be quite nice to be able to just start typing an expression after defining a matrix or changing display settings. To do this, we can simply set the app's focus on the expression box after either of these actions.

Additionally, it would be nice to update the render buttons at the same time. That would allow the user to use a matrix in an expression, then define it, and be able to render the expression as soon as they close the dialog (assuming the expression is valid).

```

# bd7f8ba18266a8a095549d815dcfe6f24de514b6
# src/lintrans/gui/main_window.py

27 class LintransMainWindow(QMainWindow):
...
438     def assign_matrix_wrapper(self, matrix_wrapper: MatrixWrapper) -> None:
439         """Assign a new value to ``self.matrix_wrapper`` and give the expression box focus.
440
441         :param matrix_wrapper: The new value of the matrix wrapper to assign
442         :type matrix_wrapper: MatrixWrapper
443         """
444         self.matrix_wrapper = matrix_wrapper
445         self.linedit_expression_box.setFocus()
446         self.update_render_buttons()
...
454     def assign_display_settings(self, display_settings: DisplaySettings) -> None:
455         """Assign a new value to ``self.plot.display_settings`` and give the expression box focus."""
456         self.plot.display_settings = display_settings
457         self.plot.update()

```



```

458         self.lineEdit_expression_box.setFocus()
459         self.update_render_buttons()

```

### 3.6.4 Fixing a crash when animating singular matrices in sequence

If we have a matrix  $\mathbf{A}$  defined as  $\begin{pmatrix} 1 & 2 \\ 1 & 2 \end{pmatrix}$ , then when we try to render  $\mathbf{A}^{-1}$ , we get a pop-up dialog box saying that we can't take the inverse of a singular matrix. This is good, since if NumPy just took the inverse blindly, it would crash. When we try to animate  $\mathbf{A}^{-1}$ , we get the same pop-up box. When we try to use it in an animation sequence, however, like `rot(45), A-1`, we don't check if each element of the sequence for singularity, so NumPy takes the inverse blindly and the whole app crashes. This is bad.

To fix this, we can simply catch the error when trying to evaluate the element in the sequence.

```

# 8db0df1d9d6a1be1f15a6f705e779d982db9ee29
# src/lintrans/gui/main_window.py

27 class LintransMainWindow(QMainWindow):
...
287     def animate_expression(self) -> None:
...
300         if ',' in text:
301             current_matrix = matrix_start
302
303             # For each expression in the list, right multiply it by the current matrix,
304             # and animate from the current matrix to that new matrix
305             for expr in text.split(',')[:-1]:
306                 try:
307                     new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
308                 except linalg.LinAlgError:
309                     self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
310                 return

```

### 3.6.5 Allowing animations to be cancelled

Currently, if you try to reset the viewport partway through an animation, it just resets the basis vectors for a tick, but then they start moving again, because the animation loop is still running. To fix this, we can track whether we should be animating using an instance variable, set it to false when the user hits reset, and break out of the animation loop when it's false.

```

# b665bc59ec99664ed7b2c17f94e76ae49c6eb331
# src/lintrans/gui/main_window.py

27 class LintransMainWindow(QMainWindow):
...
33     def __init__(self):
...
45         self.animating: bool = False
46         self.animating_sequence: bool = False
...
269     def reset_transformation(self) -> None:
270         """Reset the visualized transformation back to the identity."""
271         self.plot.visualize_matrix_transformation(self.matrix_wrapper['I'])
272         self.animating = False
273         self.animating_sequence = False
274         self.plot.update()
...
292     def animate_expression(self) -> None:
...
304         # If there's commas in the expression, then we want to animate each part at a time
305         if ',' in text:
306             current_matrix = matrix_start

```

```

307         self.animating_sequence = True
308
309         # For each expression in the list, right multiply it by the current matrix,
310         # and animate from the current matrix to that new matrix
311         for expr in text.split(',')[:-1]:
312             try:
313                 new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
314             except linalg.LinAlgError:
315                 self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
316                 return
317
318             if not self.animating_sequence:
319                 break
320
321             self.animate_between_matrices(current_matrix, new_matrix)
322             current_matrix = new_matrix
323
324             # Here we just redraw and allow for other events to be handled while we pause
325             self.plot.update()
326             QApplication.processEvents()
327             QThread.sleep(self.plot.display_settings.animation_pause_length)
328
329         self.animating_sequence = False
330
331     ...
360     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
361     ↪ None:
362
363     ...
365         self.animating = True
366
367         for i in range(0, steps + 1):
368             if not self.animating:
369                 break
370
371     ...
429         self.animating = False

```

Here, `self.animating_sequence` is whether a sequence is being animated, and `self.animating` is whether an individual matrix is currently being animated. An individual matrix means a matrix on its own, or a single element in a sequence. That means that `self.animating` can be set and unset multiple times in a single sequence.

### 3.6.6 Validating expression input

The user can only render or animate an expression if it's actually valid, as discussed in §3.1.3, and the render and animate buttons will be greyed out if the expression is invalid. But they can still type anything into the box.

It was at this point that I learned about the `QValidator` class[20]. This class allows me to control what the user can actually type. Using the implementation below, they can only enter characters that are allowed in valid matrix expressions.

```

# f73575c017548d754e4171449344a52cb44b7ef4
# src/lintrans/gui/main_window.py

28 class LintransMainWindow(QMainWindow):
29
30     ...
34     def __init__(self):
35
36     ...
125         self.lineedit_expression_box.setValidator(MatrixExpressionValidator(self))
126
127
# f73575c017548d754e4171449344a52cb44b7ef4
# src/lintrans/gui/validate.py

1 """This simple module provides a :class:`MatrixExpressionValidator` class to validate matrix expression input."""
2

```

```

3  from __future__ import annotations
4
5  import re
6
7  from PyQt5.QtGui import QValidator
8
9  from lintrans.matrices import parse
10
11
12  class MatrixExpressionValidator(QValidator):
13      """This class validates matrix expressions in an Qt input box."""
14
15      def validate(self, text: str, pos: int) -> tuple[QValidator.State, str, int]:
16          """Validate the given text according to the rules defined in the :mod:`lintrans.matrices` module."""
17          clean_text = re.sub(r'[\sA-Z\d.rot()^{}+,-]', '', text)
18
19          if clean_text == '':
20              if parse.validate_matrix_expression(clean_text):
21                  return QValidator.Acceptable, text, pos
22              else:
23                  return QValidator.Intermediate, text, pos
24
25          return QValidator.Invalid, text, pos
26

```

I also then added validators to the definition dialogs, to make sure that users can only enter valid input. Qt5 provides some basic validators already, for things like integers and floating point numbers (called **double** in C++, equivalent to **float** in Python).

```

# a2fd14b99fa752a18b42352a01142ffbc2600570
# src/lintrans/gui/dialogs/define_new_matrix.py

```

```

213  class DefineNumericallyDialog(Definedialog):
214      ...
225      # tl = top left, br = bottom right, etc.
226      self.element_tl = QtWidgets.QLineEdit(self)
227      self.element_tl.textChanged.connect(self.update_confirm_button)
228      self.element_tl.setValidator(QDoubleValidator())
229
230      self.element_tr = QtWidgets.QLineEdit(self)
231      self.element_tr.textChanged.connect(self.update_confirm_button)
232      self.element_tr.setValidator(QDoubleValidator())
233
234      self.element_bl = QtWidgets.QLineEdit(self)
235      self.element_bl.textChanged.connect(self.update_confirm_button)
236      self.element_bl.setValidator(QDoubleValidator())
237
238      self.element_br = QtWidgets.QLineEdit(self)
239      self.element_br.textChanged.connect(self.update_confirm_button)
240      self.element_br.setValidator(QDoubleValidator())
241      ...
299  class DefineAsARotationDialog(Definedialog):
300      ...
314      self.lineedit_angle = QtWidgets.QLineEdit(self)
315      self.lineedit_angle.setPlaceholderText('angle')
316      self.lineedit_angle.textChanged.connect(self.update_confirm_button)
317      self.lineedit_angle.setValidator(QDoubleValidator())
318      ...
358  class DefineAsAnExpressionDialog(Definedialog):
359      ...
372      self.lineedit_expression_box = QtWidgets.QLineEdit(self)
373      self.lineedit_expression_box.setPlaceholderText('Enter matrix expression...')
374      self.lineedit_expression_box.textChanged.connect(self.update_confirm_button)
375      self.lineedit_expression_box.setValidator(MatrixExpressionValidator())

```

### 3.6.7 Adding keyboard shortcuts

Keyboard shortcuts are often very useful and can make the process of using software much more efficient if you get good at using the shortcuts. On this note, I decided to add keyboard shortcuts to the display settings dialog.

Qt5 lets you use a & character in the text of a widget to act on the letter following it. This letter becomes underlined in the text, and the user can hold Alt and press this letter to activate the widget. I also want to be able to toggle the checkboxes by just pressing the letter without holding Alt, so I had to implement this myself with a dictionary and custom override of `keyPressEvent()`.

```
# 67d43a364ee2605b95b8caca9f1e4eb714cbb7c6
# src/lintrans/gui/dialogs/settings.py

class DisplaySettingsDialog(SettingsDialog):
    """The dialog to allow the user to edit the display settings."""

    def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
        """Create the widgets and layout of the dialog.

        :param DisplaySettings display_settings: The :class:`lintrans.gui.settings.DisplaySettings` object to mutate
        """
        super().__init__(*args, **kwargs)

        self.display_settings = display_settings
        self.setWindowTitle('Change display settings')

        self.dict_checkboxes: dict[str, QCheckBox] = dict()

        # === Create the widgets

        # Animations

        self.checkbox_smoother_determinant = QCheckBox(self)
        self.checkbox_smoother_determinant.setText('&Smoother determinant')
        self.checkbox_smoother_determinant.setToolTip(
            'Smoothly animate the determinant transition during animation (if possible)'
        )
        self.dict_checkboxes['s'] = self.checkbox_smoother_determinant

        self.checkbox_applicative_animation = QCheckBox(self)
        self.checkbox_applicative_animation.setText('&Applicative animation')
        self.checkbox_applicative_animation.setToolTip(
            'Animate the new transformation applied to the current one,\n'
            'rather than just that transformation on its own'
        )
        self.dict_checkboxes['a'] = self.checkbox_applicative_animation

        self.label_animation_pause_length = QtWidgets.QLabel(self)
        self.label_animation_pause_length.setText('Animation pause length (ms)')
        self.label_animation_pause_length.setToolTip(
            'How many milliseconds to pause for in comma-separated animations'
        )

        self.lineEdit_animation_pause_length = QtWidgets.QLineEdit(self)
        self.lineEdit_animation_pause_length.setValidator(QIntValidator(1, 999, self))

        # Matrix info

        self.checkbox_draw_determinant_parallelogram = QCheckBox(self)
        self.checkbox_draw_determinant_parallelogram.setText('Draw &determinant parallelogram')
        self.checkbox_draw_determinant_parallelogram.setToolTip(
            'Shade the parallelogram representing the determinant of the matrix'
        )
        self.checkbox_draw_determinant_parallelogram.clicked.connect(self.update_gui)
        self.dict_checkboxes['d'] = self.checkbox_draw_determinant_parallelogram

        self.checkbox_draw_determinant_text = QCheckBox(self)
        self.checkbox_draw_determinant_text.setText('Draw determinant &text')
        self.checkbox_draw_determinant_text.setToolTip(
```

```

119         'Write the text value of the determinant inside the parallelogram'
120     )
121     self.dict_checkboxes['t'] = self.checkbox_draw_determinant_text
122
123     # === Arrange the widgets in QGroupBoxes
124
125     # Animations
126
127     self.hlay_animation_pause_length = QHBoxLayout()
128     self.hlay_animation_pause_length.addWidget(self.label_animation_pause_length)
129     self.hlay_animation_pause_length.addWidget(self.lineedit_animation_pause_length)
130
131     self.vlay_groupbox_animations = QVBoxLayout()
132     self.vlay_groupbox_animations.setSpacing(20)
133     self.vlay_groupbox_animations.addWidget(self.checkbox_smooththen_determinant)
134     self.vlay_groupbox_animations.addWidget(self.checkbox_applicative_animation)
135     self.vlay_groupbox_animations.addLayout(self.hlay_animation_pause_length)
136
137     self.groupbox_animations = QGroupBox('Animations', self)
138     self.groupbox_animations.setLayout(self.vlay_groupbox_animations)
139
140     # Matrix info
141
142     self.vlay_groupbox_matrix_info = QVBoxLayout()
143     self.vlay_groupbox_matrix_info.setSpacing(20)
144     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_draw_determinant_parallelogram)
145     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_draw_determinant_text)
146
147     self.groupbox_matrix_info = QGroupBox('Matrix info', self)
148     self.groupbox_matrix_info.setLayout(self.vlay_groupbox_matrix_info)
149
150     self.vlay_options.addWidget(self.groupbox_animations)
151     self.vlay_options.addWidget(self.groupbox_matrix_info)
152
153     # Finally, we load the current settings and update the GUI
154     self.load_settings()
155     self.update_gui()
156
157     ...
158
159     def keyPressEvent(self, event: QKeyEvent) -> None:
160         """Handle a `QKeyEvent` by manually activating toggling checkboxes.
161
162         Qt handles these shortcuts automatically and allows the user to do `Alt + Key`
163         to activate a simple shortcut defined with `&`. However, I like to be able to
164         just hit `Key` and have the shortcut activate.
165         """
166         letter = event.text().lower()
167         key = event.key()
168
169         if letter in self.dict_checkboxes:
170             self.dict_checkboxes[letter].animateClick()
171
172         # Return or keypad enter
173         elif key == 0x01000004 or key == 0x01000005:
174             self.button_confirm.click()
175
176         # Escape
177         elif key == 0x01000000:
178             self.button_cancel.click()
179
180         else:
181             event.ignore()

```

### 3.6.8 Centering text in the determinant parallelogram

The text in the determinant parallelogram is the numerical value of the determinant. Currently, it's not centered. It's drawn by just writing the text at a point, chosen to be the centre of the parallelogram. The `QPainter` class uses this point as the start of the baseline of the text, so it's effectively the bottom left corner.

```

# 67d43a364ee2605b95b8caca9f1e4eb714cbb7c6
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
143     ...
144     def draw_determinant_text(self, painter: QPainter) -> None:
145         """Write the string value of the determinant in the middle of the parallelogram."""
146         painter.setPen(QPen(QColor(0, 0, 0), self.width_vector_line))
147         painter.drawText(
148             *self.canvas_coords(
149                 (self.point_i[0] + self.point_j[0]) / 2,
150                 (self.point_i[1] + self.point_j[1]) / 2
151             ),
152             f'{self.det:.2f}'
153         )

```

Obviously, this text will look better if it's centered. To do this, we can create a bounding rectangle around the parallelogram and get the painter to draw the text in the centre of that rectangle.

We build the rectangle by getting the coordinates of each vertex of the parallelogram. Then the top left corner is the minimum  $x$  coordinate with the maximum  $y$  coordinate, and the bottom right corner is the maximum  $x$  with the minimum  $y$ .

```

# 9550416c0b273b16c90eb8d6319f5e17493ef9a8
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
143     ...
144     def draw_determinant_text(self, painter: QPainter) -> None:
145         """Write the string value of the determinant in the middle of the parallelogram."""
146         painter.setPen(QPen(QColor(0, 0, 0), self.width_vector_line))
147
148         # We're building a QRect that encloses the determinant parallelogram
149         # Then we can center the text in this QRect
150         coords: list[tuple[float, float]] = [
151             (0, 0),
152             self.point_i,
153             self.point_j,
154             (
155                 self.point_i[0] + self.point_j[0],
156                 self.point_i[1] + self.point_j[1]
157             )
158         ]
159
160         xs = [t[0] for t in coords]
161         ys = [t[1] for t in coords]
162
163         top_left = QPoint(*self.canvas_coords(min(xs), max(ys)))
164         bottom_right = QPoint(*self.canvas_coords(max(xs), min(ys)))
165
166         rect = QRectF(top_left, bottom_right)
167
168         painter.drawText(
169             rect,
170             Qt.AlignHCenter | Qt.AlignVCenter,
171             f'{self.det:.2f}'
172         )

```

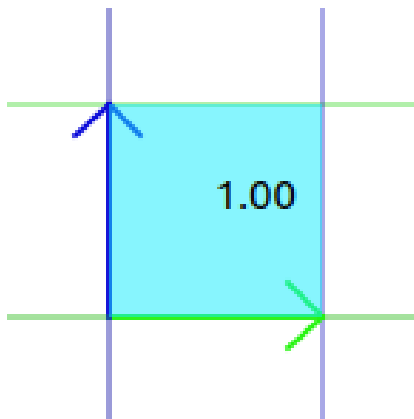


Figure 3.22: Text not centered.

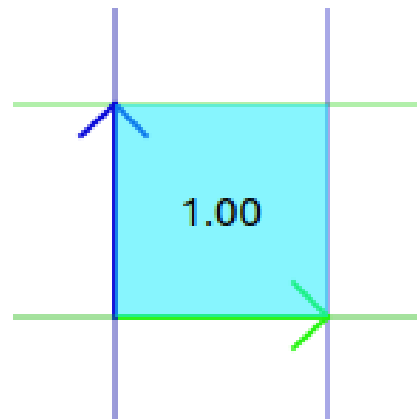


Figure 3.23: Text centered.

### 3.6.9 Defining matrices as expressions

Currently, you can “define” a matrix in terms of an expression, but it doesn’t really define the matrix like that. Instead, it evaluates the expression immediately, and assigns that numerical result to the name you specified. It would be much better if the matrix could be actually defined as the expression, and then evaluated only when it needs to be used. Then, the user could have a matrix **M** defined as something like  $0.5A - 1\text{rot}(45)B$ , and it would always have that value, even if the user has changed the definition of **A** or **B** since defining **M**.

To do this, I’ll have to completely change how matrices are stored and retrieved. The `MatrixWrapper` class contains a dictionary `self._matrices`, which currently maps `str` to `Optional[MatrixType]`, meaning that a matrix could be a  $2 \times 2$  NumPy array, or nothing. I’m going to change this type to `Optional[Union[MatrixType, str]]`. This means that if a matrix exists, then it’s either a  $2 \times 2$  NumPy array or a string. We then check which one it is when we retrieve the matrix, and act accordingly. If it’s an expression, then we evaluate and return the numerical result.

Here’s the relevant parts of the old `MatrixWrapper` class:

```
# 9550416c0b273b16c90eb8d6319f5e17493ef9a8
# src/lintrans/matrices/wrapper.py

17 class MatrixWrapper:
...
35     def __init__(self):
36         """Initialise a :class:`MatrixWrapper` object with a dictionary of matrices which can be accessed."""
37         self._matrices: dict[str, Optional[MatrixType]] = {
38             'A': None, 'B': None, 'C': None, 'D': None,
39             'E': None, 'F': None, 'G': None, 'H': None,
40             'I': np.eye(2), # I is always defined as the identity matrix
41             'J': None, 'K': None, 'L': None, 'M': None,
42             'N': None, 'O': None, 'P': None, 'Q': None,
43             'R': None, 'S': None, 'T': None, 'U': None,
44             'V': None, 'W': None, 'X': None, 'Y': None,
45             'Z': None
46         }
...
91     def __getitem__(self, name: str) -> Optional[MatrixType]:
92         """Get the matrix with the given name.
93
94         If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)``, with
95         a given angle in degrees, then we return a new matrix representing a rotation by that angle.
96
97         :param str name: The name of the matrix to get
98         :returns: The value of the matrix (may be None)
99         :rtype: Optional[MatrixType]
100
```

```

101         :raises NameError: If there is no matrix with the given name
102         """
103         # Return a new rotation matrix
104         if (match := re.match(r'rot\((-?\d*\.\d*)\)', name)) is not None:
105             return create_rotation_matrix(float(match.group(1)))
106
107         if name not in self._matrices:
108             raise NameError(f'Unrecognised matrix name "{name}"')
109
110         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
111         return copy(self._matrices[name])
112
113     def __setitem__(self, name: str, new_matrix: Optional[MatrixType]) -> None:
114         """Set the value of matrix ``name`` with the new_matrix.
115
116         :param str name: The name of the matrix to set the value of
117         :param Optional[MatrixType] new_matrix: The value of the new matrix (may be None)
118
119         :raises NameError: If the name isn't a valid matrix name or is 'I'
120         :raises TypeError: If the matrix isn't a valid 2x2 NumPy array
121         """
122         if name not in self._matrices:
123             raise NameError('Matrix name must be a single capital letter')
124
125         if name == 'I':
126             raise NameError('Matrix name cannot be "I"')
127
128         if new_matrix is None:
129             self._matrices[name] = None
130             return
131
132         if not is_matrix_type(new_matrix):
133             raise TypeError('Matrix must be a 2x2 NumPy array')
134
135         # All matrices must have float entries
136         a = float(new_matrix[0][0])
137         b = float(new_matrix[0][1])
138         c = float(new_matrix[1][0])
139         d = float(new_matrix[1][1])
140
141         self._matrices[name] = np.array([[a, b], [c, d]])
142
143     def is_valid_expression(self, expression: str) -> bool:
144         """Check if the given expression is valid, using the context of the wrapper.
145
146         This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
147         ensures that all the matrices in the expression are defined in the wrapper.
148
149         :param str expression: The expression to validate
150         :returns: Whether the expression is valid in this wrapper
151         :rtype: bool
152         """
153         # Get rid of the transposes to check all capital letters
154         new_expression = expression.replace('^T', '').replace('^{T}', '')
155
156         # Make sure all the referenced matrices are defined
157         for matrix in {x for x in new_expression if re.match('[A-Z]', x)}:
158             if self[matrix] is None:
159                 return False
160
161         return validate_matrix_expression(expression)

```

And here's the new version, which supports matrices defined as expressions:

```

# 01e866a74cf0f02ecba6438763d43e6eb90fe218
# src/lintrans/matrices/wrapper.py

17 class MatrixWrapper:
18     ...
38     def __init__(self):
39         """Initialise a :class:`MatrixWrapper` object with a dictionary of matrices which can be accessed."""

```



```

40     self._matrices: dict[str, Optional[Union[MatrixType, str]]] = {
41         'A': None, 'B': None, 'C': None, 'D': None,
42         'E': None, 'F': None, 'G': None, 'H': None,
43         'I': np.eye(2), # I is always defined as the identity matrix
44         'J': None, 'K': None, 'L': None, 'M': None,
45         'N': None, 'O': None, 'P': None, 'Q': None,
46         'R': None, 'S': None, 'T': None, 'U': None,
47         'V': None, 'W': None, 'X': None, 'Y': None,
48         'Z': None
49     }
...
94     def __getitem__(self, name: str) -> Optional[MatrixType]:
95         """Get the matrix with the given name.
96
97         If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)``, with
98         a given angle in degrees, then we return a new matrix representing a rotation by that angle.
99
100         :param str name: The name of the matrix to get
101         :returns: The value of the matrix (may be None)
102         :rtype: Optional[MatrixType]
103
104         :raises NameError: If there is no matrix with the given name
105         """
106         # Return a new rotation matrix
107         if (match := re.match(r'rot((-?\d*\.\d*)\)', name)) is not None:
108             return create_rotation_matrix(float(match.group(1)))
109
110         if name not in self._matrices:
111             raise NameError(f'Unrecognised matrix name "{name}"')
112
113         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
114         matrix = copy(self._matrices[name])
115
116         if isinstance(matrix, str):
117             return self.evaluate_expression(matrix)
118
119         return matrix
120
121     def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:
122         """Set the value of matrix ``name`` with the new_matrix.
123
124         :param str name: The name of the matrix to set the value of
125         :param Optional[Union[MatrixType, str]] new_matrix: The value of the new matrix (may be None)
126
127         :raises NameError: If the name isn't a legal matrix name
128         :raises TypeError: If the matrix isn't a valid 2x2 NumPy array
129         """
130         if not (name in self._matrices and name != 'I'):
131             raise NameError('Matrix name is illegal')
132
133         if new_matrix is None:
134             self._matrices[name] = None
135             return
136
137         if isinstance(new_matrix, str):
138             if self.is_valid_expression(new_matrix):
139                 self._matrices[name] = new_matrix
140                 return
141
142         if not is_matrix_type(new_matrix):
143             raise TypeError('Matrix must be a 2x2 NumPy array')
144
145         # All matrices must have float entries
146         a = float(new_matrix[0][0])
147         b = float(new_matrix[0][1])
148         c = float(new_matrix[1][0])
149         d = float(new_matrix[1][1])
150
151         self._matrices[name] = np.array([[a, b], [c, d]])
152
153     def get_expression(self, name: str) -> Optional[str]:
154         """If the named matrix is defined as an expression, return that expression, else return None.
155

```

```

156         :param str name: The name of the matrix
157         :returns: The expression that the matrix is defined as, or None
158         :rtype: Optional[str]
159
160         :raises NameError: If the name is invalid
161         """
162         if name not in self._matrices:
163             raise NameError('Matrix must have a legal name')
164
165         matrix = self._matrices[name]
166         if isinstance(matrix, str):
167             return matrix
168
169         return None
170
171     def is_valid_expression(self, expression: str) -> bool:
172         """Check if the given expression is valid, using the context of the wrapper.
173
174         This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
175         ensures that all the matrices in the expression are defined in the wrapper.
176
177         :param str expression: The expression to validate
178         :returns: Whether the expression is valid in this wrapper
179         :rtype: bool
180         """
181         # Get rid of the transposes to check all capital letters
182         new_expression = expression.replace('^T', '').replace('{T}', '')
183
184         # Make sure all the referenced matrices are defined
185         for matrix in {x for x in new_expression if re.match('[A-Z]', x)}:
186             if self[matrix] is None:
187                 return False
188
189             if (expr := self.get_expression(matrix)) is not None:
190                 if not self.is_valid_expression(expr):
191                     return False
192
193         return validate_matrix_expression(expression)

```

One of the more subtle things added here is on lines 189-191. When checking if an expression is valid in the context of the wrapper, we have to make sure all the referenced matrices are actually defined, but if any of those matrices are defined as an expression, then obviously that expression has to be valid as well. This recursion means that all references to matrices must be valid, even traversing down through matrices that are defined as expressions.

I also added some unit tests to automatically test this new feature.

```

# 239bcbfd1dde3f7623318d03e8544dd67dc02e3d
# tests/matrices/matrix_wrapper/test_setitem_and_getitem.py
42 def test_set_expression(test_wrapper: MatrixWrapper) -> None:
43     """Test that MatrixWrapper.__setitem__() can accept a valid expression."""
44     test_wrapper['N'] = 'A^2'
45     test_wrapper['O'] = 'BA+2C'
46     test_wrapper['P'] = 'E^T'
47     test_wrapper['Q'] = 'C^-1B'
48     test_wrapper['R'] = 'A^{2}3B'
49     test_wrapper['S'] = 'N^-1'
50     test_wrapper['T'] = 'PQP^-1'
51
52     with pytest.raises(TypeError):
53         test_wrapper['U'] = 'A+1'
54         test_wrapper['V'] = 'K'
55         test_wrapper['W'] = 'L^2'
56         test_wrapper['X'] = 'M^-1'
57
58
59 def test_simple_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
60     """Test that expression-defined matrices are evaluated dynamically."""
61     test_wrapper['N'] = 'A^2'

```

```

62     test_wrapper['0'] = '4B'
63     test_wrapper['P'] = 'A+C'
64
65     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
66     assert (test_wrapper['0'] == test_wrapper.evaluate_expression('4B')).all()
67     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
68
69     assert (test_wrapper.evaluate_expression('N^2 + 30') ==
70             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
71             3 * test_wrapper.evaluate_expression('4B')
72             ).all()
73     assert (test_wrapper.evaluate_expression('P^-1 - 3N0^2') ==
74             la.inv(test_wrapper.evaluate_expression('A+C')) -
75             (3 * test_wrapper.evaluate_expression('A^2')) @
76             la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
77             ).all()
78
79     test_wrapper['A'] = np.array([
80         [19, -21.5],
81         [84, 96.572]
82     ])
83     test_wrapper['B'] = np.array([
84         [-0.993, 2.52],
85         [1e10, 0]
86     ])
87     test_wrapper['C'] = np.array([
88         [0, 19512],
89         [1.414, 19]
90     ])
91
92     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
93     assert (test_wrapper['0'] == test_wrapper.evaluate_expression('4B')).all()
94     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
95
96     assert (test_wrapper.evaluate_expression('N^2 + 30') ==
97             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
98             3 * test_wrapper.evaluate_expression('4B')
99             ).all()
100    assert (test_wrapper.evaluate_expression('P^-1 - 3N0^2') ==
101            la.inv(test_wrapper.evaluate_expression('A+C')) -
102            (3 * test_wrapper.evaluate_expression('A^2')) @
103            la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
104            ).all()
105
106
107    def test_recursive_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
108        """Test that dynamic evaluation works recursively."""
109        test_wrapper['N'] = 'A^2'
110        test_wrapper['0'] = '4B'
111        test_wrapper['P'] = 'A+C'
112
113        test_wrapper['Q'] = 'N^-1'
114        test_wrapper['R'] = 'P-40'
115        test_wrapper['S'] = 'NOP'
116
117        assert test_wrapper['Q'] == pytest.approx(test_wrapper.evaluate_expression('A^-2'))
118        assert test_wrapper['R'] == pytest.approx(test_wrapper.evaluate_expression('A + C - 16B'))
119        assert test_wrapper['S'] == pytest.approx(test_wrapper.evaluate_expression('A^{2}4BA + A^{2}4BC'))
120
121
122    def test_set_identity_error(new_wrapper: MatrixWrapper) -> None:
123        """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to I."""
124        with pytest.raises(NameError):
125            new_wrapper['I'] = test_matrix
126
127
128    def test_set_name_error(new_wrapper: MatrixWrapper) -> None:
129        """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to an invalid name."""
130        with pytest.raises(NameError):
131            new_wrapper['bad name'] = test_matrix
132            new_wrapper['123456'] = test_matrix
133            new_wrapper['Th15 Is an 1nV@l1D n@m3'] = test_matrix
134            new_wrapper['abc'] = test_matrix

```

```

135     new_wrapper['a'] = test_matrix
136
137
138 def test_set_type_error(new_wrapper: MatrixWrapper) -> None:
139     """Test that MatrixWrapper().__setitem__() raises a TypeError when trying to set a non-matrix."""
140     with pytest.raises(TypeError):
141         new_wrapper['M'] = 12
142         new_wrapper['M'] = [1, 2, 3, 4, 5]
143         new_wrapper['M'] = [[1, 2], [3, 4]]
144         new_wrapper['M'] = True
145         new_wrapper['M'] = 24.3222
146         new_wrapper['M'] = 'This is totally a matrix, I swear'
147         new_wrapper['M'] = MatrixWrapper
148         new_wrapper['M'] = MatrixWrapper()
149         new_wrapper['M'] = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]])
150         new_wrapper['M'] = np.eye(100)

# ea00703f19c13af86c39ae30170569819937fa31
# tests/matrices/matrix_wrapper/test_misc.py

1 """Test the miscellaneous methods of the MatrixWrapper class."""
2
3 from lintrans.matrices import MatrixWrapper
4
5
6 def test_get_expression(test_wrapper: MatrixWrapper) -> None:
7     """Test the get_expression method of the MatrixWrapper class."""
8     test_wrapper['N'] = 'A^2'
9     test_wrapper['O'] = '4B'
10    test_wrapper['P'] = 'A+C'
11
12    test_wrapper['Q'] = 'N^-1'
13    test_wrapper['R'] = 'P-40'
14    test_wrapper['S'] = 'NOP'
15
16    assert test_wrapper.get_expression('A') is None
17    assert test_wrapper.get_expression('B') is None
18    assert test_wrapper.get_expression('C') is None
19    assert test_wrapper.get_expression('D') is None
20    assert test_wrapper.get_expression('E') is None
21    assert test_wrapper.get_expression('F') is None
22    assert test_wrapper.get_expression('G') is None
23
24    assert test_wrapper.get_expression('N') == 'A^2'
25    assert test_wrapper.get_expression('O') == '4B'
26    assert test_wrapper.get_expression('P') == 'A+C'
27
28    assert test_wrapper.get_expression('Q') == 'N^-1'
29    assert test_wrapper.get_expression('R') == 'P-40'
30    assert test_wrapper.get_expression('S') == 'NOP'

```

I then had to fix a small bug where the DefineAsAnExpressionDialog would evaluate the expression before assigning it, so I had to change that to just assign the test instead.

```

# 54e10dbfd3a1f3a962955c7fa3908848f5bd95b0
# src/lintrans/gui/dialogs/define_new_matrix.py

343 class DefineAsAnExpressionDialog(DefineDialog):
344     ...
345
346     def confirm_matrix(self) -> None:
347         """Evaluate the matrix expression and assign its value to the name in the combo box."""
348         self.matrix_wrapper[self.selected_letter] = self.lineedit_expression_box.text()
349         self.accept()

```

I also created a virtual method in the DefineDialog superclass, which standardised how dialogs load a matrix when it's selected in the drop-down. The numerical and visual definition dialogs already did this, but it was inconsistent, so I made it the same across all subclasses, and added it to the expression dialog.

```

# d1b60b20666ab9297cdbf675b6226587fd2e417f
# src/lintrans/gui/dialogs/define_new_matrix.py

59 class DefinedDialog(QDialog):
...
69     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
...
98         self.combobox_letter = QtWidgets.QComboBox(self)
99
100        for letter in ALPHABET_NO_I:
101            self.combobox_letter.addItem(letter)
102
103        self.combobox_letter.activated.connect(self.load_matrix)
...
134    def load_matrix(self, index: int) -> None:
135        """Load the selected matrix into the dialog.
136
137        This method is optionally able to be overridden. If it is not overridden,
138        then no matrix is loaded when selecting a name.
139
140        We have this method in the superclass so that we can define it as the slot
141        for the combobox.changed signal in this constructor, rather than having to
142        define that in the constructor of every subclass.
143        """
...
352 class DefineAsAnExpressionDialog(DefinedDialog):
...
386    def load_matrix(self, index: int) -> None:
387        """If the selected matrix is defined an expression, load that expression into the box."""
388        name = ALPHABET_NO_I[index]
389
390        if (expr := self.matrix_wrapper.get_expression(name)) is not None:
391            self.lineedit_expression_box.setText(expr)
392        else:
393            self.lineedit_expression_box.setText('')

```

Unfortunately, my initial implementation of this had a few bugs, and I noticed a few hours later that if you first define **A** as anything concrete, then you can define **A** to be the expression **A**. Then, when you put it in the expression box, the app just crashes. This is because it recurs forever, since it doesn't realise that the definition of **A** is self-referential<sup>14</sup>.

To fix this, I can check that the expression is valid and that it doesn't contain itself before assigning the expression to the matrix name.

```

# 742e0955e344deab2c9302ba9a6c7298ec4583d4
# src/lintrans/gui/dialogs/define_new_matrix.py

362 class DefineAsAnExpressionDialog(DefinedDialog):
...
393     def update_confirm_button(self) -> None:
...
395         text = self.lineedit_expression_box.text()
396         valid_expression = self.matrix_wrapper.is_valid_expression(text)
397
398         self.button_confirm.setEnabled(valid_expression and self.selected_letter not in text)

```

I also added this logic directly to the wrapper, so that there was no risk of me creating this kind of bug elsewhere.

```

# e56a5a90034f8335b046dd1bf76321eb48892050
# src/lintrans/matrices/wrapper.py

17 class MatrixWrapper:
...
125     def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:

```

<sup>14</sup>Obviously it doesn't actually recur forever, but Python stops recursion after 1000 levels and crashes the program.

```
...
145         if isinstance(new_matrix, str):
146             if self.is_valid_expression(new_matrix):
147                 if name not in new_matrix:
148                     self._matrices[name] = new_matrix
149                     return
150             else:
151                 raise ValueError('Cannot define a matrix recursively')
```

While I was working with expressions so much, I realised that defining a matrix as a rotation was a bit redundant when you can just use an expression like `rot(45)`. I spoke to the teacher that's going to use `lintrans` when it's finished, and she said that radians aren't really needed. The radians checkbox was the only unique part of the `DefineAsARotationDialog` class. Since it's not important, I decided to remove the whole dialog.

### 3.7 Implementing eigenstuffs

It's not universal, but the word 'eigenstuffs' is common enough in mathematics that I'm comfortable using it here to mean eigenvalues, eigenvectors, and eigenlines, where an eigenline is the span of an eigenvector.

#### 3.7.1 Drawing eigenvectors

An eigenvector  $\mathbf{v}$  of a matrix  $\mathbf{M}$  is a vector that satisfies the equation  $\mathbf{M}\mathbf{v} = \lambda\mathbf{v}$  for some scalar  $\lambda$ . Thankfully, I don't have to worry about actually computing  $\mathbf{v}$  or  $\lambda$ , since NumPy has the `numpy.linalg.eig()` function[14].

This function takes a square matrix and returns an array of eigenvalues ( $\lambda$ ), and a matrix of their associated eigenvectors ( $\mathbf{v}$ ). Some matrices don't have any real eigenvalues, but all  $2 \times 2$  matrices will have 2 (possibly complex) eigenvalues, as a direct consequence of the Fundamental Theorem of Algebra<sup>15</sup>. We don't want to try to render an eigenvector if its eigenvalue is complex, so we have to check and only render the real ones. Python doesn't distinguish really between `float` and `complex` types, so we can just check the `.imag` property no matter what. If it's 0, then we keep the eigenvalue. NumPy normalizes the eigenvectors to have a length of 1, but I'd much prefer them to have a length equal to their associated eigenvalue. To do that, we can just multiply the eigenvectors by their eigenvalues.

We then just draw a vector, consisting of a line and an arrowhead, from the origin to the extended eigenvector.

```
# b8614334de5cba4b1a6d92508b08fa8bd2fe77c0
# src/lintrans/gui/plots/classes.py

142 class VectorGridPlot(BackgroundPlot):
143     ...
151     def __init__(self, *args, **kwargs):
152         ...
163         self.colour_eigen = QColor('#ff9000')
164         ...
450     def draw_eigenvectors(self, painter: QPainter) -> None:
451         """Draw the eigenvectors of the displayed matrix transformation."""
452         painter.setPen(QPen(self.colour_eigen, self.width_vector_line))
453
454         values, vectors = np.linalg.eig(self.matrix)
455         vectors = vectors.T
456
457         for value, vector in zip(values, vectors):
458             x = value * vector[0]
459             y = value * vector[1]
460
461             if x.imag != 0 or y.imag != 0:
462                 continue
463
464             painter.drawLine(*self.canvas_origin, *self.canvas_coords(x, y))
465             self.draw_arrowhead_away_from_origin(painter, (x, y))

# b8614334de5cba4b1a6d92508b08fa8bd2fe77c0
# src/lintrans/gui/plots/widgets.py

13 class VisualizeTransformationWidget(VectorGridPlot):
14     ...
42     def paintEvent(self, event: QPaintEvent) -> None:
43         ...
58         self.draw_eigenvectors(painter)
```

---

<sup>15</sup> $\mathbf{M}\mathbf{v} = \lambda\mathbf{v} \implies \mathbf{M}\mathbf{v} = \lambda\mathbf{I}\mathbf{v} \implies (\mathbf{M} - \lambda\mathbf{I})\mathbf{v} = \mathbf{0} \implies \det(\mathbf{M} - \lambda\mathbf{I}) = 0$  (since we only want non-zero vectors)  
 $\implies \begin{vmatrix} a-\lambda & b \\ c & d-\lambda \end{vmatrix} = 0 \implies (a-\lambda)(d-\lambda) - bc = 0 \implies \lambda^2 - (a+d)\lambda + (ad-bc) = 0$   
 $\implies \lambda$  has 2 solutions in  $\mathbb{C}$  by the Fundamental Theorem of Algebra[7]

At this point in development, I didn't particularly care about the colours of various elements. It was more important to get things working first, so I ended up choosing **this horrible yellow** for the eigenvectors. It's clearly an awful choice for text, and it's not very good for the eigenvectors either, since it makes them hard to see against the white background. I wasn't really considering the usability features discussed in §2.4, but since I was the only user, and changing a few colours later on wouldn't be much work, I wasn't worried about it.

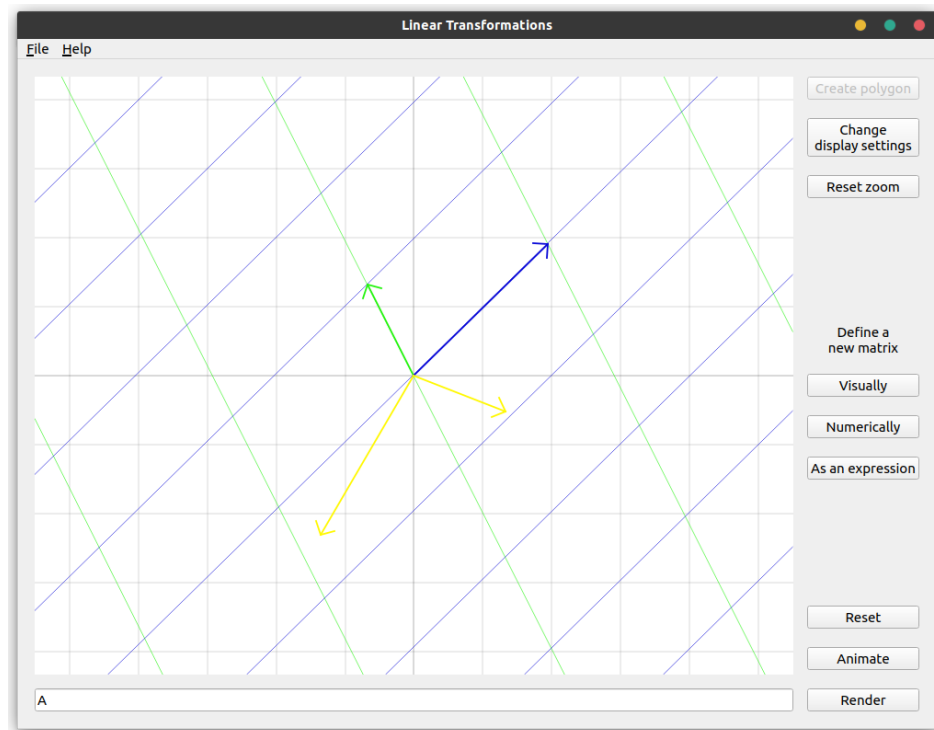


Figure 3.24: The eigenvectors being displayed for an arbitrary matrix



## References

- [1] Alan O'Callaghan (Alanocallaghan). *color-oracle-java*. Version 1.3. URL: <https://github.com/Alanocallaghan/color-oracle-java>.
- [2] Dyson Dyson (DoctorDalek1963). *lintrans*. URL: <https://github.com/DoctorDalek1963/lintrans>.
- [3] Dyson Dyson (DoctorDalek1963). *Which framework should I use for creating draggable points and connecting lines on a 2D grid?* 26th Jan. 2022. URL: <https://www.reddit.com/r/learnpython/comments/sd2lbr>.
- [4] Ross Wilson (rzzzwilson). *Python-Etudes/PyQtCustomWidget*. URL: <https://gitlab.com/rzzzwilson/python-etudes/-/tree/master/PyQtCustomWidget>.
- [5] Ross Wilson (rzzzwilson). *Python-Etudes/PyQtCustomWidget - ijvectors.py*. 26th Jan. 2022. URL: <https://gitlab.com/rzzzwilson/python-etudes/-/blob/2b43f5d3c95aa4410db5bed77195bf242318a304/PyQtCustomWidget/ijvectors.py>.
- [6] *2D linear transformation*. URL: <https://www.desmos.com/calculator/upooihuy4s>.
- [7] *Fundamental theorem of algebra*. Wikipedia. URL: [https://en.wikipedia.org/wiki/Fundamental\\_theorem\\_of\\_algebra](https://en.wikipedia.org/wiki/Fundamental_theorem_of_algebra).
- [8] Grant Sanderson (3blue1brown). *Essence of Linear Algebra*. 6th Aug. 2016. URL: [https://www.youtube.com/playlist?list=PLZHQ0b0WTQDPD3MizzM2xVFitgF8hE\\_ab](https://www.youtube.com/playlist?list=PLZHQ0b0WTQDPD3MizzM2xVFitgF8hE_ab).
- [9] H. Hohn et al. *Matrix Vector*. MIT. 2001. URL: <https://mathlets.org/mathlets/matrix-vector/>.
- [10] Jacek Wodecki and ekhumoro. *How to update window in PyQt5?* URL: <https://stackoverflow.com/questions/42045676/how-to-update-window-in-pyqt5>.
- [11] je1324. *Visualizing Linear Transformations*. 15th Mar. 2018. URL: <https://www.geogebra.org/m/YCZa8TAH>.
- [12] Nathaniel Vaughn Kelso and Bernie Jenny. *Color Oracle*. Version 1.3. URL: <https://colororacle.org/>.
- [13] *Normalize a matrix such that the determinat = 1*. ResearchGate. 26th June 2017. URL: [https://www.researchgate.net/post/normalize\\_a\\_matrix\\_such\\_that\\_the\\_determinat\\_1](https://www.researchgate.net/post/normalize_a_matrix_such_that_the_determinat_1).
- [14] *NumPy eig() function*. NumPy Developers. URL: <https://numpy.org/doc/1.23/reference/generated/numpy.linalg.eig.html>.
- [15] *Plotting with Matplotlib. Create PyQt5 plots with the popular Python plotting library*. URL: <https://www.pythonguis.com/tutorials/plotting-matplotlib/>.
- [16] *PyQt5 Graphics View Framework*. The Qt Company. URL: <https://doc.qt.io/qtforpython-5/overviews/graphicsview.html>.
- [17] *Python 3 Data model - special methods*. Python Software Foundation. URL: <https://docs.python.org/3/reference/datamodel.html#special-method-names>.
- [18] *Python 3.10 Downloads*. Python Software Foundation. URL: <https://www.python.org/downloads/release/python-3100/>.
- [19] *Qt5 for Linux/X11*. The Qt Company. URL: <https://doc.qt.io/qt-5/linux.html>.
- [20] *QValidator class*. The Qt Company. URL: <https://doc.qt.io/qt-5/qvalidator.html>.
- [21] *QWheelEvent class*. The Qt Company. URL: <https://doc.qt.io/qt-5/qwheelevent.html>.
- [22] *QWidget Class (mouseMoveEvent() method)*. The Qt Company. URL: <https://doc.qt.io/qt-5/qwidget.html#mouseMoveEvent>.
- [23] *QWidget Class (repaint() method)*. The Qt Company. URL: <https://doc.qt.io/qt-5/qwidget.html#repaint>.
- [24] *QWidget Class (update() method)*. The Qt Company. URL: <https://doc.qt.io/qt-5/qwidget.html#update>.
- [25] Shad Sharma. *Linear Transformation Visualizer*. 4th May 2017. URL: <https://shad.io/MatVis/>.
- [26] Rod Stephens. *Draw lines with arrowheads in C#*. 5th Dec. 2014. URL: [http://csharpshelper.com/howtos/howto\\_draw\\_arrows.html](http://csharpshelper.com/howtos/howto_draw_arrows.html).

- [27] *The Event System*. The Qt Company. URL: <https://doc.qt.io/qt-5/eventsandfilters.html>.
- [28] *Types of Color Blindness*. National Eye Institute. URL: <https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/color-blindness/types-color-blindness>.

## A Project code

### A.1 updating.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides functions for updating the lintrans executable in a proper installation.
8
9  If the user is using a standalone executable for lintrans, then we don't know where it is and
10 we therefore can't update it.
11 """
12
13 from __future__ import annotations
14
15 import os
16 import re
17 import subprocess
18 from threading import Thread
19 from typing import Optional, Tuple
20 from urllib.error import URLError
21 from urllib.request import urlopen
22
23 from packaging import version
24
25 from lintrans.global_settings import GlobalSettings
26
27
28 def new_version_exists() -> Tuple[bool, Optional[str]]:
29     """Check if the latest version of lintrans is newer than the current version.
30
31     This function either returns (False, None) or (True, str) where the string is the new version.
32
33     .. note::
34         This function will default to False if it can't get the current or latest version, or if
35         :meth:`~lintrans.global_settings.GlobalSettings.get_executable_path` returns ''
36         (probablybecause lintrans is being run as a Python package)
37
38         However, it will return True if the executable path is defined but the executable doesn't actually exist.
39
40         This last behaviour is mostly to make testing easier by spoofing
41         :meth:`~lintrans.global_settings.GlobalSettings.get_executable_path`.
42     """
43     executable_path = GlobalSettings().get_executable_path()
44     if executable_path == '':
45         return False, None
46
47     try:
48         html: str = urlopen('https://github.com/DoctorDalek1963/lintrans/releases/latest').read().decode()
49     except (UnicodeDecodeError, URLError):
50         return False, None
51
52     match = re.search(
53         r'(?<=DoctorDalek1963/lintrans/releases/tag/v)\d+\.\d+\.\d+(?=?;)',
54         html
55     )
56     if match is None:
57         return False, None
58
59     latest_version_str = match.group(0)
60     latest_version = version.parse(latest_version_str)
61
62     # If the executable doesn't exist, then we definitely want to update it
63     if not os.path.isfile(executable_path):
64         return True, latest_version_str
65
66     # Now check the current version
67     version_output = subprocess.run(

```

```

68         [executable_path, '--version'],
69         stdout=subprocess.PIPE,
70         shell=(os.name == 'nt')
71     ).stdout.decode()
72
73     match = re.search(r'(?<=lintrans \(\version \)d+\\.d+\\.d+(-w+(-?\d+))?(?=\\)', version_output)
74
75     if match is None:
76         return False, None
77
78     current_version = version.parse(match.group(0))
79
80     if latest_version > current_version:
81         return True, latest_version_str
82
83     return False, None
84
85
86 def update_lintrans() -> None:
87     """Update the lintrans binary executable, failing silently.
88
89     This function only makes sense if lintrans was installed, rather than being used as an executable.
90     We ask the :class:`~lintrans.global_settings.GlobalSettings` singleton where the executable is and,
91     if it exists, then we replace the old executable with the new one. This means that the next time
92     lintrans gets run, it will use the most recent version.
93
94     .. note::
95         This function doesn't care if the latest version on GitHub is actually newer than the current
96         version. Use :func:`new_version_exists` to check.
97     """
98     executable_path = GlobalSettings().get_executable_path()
99     if executable_path == '':
100         return
101
102     try:
103         html: str = urlopen('https://github.com/DoctorDalek1963/lintrans/releases/latest').read().decode()
104     except (UnicodeDecodeError, URLError):
105         return
106
107     match = re.search(
108         r'(?<=DoctorDalek1963/lintrans/releases/tag/v)d+\\.d+\\.d+(?=;|)',
109         html
110     )
111     if match is None:
112         return
113
114     latest_version = version.parse(match.group(0))
115
116     # We now know that the latest version is newer, and where the executable is,
117     # so we can begin the replacement process
118     url = 'https://github.com/DoctorDalek1963/lintrans/releases/download/'
119
120     if os.name == 'posix':
121         url += f'v{latest_version}/lintrans-Linux-{latest_version}'
122
123     elif os.name == 'nt':
124         url += f'v{latest_version}/lintrans-Windows-{latest_version}.exe'
125
126     else:
127         return
128
129     temp_file = GlobalSettings().get_update_download_filename()
130
131     # If the temp file already exists, then another instance of lintrans (probably
132     # in a background thread) is currently updating, so we don't want to interfere
133     if os.path.isfile(temp_file):
134         return
135
136     with open(temp_file, 'wb') as f:
137         try:
138             f.write(urlopen(url).read())
139         except URLError:
140             return

```

```

141
142     if os.name == 'posix':
143         os.rename(temp_file, executable_path)
144         subprocess.run(['chmod', '+x', executable_path])
145
146     elif os.name == 'nt':
147         # On Windows, we need to leave a process running in the background to automatically
148         # replace the exe file when lintrans stops running
149         script = '@echo off\n' \
150             ':loop\n\n' \
151             'timeout 5 >nul\n' \
152             'tasklist /fi "IMAGENAME eq lintrans.exe" /fo csv 2>nul | find /I "lintrans.exe" >nul\n' \
153             'if "%ERRORLEVEL%"=="0" goto :loop\n\n' \
154             f'del "{executable_path}"\n' \
155             f'rename "{temp_file}" lintrans.exe\n\n' \
156             'start /b "" cmd /c del "%~f0"&exit /b'
157
158         replace_bat = GlobalSettings().get_update_replace_bat_filename()
159         with open(replace_bat, 'w', encoding='utf-8') as f:
160             f.write(script)
161
162         subprocess.Popen(['start', '/min', replace_bat], shell=True)
163
164
165 def update_lintrans_in_background(*, check: bool) -> None:
166     """Use multithreading to run :func:`update_lintrans` in the background."""
167     def func() -> None:
168         if check:
169             if new_version_exists()[0]:
170                 update_lintrans()
171         else:
172             update_lintrans()
173
174     p = Thread(target=func)
175     p.start()

```

## A.2 global\_settings.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides the :class:`GlobalSettings` class, which is used to access global settings."""
8
9  from __future__ import annotations
10
11  import os
12  import pathlib
13  import pickle
14  import subprocess
15  import sys
16  from copy import copy
17  from dataclasses import dataclass
18  from enum import Enum
19  from pathlib import Path
20  from typing import Optional, Tuple
21
22  from singleton_decorator import singleton
23
24  import lintrans
25
26  UpdateType = Enum('UpdateType', 'auto prompt never')
27  """An enum of possible update prompt types."""
28
29
30  @dataclass(slots=True)
31  class GlobalSettingsData:
32     """A simple dataclass to store the configurable data of the global settings."""

```

```

33
34     update_type: UpdateType = UpdateType.prompt
35     """This is the desired type of update prompting."""
36
37     cursor_epsilon: int = 5
38     """This is the distance in pixels that the cursor needs to be from the point to drag it."""
39
40     snap_dist: float = 0.1
41     """This is the distance in grid coords that the cursor needs to be from an integer point to snap to it."""
42
43     snap_to_int_coords: bool = True
44     """This decides whether or not vectors should snap to integer coordinates when being dragged around."""
45
46     def save_to_file(self, filename: str) -> None:
47         """Save the global settings data to a file, creating parent directories as needed."""
48         parent_dir = pathlib.Path(os.path.expanduser(filename)).parent.absolute()
49
50         if not os.path.isdir(parent_dir):
51             os.makedirs(parent_dir)
52
53         data: Tuple[str, GlobalSettingsData] = (lintrans.__version__, self)
54
55         with open(filename, 'wb') as f:
56             pickle.dump(data, f, protocol=4)
57
58     @classmethod
59     def load_from_file(cls, filename: str) -> Tuple[str, GlobalSettingsData]:
60         """Return the global settings data that was previously saved to ``filename`` along with some extra
61         ↪ information.
62
63         The tuple we return has the version of lintrans that was used to save the file, and the data itself.
64
65         :raises EOFError: If the file doesn't contain a pickled Python object
66         :raises FileNotFoundError: If the file doesn't exist
67         :raises ValueError: If the file contains a pickled object of the wrong type
68         """
69         if not os.path.isfile(filename):
70             return lintrans.__version__, cls()
71
72         with open(filename, 'rb') as f:
73             file_data = pickle.load(f)
74
75         if not isinstance(file_data, tuple):
76             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be tuple)')
77
78         # Create a default object and overwrite the fields that we have
79         data = cls()
80         for attr in file_data[1].__slots__:
81             # Try to get the attribute from the old data, but don't worry if we can't,
82             # because that means it's from an older version, so we can use the default
83             # values from `cls()`
84             try:
85                 setattr(data, attr, getattr(file_data[1], attr))
86             except AttributeError:
87                 pass
88
89         return file_data[0], data
90
91 @singleton
92 class GlobalSettings:
93     """A singleton class to provide global settings that can be shared throughout the app.
94
95     .. note::
96         This is a singleton class because we only want :meth:`__init__` to be called once
97         to reduce processing time. We also can't cache it as a global variable because that
98         would be created at import time, leading to infinite process recursion when lintrans
99         tries to call its own executable to find out if it's compiled or interpreted.
100
101     The directory methods are split up into things like :meth:`get_save_directory` and
102     :meth:`get_crash_reports_directory` to make sure the directories exist and discourage
103     the use of other directories in the root one.
104     """

```

```
105
106 def __init__(self) -> None:
107     """Create the global settings object and initialize state."""
108     # The root directory is OS-dependent
109     if os.name == 'posix':
110         self._directory = os.path.join(
111             os.path.expanduser('~'),
112             '.lintrans'
113         )
114
115     elif os.name == 'nt':
116         self._directory = os.path.join(
117             os.path.expandvars('%APPDATA%'),
118             'lintrans'
119         )
120
121     else:
122         # This should be unreachable because the only other option for os.name is 'java'
123         # for Jython, but Jython only supports Python 2.7, which has been EOL for a while
124         # lintrans is only compatible with Python >= 3.10 anyway
125         raise OSError(f'Unrecognised OS "{os.name}"')
126
127     sub_directories = ['saves', 'crash_reports']
128
129     os.makedirs(self._directory, exist_ok=True)
130     for sub_directory in sub_directories:
131         os.makedirs(os.path.join(self._directory, sub_directory), exist_ok=True)
132
133     self._executable_path: Optional[str] = None
134
135     self._settings_file = os.path.join(self._directory, 'settings.dat')
136     self._display_settings_file = os.path.join(self._directory, 'display_settings.dat')
137
138     try:
139         self._data = GlobalSettingsData.load_from_file(self._settings_file)[1]
140     except KeyError:
141         self._data = GlobalSettingsData()
142         self._data.save_to_file(self._settings_file)
143
144 def get_executable_path(self) -> str:
145     """Return the path to the binary executable, or an empty string if lintrans is not installed standalone.
146
147     This method will call :attr:`sys.executable` to see if it's lintrans. If it is, then we cache the path for
148     future use and return it. Otherwise, it's a Python interpreter, so we return an empty string instead.
149     """
150     if self._executable_path is None:
151         executable_path = sys.executable
152         if os.path.isfile(executable_path):
153             version_output = subprocess.run(
154                 [executable_path, '--version'],
155                 stdout=subprocess.PIPE,
156                 shell=(os.name == 'nt')
157             ).stdout.decode()
158
159             if 'lintrans' in version_output:
160                 self._executable_path = executable_path
161             else:
162                 self._executable_path = ''
163
164     return self._executable_path or ''
165
166 def get_save_directory(self) -> str:
167     """Return the default directory for save files."""
168     return os.path.join(self._directory, 'saves')
169
170 def get_crash_reports_directory(self) -> str:
171     """Return the default directory for crash reports."""
172     return os.path.join(self._directory, 'crash_reports')
173
174 def get_settings_file(self) -> str:
175     """Return the full path of the settings file."""
176     return self._settings_file
177
```

```

178     def save_display_settings(self, settings: lintrans.gui.settings.DisplaySettings) -> None:
179         """Save the given display settings to the default file."""
180         settings.save_to_file(self._display_settings_file)
181
182     def get_display_settings(self) -> lintrans.gui.settings.DisplaySettings:
183         """Get the display settings from the default file, using the defaults for anything that's not available."""
184         return lintrans.gui.settings.DisplaySettings.load_from_file(self._display_settings_file)[1]
185
186     def get_update_download_filename(self) -> str:
187         """Return a name for a temporary file next to the executable.
188
189         This method is used when downloading a new version of lintrans into a temporary file.
190         This is needed to allow :func:`os.rename` instead of :func:`shutil.move`. The first
191         requires the src and dest to be on the same partition, but also allows us to replace
192         the running executable.
193         """
194         return str(Path(self.get_executable_path()).parent / 'lintrans-update-temp.dat')
195
196     def get_update_replace_bat_filename(self) -> str:
197         """Return the full path of the ``replace.bat`` file needed to update on Windows.
198
199         See :meth:`get_update_download_filename`.
200         """
201         return str(Path(self.get_executable_path()).parent / 'replace.bat')
202
203     def get_data(self) -> GlobalSettingsData:
204         """Return a copy of the internal global settings data."""
205         return copy(self._data)
206
207     def set_data(self, data: GlobalSettingsData) -> None:
208         """Set the internal global settings data and save it to a file."""
209         self._data = data
210         self._data.save_to_file(self._settings_file)
211
212     def set_update_type(self, type_: UpdateType) -> None:
213         """Set the internal data update type."""
214         data = self.get_data()
215         data.update_type = type_
216         self.set_data(data)

```

### A.3 crash\_reporting.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides functions to report crashes and log them.
8
9  The only functions you should be calling directly are :func:`set_excepthook`
10 and :func:`set_signal_handler` to setup handlers for unhandled exceptions
11 and unhandled operating system signals respectively.
12 """
13
14 from __future__ import annotations
15
16 import os
17 import platform
18 import signal
19 import sys
20 from datetime import datetime
21 from signal import SIGABRT, SIGFPE, SIGILL, SIGSEGV, SIGTERM
22 from textwrap import indent
23 from types import FrameType, TracebackType
24 from typing import NoReturn, Type
25
26 from PyQt5.QtCore import PYQT_VERSION_STR, QT_VERSION_STR
27 from PyQt5.QtWidgets import QApplication
28

```



```

29 import lintrans
30 from lintrans.typing_ import is_matrix_type
31
32 from .global_settings import GlobalSettings
33 from .gui.main_window import LintransMainWindow
34
35
36 def _get_datetime_string() -> str:
37     """Get the date and time as a string with a space in the middle."""
38     return datetime.now().strftime('%Y-%m-%d %H:%M:%S')
39
40
41 def _get_main_window() -> LintransMainWindow:
42     """Return the only instance of :class:`~lintrans.gui.main_window.LintransMainWindow`.
43
44     :raises RuntimeError: If there is not exactly 1 instance of
45     ↪ :class:`~lintrans.gui.main_window.LintransMainWindow`
46     """
47     widgets = [
48         x for x in QApplication.topLevelWidgets()
49         if isinstance(x, LintransMainWindow)
50     ]
51
52     if len(widgets) != 1:
53         raise RuntimeError(f'Expected 1 widget of type LintransMainWindow but found {len(widgets)}')
54
55     return widgets[0]
56
57 def _get_system_info() -> str:
58     """Return a string of all the system we could gather."""
59     info = 'SYSTEM INFO:\n'
60
61     info += f'  lintrans: {lintrans.__version__}\n'
62     info += f'  Python: {platform.python_version()}\n'
63     info += f'  Qt5: {QT_VERSION_STR}\n'
64     info += f'  PyQt5: {PYQT_VERSION_STR}\n'
65     info += f'  Platform: {platform.platform()}\n'
66
67     info += '\n'
68     return info
69
70
71 def _get_error_origin(
72     *,
73     exc_type: Type[BaseException] | None,
74     exc_value: BaseException | None,
75     traceback: TracebackType | None,
76     signal_number: int | None,
77     stack_frame: FrameType | None
78 ) -> str:
79     """Return a string specifying the full origin of the error, as best as we can determine.
80
81     This function has effectively two signatures. If the fatal error is caused by an exception,
82     then the first 3 arguments will be used to match the signature of :func:`sys.excepthook`.
83     If it's caused by a signal, then the last two will be used to match the signature of the
84     handler in :func:`signal.signal`. This function should never be used outside this file, so
85     we don't account for a mixture of arguments.
86
87     :param exc_type: The type of the exception that caused the crash
88     :param exc_value: The value of the exception itself
89     :param traceback: The traceback object
90     :param signal_number: The number of the signal that caused the crash
91     :param stack_frame: The current stack frame object
92
93     :type exc_type: Type[BaseException] | None
94     :type exc_value: BaseException | None
95     :type traceback: types.TracebackType | None
96     :type signal_number: int | None
97     :type stack_frame: types.FrameType | None
98     """
99     origin = 'CRASH ORIGIN:\n'
100

```

```

101     if exc_type is not None and exc_value is not None and traceback is not None:
102         # We want the frame where the exception actually occurred, so we have to descend the traceback
103         # I don't know why we aren't given this traceback in the first place
104         tb = traceback
105         while tb.tb_next is not None:
106             tb = tb.tb_next
107
108         frame = tb.tb_frame
109
110         origin += f' Exception "{exc_value}"\n of type {exc_type.__name__} in call to {frame.f_code.co_name}()\n'
111         ↵ \
112         f' on line {frame.f_lineno} of {frame.f_code.co_filename}'
113
114     elif signal_number is not None and stack_frame is not None:
115         origin += f' Signal "{signal.strsignal(signal_number)}" received in call to
116         ↵ {stack_frame.f_code.co_name}()\n' \
117         f' on line {stack_frame.f_lineno} of {stack_frame.f_code.co_filename}'
118
119     else:
120         origin += ' UNKNOWN (not exception or signal)'
121
122     origin += '\n\n'
123
124     return origin
125
126 def _get_display_settings() -> str:
127     """Return a string representing all of the display settings."""
128     raw_settings = _get_main_window()._plot.display_settings
129     display_settings = {
130         k: getattr(raw_settings, k)
131         for k in raw_settings.__slots__
132         if not k.startswith('_')
133     }
134
135     string = 'Display settings:\n'
136
137     for setting, value in display_settings.items():
138         string += f' {setting}: {value}\n'
139
140     return string
141
142 def _get_post_mortem() -> str:
143     """Return whatever post mortem data we could gather from the window."""
144     window = _get_main_window()
145
146     try:
147         matrix_wrapper = window._matrix_wrapper
148         expression_history = window._expression_history
149         exp_hist_index = window._expression_history_index
150         plot = window._plot
151         point_i = plot.point_i
152         point_j = plot.point_j
153
154     except (AttributeError, RuntimeError) as e:
155         return f'UNABLE TO GET POST MORTEM DATA:\n {e!r}\n'
156
157     post_mortem = 'Matrix wrapper:\n'
158
159     for matrix_name, matrix_value in matrix_wrapper.get_defined_matrices():
160         post_mortem += f' {matrix_name}: '
161
162         if is_matrix_type(matrix_value):
163             post_mortem += f'[{matrix_value[0][0]} {matrix_value[0][1]}; {matrix_value[1][0]} {matrix_value[1][1]}]'
164         else:
165             post_mortem += f'"{matrix_value}"'
166
167         post_mortem += '\n'
168
169     post_mortem += f'\nExpression box: "{window._lineedit_expression_box.text()}"'
170     post_mortem += f'\nCurrently displayed: [{point_i[0]} {point_j[0]}; {point_i[1]} {point_j[1]}]'
171     post_mortem += f'\nAnimating (sequence): {window._animating} ({window._animating_sequence})\n'

```

```

172
173     post_mortem += f'\nExpression history (index={exp_hist_index}):'
174     post_mortem += '\n ['
175     for item in expression_history:
176         post_mortem += f'\n     {item!r},'
177     post_mortem += '\n ]\n'
178
179     post_mortem += f'\nGrid spacing: {plot.grid_spacing}'
180     post_mortem += f'\nWindow size: {window.width()} x {window.height()}'
181     post_mortem += f'\nViewport size: {plot.width()} x {plot.height()}'
182     post_mortem += f'\nGrid corner: {plot._grid_corner()}\n'
183
184     post_mortem += '\n' + _get_display_settings()
185
186     string = 'POST MORTEM:\n'
187     string += indent(post_mortem, ' ')
188     return string
189
190
191 def _get_crash_report(datetime_string: str, error_origin: str) -> str:
192     """Return a string crash report, ready to be written to a file and stderr.
193
194     :param str datetime_string: The datetime to use in the report; should be the same as the one in the filename
195     :param str error_origin: The origin of the error. Get this by calling :func:`_get_error_origin`
196     """
197     report = f'CRASH REPORT at {datetime_string}\n\n'
198     report += _get_system_info()
199     report += error_origin
200     report += _get_post_mortem()
201
202     return report
203
204
205 def _report_crash(
206     *,
207     exc_type: Type[BaseException] | None = None,
208     exc_value: BaseException | None = None,
209     traceback: TracebackType | None = None,
210     signal_number: int | None = None,
211     stack_frame: FrameType | None = None
212 ) -> NoReturn:
213     """Generate a crash report and write it to a log file and stderr.
214
215     See :func:`_get_error_origin` for an explanation of the arguments. Everything is
216     handled internally if you just use the public functions :func:`set_excepthook` and
217     :func:`set_signal_handler`.
218     """
219     datetime_string = _get_datetime_string()
220
221     filename = os.path.join(
222         GlobalSettings().get_crash_reports_directory(),
223         datetime_string.replace(" ", "_") + '.log'
224     )
225     report = _get_crash_report(
226         datetime_string,
227         _get_error_origin(
228             exc_type=exc_type,
229             exc_value=exc_value,
230             traceback=traceback,
231             signal_number=signal_number,
232             stack_frame=stack_frame
233         )
234     )
235
236     print('\n\n' + report, end='', file=sys.stderr)
237     with open(filename, 'w', encoding='utf-8') as f:
238         f.write(report)
239
240     sys.exit(255)
241
242
243 def set_excepthook() -> None:
244     """Change :func:`sys.excepthook` to generate a crash report first."""

```

```

245     def _custom_excepthook(
246         exc_type: Type[BaseException],
247         exc_value: BaseException,
248         traceback: TracebackType | None
249     ) -> None:
250         _report_crash(exc_type=exc_type, exc_value=exc_value, traceback=traceback)
251
252     sys.excepthook = _custom_excepthook
253
254
255     def set_signal_handler() -> None:
256         """Set the signal handlers to generate crash reports first."""
257         def _handler(number, frame) -> None:
258             _report_crash(signal_number=number, stack_frame=frame)
259
260         for sig_num in (SIGABRT, SIGFPE, SIGILL, SIGSEGV, SIGTERM):
261             if sig_num in signal.valid_signals():
262                 signal.signal(sig_num, _handler)
263
264         try:
265             from signal import SIGQUIT
266             signal.signal(SIGQUIT, _handler)
267         except ImportError:
268             pass

```

## A.4 \_\_main\_\_.py

```

1  #!/usr/bin/env python
2
3  # lintrans - The linear transformation visualizer
4  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
5
6  # This program is licensed under GNU GPLv3, available here:
7  # <https://www.gnu.org/licenses/gpl-3.0.html>
8
9  """This module provides a :func:`main` function to interpret command line arguments and run the program."""
10
11  from argparse import ArgumentParser
12  from textwrap import dedent
13
14  from lintrans import __version__, gui
15  from lintrans.crash_reporting import set_excepthook, set_signal_handler
16
17
18  def main() -> None:
19      """Interpret program-specific command line arguments and run the main window in most cases.
20
21      If the user supplies ``--help`` or ``--version``, then we simply respond to that and then return.
22      If they don't supply either of these, then we run :func:`lintrans.gui.main_window.main`.
23
24      :param List[str] args: The full argument list (including program name)
25      """
26      parser = ArgumentParser(add_help=False)
27
28      parser.add_argument(
29          'filename',
30          nargs='?',
31          type=str,
32          default=None
33      )
34
35      parser.add_argument(
36          '-h',
37          '--help',
38          default=False,
39          action='store_true'
40      )
41
42      parser.add_argument(
43          '-V',

```

```

44     '--version',
45     default=False,
46     action='store_true'
47 )
48
49 parsed_args = parser.parse_args()
50
51 if parsed_args.help:
52     print(dedent('''
53     Usage: lintrans [option] [filename]
54
55     Arguments:
56         filename          The name of a session file to open
57
58     Options:
59         -h, --help        Display this help text and exit
60         -V, --version      Display the version information and exit''[1:]))
61     return
62
63 if parsed_args.version:
64     print(dedent(f'''
65     lintrans (version {__version__})
66     The linear transformation visualizer
67
68     Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
69
70     This program is licensed under GNU GPLv3, available here:
71     <https://www.gnu.org/licenses/gpl-3.0.html>''[1:]))
72     return
73
74 gui.main(parsed_args.filename)
75
76
77 if __name__ == '__main__':
78     set_excepthook()
79     set_signal_handler()
80     main()

```

## A.5 \_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This is the top-level ``lintrans`` package, which contains all the subpackages of the project."""
8
9  from . import (crash_reporting, global_settings, gui, matrices, typing_,
10                updating)
11
12  __version__ = '0.4.2-alpha'
13
14  __all__ = ['crash_reporting', 'global_settings', 'gui', 'matrices', 'typing_', 'updating', '__version__']

```

## A.6 gui/validate.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This simple module provides a :class:`MatrixExpressionValidator` class to validate matrix expression input."""
8
9  from __future__ import annotations
10
11  import re

```

```

12 from typing import Tuple
13
14 from PyQt5.QtGui import QValidator
15
16 from lintrans.matrices import parse
17
18
19 class MatrixExpressionValidator(QValidator):
20     """This class validates matrix expressions in a Qt input box."""
21
22     def validate(self, text: str, pos: int) -> Tuple[QValidator.State, str, int]:
23         """Validate the given text according to the rules defined in the :mod:`lintrans.matrices` module."""
24         # We want to extend the naive character class by adding a comma, which isn't
25         # normally allowed in expressions, but is allowed for sequential animations
26         bad_chars = re.sub(parse.NAIVE_CHARACTER_CLASS[:-1] + ',,', '', text)
27
28         # If there are bad chars, just reject it
29         if bad_chars != '':
30             return QValidator.Invalid, text, pos
31
32         # Now we need to check if it's actually a valid expression
33         if all(parse.validate_matrix_expression(expression) for expression in text.split(',')):
34             return QValidator.Acceptable, text, pos
35
36         # Else, if it's got all the right characters but it's not a valid expression
37         return QValidator.Intermediate, text, pos

```

## A.7 gui/utility.py

```

1 # lintrans - The linear transformation visualizer
2 # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4 # This program is licensed under GNU GPLv3, available here:
5 # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7 """This module provides utility functions for the whole GUI, such as :func:`qapp`."""
8
9 from PyQt5.QtCore import QApplication
10
11
12 def qapp() -> QApplication:
13     """Return the equivalent of the global :class:`QApp` pointer.
14
15     :raises RuntimeError: If :meth:`QCoreApplication.instance` returns ``None``
16     """
17     instance = QApplication.instance()
18
19     if instance is None:
20         raise RuntimeError('qApp undefined')
21
22     return instance

```

## A.8 gui/settings.py

```

1 # lintrans - The linear transformation visualizer
2 # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4 # This program is licensed under GNU GPLv3, available here:
5 # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7 """This module contains the :class:`DisplaySettings` class, which holds configuration for display."""
8
9 from __future__ import annotations
10
11 import os
12 import pathlib
13 import pickle
14 from dataclasses import dataclass

```

```

15 from typing import Tuple
16
17 import lintrans
18
19
20 @dataclass(slots=True)
21 class DisplaySettings:
22     """This class simply holds some attributes to configure display."""
23
24     # === Basic stuff
25
26     draw_background_grid: bool = True
27     """This controls whether we want to draw the background grid.
28
29     The background axes will always be drawn. This makes it easy to identify the center of the space.
30     """
31
32     draw_transformed_grid: bool = True
33     """This controls whether we want to draw the transformed grid. Vectors are handled separately."""
34
35     draw_basis_vectors: bool = True
36     """This controls whether we want to draw the transformed basis vectors."""
37
38     label_basis_vectors: bool = False
39     """This controls whether we want to label the `i` and `j` basis vectors."""
40
41     # === Animations
42
43     smoothen_determinant: bool = True
44     """This controls whether we want the determinant to change smoothly during the animation.
45
46     .. note::
47         Even if this is `True`, it will be ignored if we're animating from a positive det matrix to
48         a negative det matrix, or vice versa, because if we try to smoothly animate that determinant,
49         things blow up and the app often crashes.
50     """
51
52     applicative_animation: bool = True
53     """There are two types of simple animation, transitional and applicative.
54
55     Let `C` be the matrix representing the currently displayed transformation, and let `T` be the target matrix.
56     Transitional animation means that we animate directly from `C` from `T`,
57     and applicative animation means that we animate from `C` to `TC`, so we apply `T` to `C`.
58     """
59
60     animation_time: int = 1200
61     """This is the number of milliseconds that an animation takes."""
62
63     animation_pause_length: int = 400
64     """This is the number of milliseconds that we wait between animations when using comma syntax."""
65
66     # === Matrix info
67
68     draw_determinant_parallelogram: bool = False
69     """This controls whether or not we should shade the parallelogram representing the determinant of the matrix."""
70
71     show_determinant_value: bool = True
72     """This controls whether we should write the text value of the determinant inside the parallelogram.
73
74     The text only gets draw if :attr:`draw_determinant_parallelogram` is also True.
75     """
76
77     draw_eigenvectors: bool = False
78     """This controls whether we should draw the eigenvectors of the transformation."""
79
80     draw_eigenlines: bool = False
81     """This controls whether we should draw the eigenlines of the transformation."""
82
83     # === Polygon
84
85     draw_untransformed_polygon: bool = True
86     """This controls whether we should draw the untransformed version of the user-defined polygon."""
87

```

```

88     draw_transformed_polygon: bool = True
89     """This controls whether we should draw the transformed version of the user-defined polygon."""
90
91     # == Input/output vectors
92
93     draw_input_vector: bool = True
94     """This controls whether we should draw the input vector in the main viewport."""
95
96     draw_output_vector: bool = True
97     """This controls whether we should draw the output vector in the main viewport."""
98
99     def save_to_file(self, filename: str) -> None:
100         """Save the display settings to a file, creating parent directories as needed."""
101         parent_dir = pathlib.Path(os.path.expanduser(filename)).parent.absolute()
102
103         if not os.path.isdir(parent_dir):
104             os.makedirs(parent_dir)
105
106         data: Tuple[str, DisplaySettings] = (lintrans.__version__, self)
107
108         with open(filename, 'wb') as f:
109             pickle.dump(data, f, protocol=4)
110
111     @classmethod
112     def load_from_file(cls, filename: str) -> Tuple[str, DisplaySettings]:
113         """Return the display settings that were previously saved to ``filename`` along with some extra information.
114
115         The tuple we return has the version of lintrans that was used to save the file, and the data itself.
116
117         :raises EOFError: If the file doesn't contain a pickled Python object
118         :raises FileNotFoundError: If the file doesn't exist
119         :raises ValueError: If the file contains a pickled object of the wrong type
120         """
121         if not os.path.isfile(filename):
122             return lintrans.__version__, cls()
123
124         with open(filename, 'rb') as f:
125             file_data = pickle.load(f)
126
127         if not isinstance(file_data, tuple):
128             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be tuple)')
129
130         # Create a default object and overwrite the fields that we have
131         data = cls()
132         for attr in file_data[1].__slots__:
133             # Try to get the attribute from the old data, but don't worry if we can't,
134             # because that means it's from an older version, so we can use the default
135             # values from `cls()`
136             try:
137                 setattr(data, attr, getattr(file_data[1], attr))
138             except AttributeError:
139                 pass
140
141         return file_data[0], data

```

## A.9 gui/main\_window.py

```

1     # lintrans - The linear transformation visualizer
2     # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4     # This program is licensed under GNU GPLv3, available here:
5     # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7     """This module provides the :class:`LintransMainWindow` class, which provides the main window for the GUI."""
8
9     from __future__ import annotations
10
11     import os
12     import re
13     import sys

```



```

14 import webbrowser
15 from copy import deepcopy
16 from pathlib import Path
17 from pickle import UnpicklingError
18 from typing import List, NoReturn, Optional, Type
19
20 import numpy as np
21 from numpy import linalg
22 from numpy.linalg import LinAlgError
23 from PyQt5 import QtWidgets
24 from PyQt5.QtCore import QObject, Qt, QThread, pyqtSignal, pyqtSlot
25 from PyQt5.QtGui import QCloseEvent, QIcon, QKeyEvent, QKeySequence
26 from PyQt5.QtWidgets import (QAction, QApplication, QFileDialog, QHBoxLayout,
27                               QMainWindow, QMenu, QMessageBox, QPushButton,
28                               QShortcut, QSizePolicy, QSpacerItem,
29                               QStyleFactory, QVBoxLayout)
30
31 import lintrans
32 from lintrans import updating
33 from lintrans.global_settings import GlobalSettings, UpdateType
34 from lintrans.gui.dialogs.settings import GlobalSettingsDialog
35 from lintrans.matrices import MatrixWrapper
36 from lintrans.matrices.parse import validate_matrix_expression
37 from lintrans.matrices.utility import polar_coords, rotate_coord
38 from lintrans.typing_ import MatrixType, VectorType
39
40 from .dialogs import (AboutDialog, DefineAsExpressionDialog,
41                       DefineMatrixDialog, DefineNumericallyDialog,
42                       DefinePolygonDialog, DefineVisuallyDialog,
43                       DisplaySettingsDialog, FileSelectDialog, InfoPanelDialog,
44                       PromptUpdateDialog)
45 from .plots import MainViewPortWidget
46 from .session import Session
47 from .settings import DisplaySettings
48 from .utility import qapp
49 from .validate import MatrixExpressionValidator
50
51
52 class _UpdateChecker(QObject):
53     """A simple class to act as a worker for a :class:`QThread`."""
54
55     signal_prompt_update: pyqtSignal = pyqtSignal(str)
56     """A signal that is emitted if a new version is found. The argument is the new version string."""
57
58     finished: pyqtSignal = pyqtSignal()
59     """A signal that is emitted when the worker has finished. Intended to be used for cleanup."""
60
61     def check_for_updates_and_emit(self) -> None:
62         """Check for updates, and emit :attr:`signal_prompt_update` if there's a new version.
63
64         This method exists to be run in a background thread to trigger a prompt if a new version is found.
65         """
66         update_type = GlobalSettings().get_data().update_type
67
68         if update_type == UpdateType.never:
69             return
70
71         if update_type == UpdateType.auto:
72             updating.update_lintrans_in_background(check=True)
73             return
74
75         # If we get here, then update_type must be prompt,
76         # so we can check for updates and possibly prompt the user
77         new, version = updating.new_version_exists()
78         if new:
79             self.signal_prompt_update.emit(version)
80
81         self.finished.emit()
82
83
84 class LintransMainWindow(QMainWindow):
85     """This class provides a main window for the GUI using the Qt framework.
86

```

```
87     This class should not be used directly, instead call :func:`main` to create the GUI.
88     """
89
90     def __init__(self):
91         """Create the main window object, and create and arrange every widget in it.
92
93         This doesn't show the window, it just constructs it. Use :func:`main` to show the GUI.
94         """
95         super().__init__()
96
97         self._matrix_wrapper = MatrixWrapper()
98
99         self._expression_history: List[str] = []
100        self._expression_history_index: Optional[int] = None
101
102        self.setWindowTitle(['*'] * lintrans)
103        self.setMinimumSize(800, 650)
104
105        path = Path(__file__).parent.absolute() / 'assets' / 'icon.jpg'
106        self.setWindowIcon(QIcon(str(path)))
107
108        self._animating: bool = False
109        self._animating_sequence: bool = False
110        self._reset_during_animation: bool = False
111
112        self._save_filename: Optional[str] = None
113
114        # Set up thread and worker to check for updates
115
116        self._thread_updates = QThread()
117        self._worker_updates = _UpdateChecker()
118        self._worker_updates.moveToThread(self._thread_updates)
119
120        self._thread_updates.started.connect(self._worker_updates.check_for_updates_and_emit)
121        self._worker_updates.signal_prompt_update.connect(self._prompt_update)
122        self._worker_updates.finished.connect(self._thread_updates.quit)
123        self._worker_updates.finished.connect(self._worker_updates.deleteLater)
124        self._thread_updates.finished.connect(self._thread_updates.deleteLater)
125
126        # === Create menubar
127
128        menubar = QtWidgets.QMenuBar(self)
129
130        menu_file = QMenu(menubar)
131        menu_file.setTitle('&File')
132
133        menu_help = QMenu(menubar)
134        menu_help.setTitle('&Help')
135
136        action_global_settings = QAction(self)
137        action_global_settings.setText('Settings')
138        action_global_settings.setShortcut('Ctrl+Alt+S')
139        action_global_settings.triggered.connect(self._dialog_change_global_settings)
140
141        action_reset_session = QAction(self)
142        action_reset_session.setText('Reset session')
143        action_reset_session.triggered.connect(self._reset_session)
144
145        action_open = QAction(self)
146        action_open.setText('&Open')
147        action_open.setShortcut('Ctrl+O')
148        action_open.triggered.connect(self._ask_for_session_file)
149
150        action_save = QAction(self)
151        action_save.setText('&Save')
152        action_save.setShortcut('Ctrl+S')
153        action_save.triggered.connect(self._save_session)
154
155        action_save_as = QAction(self)
156        action_save_as.setText('Save as...')
157        action_save_as.setShortcut('Ctrl+Shift+S')
158        action_save_as.triggered.connect(self._save_session_as)
159
```

```

160     action_quit = QAction(self)
161     action_quit.setText('&Quit')
162     action_quit.triggered.connect(self.close)
163
164     # If this is an old release, use the docs for this release. Else, use the latest docs
165     # We use the latest because most use cases for non-stable releases will be in development and testing
166     docs_link = 'https://lintrans.readthedocs.io/en/'
167
168     if re.match(r'^\d+\.\d+\.\d+$', lintrans.__version__):
169         docs_link += 'v' + lintrans.__version__
170     else:
171         docs_link += 'latest'
172
173     action_tutorial = QAction(self)
174     action_tutorial.setText('&Tutorial')
175     action_tutorial.setShortcut('F1')
176     action_tutorial.triggered.connect(
177         lambda: webbrowser.open_new_tab(docs_link + '/tutorial/index.html')
178     )
179
180     action_docs = QAction(self)
181     action_docs.setText('&Docs')
182     action_docs.triggered.connect(
183         lambda: webbrowser.open_new_tab(docs_link + '/backend/lintrans.html')
184     )
185
186     menu_feedback = QMenu(menu_help)
187     menu_feedback.setTitle('Give feedback')
188
189     action_bug_report = QAction(self)
190     action_bug_report.setText('Report a bug')
191     action_bug_report.triggered.connect(
192         lambda: webbrowser.open_new_tab('https://forms.gle/Q82cLTtgPLcV4xQD6')
193     )
194
195     action_suggest_feature = QAction(self)
196     action_suggest_feature.setText('Suggest a new feature')
197     action_suggest_feature.triggered.connect(
198         lambda: webbrowser.open_new_tab('https://forms.gle/mVWbHiMBw9Zq5Ze37')
199     )
200
201     menu_feedback.addAction(action_bug_report)
202     menu_feedback.addAction(action_suggest_feature)
203
204     action_about = QAction(self)
205     action_about.setText('&About')
206     action_about.triggered.connect(lambda: AboutDialog(self).open())
207
208     menu_file.addAction(action_global_settings)
209     menu_file.addSeparator()
210     menu_file.addAction(action_reset_session)
211     menu_file.addAction(action_open)
212     menu_file.addSeparator()
213     menu_file.addAction(action_save)
214     menu_file.addAction(action_save_as)
215     menu_file.addSeparator()
216     menu_file.addAction(action_quit)
217
218     menu_help.addAction(action_tutorial)
219     menu_help.addAction(action_docs)
220     menu_help.addSeparator()
221     menu_help.addMenu(menu_feedback)
222     menu_help.addSeparator()
223     menu_help.addAction(action_about)
224
225     menubar.addAction(menu_file.menuAction())
226     menubar.addAction(menu_help.menuAction())
227
228     self.setMenuBar(menubar)
229
230     # === Create widgets
231
232     # Left layout: the plot and input box

```

```

233
234     self._plot = MainViewportWidget(
235         self,
236         display_settings=GlobalSettings().get_display_settings(),
237         polygon_points=[]
238     )
239
240     self._lineEdit_expression_box = QtWidgets.QLineEdit(self)
241     self._lineEdit_expression_box.setPlaceholderText('Enter matrix expression...')
242     self._lineEdit_expression_box.setValidator(MatrixExpressionValidator(self))
243     self._lineEdit_expression_box.textChanged.connect(self._update_render_buttons)
244
245     # Right layout: all the buttons
246
247     # Misc buttons
248
249     button_define_polygon = QPushButton(self)
250     button_define_polygon.setText('Define polygon')
251     button_define_polygon.clicked.connect(self._dialog_define_polygon)
252     button_define_polygon.setToolTip('Define a polygon to view its transformation<br><b>(Ctrl + P)</b>')
253     QShortcut(QKeySequence('Ctrl+P'), self).activated.connect(button_define_polygon.click)
254
255     self._button_change_display_settings = QPushButton(self)
256     self._button_change_display_settings.setText('Change\ndisplay settings')
257     self._button_change_display_settings.clicked.connect(self._dialog_change_display_settings)
258     self._button_change_display_settings.setToolTip(
259         "Change which things are rendered and how they're rendered<br><b>(Ctrl + D)</b>"
260     )
261     QShortcut(QKeySequence('Ctrl+D'), self).activated.connect(self._button_change_display_settings.click)
262
263     button_reset_zoom = QPushButton(self)
264     button_reset_zoom.setText('Reset zoom')
265     button_reset_zoom.clicked.connect(self._reset_zoom)
266     button_reset_zoom.setToolTip('Reset the zoom level back to normal<br><b>(Ctrl + Shift + R)</b>')
267     QShortcut(QKeySequence('Ctrl+Shift+R'), self).activated.connect(button_reset_zoom.click)
268
269     # Define new matrix buttons and their groupbox
270
271     self._button_define_visually = QPushButton(self)
272     self._button_define_visually.setText('Visually')
273     self._button_define_visually.setToolTip('Drag the basis vectors<br><b>(Alt + 1)</b>')
274     self._button_define_visually.clicked.connect(lambda: self._dialog_define_matrix(DefineVisuallyDialog))
275     QShortcut(QKeySequence('Alt+1'), self).activated.connect(self._button_define_visually.click)
276
277     self._button_define_numerically = QPushButton(self)
278     self._button_define_numerically.setText('Numerically')
279     self._button_define_numerically.setToolTip('Define a matrix just with numbers<br><b>(Alt + 2)</b>')
280     self._button_define_numerically.clicked.connect(lambda: self._dialog_define_matrix(DefineNumericallyDialog))
281     QShortcut(QKeySequence('Alt+2'), self).activated.connect(self._button_define_numerically.click)
282
283     self._button_define_as_expression = QPushButton(self)
284     self._button_define_as_expression.setText('As an expression')
285     self._button_define_as_expression.setToolTip('Define a matrix in terms of other matrices<br><b>(Alt +
286     ↩ 3)</b>')
287     self._button_define_as_expression.clicked.connect(
288         lambda: self._dialog_define_matrix(DefineAsExpressionDialog)
289     )
290     QShortcut(QKeySequence('Alt+3'), self).activated.connect(self._button_define_as_expression.click)
291
292     vlay_define_new_matrix = QVBoxLayout()
293     vlay_define_new_matrix.setSpacing(20)
294     vlay_define_new_matrix.addWidget(self._button_define_visually)
295     vlay_define_new_matrix.addWidget(self._button_define_numerically)
296     vlay_define_new_matrix.addWidget(self._button_define_as_expression)
297
298     groupbox_define_new_matrix = QtWidgets.QGroupBox('Define a new matrix', self)
299     groupbox_define_new_matrix.setLayout(vlay_define_new_matrix)
300
301     # Info panel button
302
303     self._button_info_panel = QPushButton(self)
304     self._button_info_panel.setText('Show defined matrices')
305     self._button_info_panel.clicked.connect(self._open_info_panel)

```

```

305     self._button_info_panel.setToolTip(
306         'Open an info panel with all matrices that have been defined in this session<br><b>(Ctrl + M)</b>'
307     )
308     QShortcut(QKeySequence('Ctrl+M'), self).activated.connect(self._button_info_panel.click)
309
310     # Render buttons
311
312     button_reset = QPushButton(self)
313     button_reset.setText('Reset')
314     button_reset.clicked.connect(self._reset_transformation)
315     button_reset.setToolTip('Reset the visualized transformation back to the identity<br><b>(Ctrl + R)</b>')
316     QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(button_reset.click)
317
318     self._button_render = QPushButton(self)
319     self._button_render.setText('Render')
320     self._button_render.setEnabled(False)
321     self._button_render.clicked.connect(self._render_expression)
322     self._button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
323     QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_render.click)
324
325     self._button_animate = QPushButton(self)
326     self._button_animate.setText('Animate')
327     self._button_animate.setEnabled(False)
328     self._button_animate.clicked.connect(self._animate_expression)
329     self._button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
330     QShortcut(QKeySequence('Ctrl+Shift+Return'), self).activated.connect(self._button_animate.click)
331
332     # === Arrange widgets
333
334     vlay_left = QVBoxLayout()
335     vlay_left.addWidget(self._plot)
336     vlay_left.addWidget(self._lineedit_expression_box)
337
338     vlay_misc_buttons = QVBoxLayout()
339     vlay_misc_buttons.setSpacing(20)
340     vlay_misc_buttons.addWidget(button_define_polygon)
341     vlay_misc_buttons.addWidget(self._button_change_display_settings)
342     vlay_misc_buttons.addWidget(button_reset_zoom)
343
344     vlay_info_buttons = QVBoxLayout()
345     vlay_info_buttons.setSpacing(20)
346     vlay_info_buttons.addWidget(self._button_info_panel)
347
348     vlay_render = QVBoxLayout()
349     vlay_render.setSpacing(20)
350     vlay_render.addWidget(button_reset)
351     vlay_render.addWidget(self._button_animate)
352     vlay_render.addWidget(self._button_render)
353
354     vlay_right = QVBoxLayout()
355     vlay_right.setSpacing(50)
356     vlay_right.addLayout(vlay_misc_buttons)
357     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
358     vlay_right.addWidget(groupbox_define_new_matrix)
359     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
360     vlay_right.addLayout(vlay_info_buttons)
361     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
362     vlay_right.addLayout(vlay_render)
363
364     hlay_all = QHBoxLayout()
365     hlay_all.setSpacing(15)
366     hlay_all.addLayout(vlay_left)
367     hlay_all.addLayout(vlay_right)
368
369     central_widget = QWidget()
370     central_widget.setLayout(hlay_all)
371     central_widget.setContentsMargins(10, 10, 10, 10)
372
373     self.setCentralWidget(central_widget)
374
375     def closeEvent(self, event: QCloseEvent) -> None:
376         """Handle a :class:`QCloseEvent` by confirming if the user wants to save, and cancelling animation."""
377         if not self.isWindowModified():

```

```

378         self._animating = False
379         self._animating_sequence = False
380         GlobalSettings().save_display_settings(self._plot.display_settings)
381         event.accept()
382         return
383
384     if self._save_filename is not None:
385         text = f"If you don't save, then changes made to {self._save_filename} will be lost."
386     else:
387         text = "If you don't save, then changes made will be lost."
388
389     dialog = QMessageBox(self)
390     dialog.setIcon(QMessageBox.Question)
391     dialog.setWindowTitle('Save changes?')
392     dialog.setText(text)
393     dialog.setStandardButtons(QMessageBox.Save | QMessageBox.Discard | QMessageBox.Cancel)
394     dialog.setDefaultButton(QMessageBox.Save)
395
396     pressed_button = dialog.exec()
397
398     if pressed_button == QMessageBox.Save:
399         self._save_session()
400
401     if pressed_button in (QMessageBox.Save, QMessageBox.Discard):
402         self._animating = False
403         self._animating_sequence = False
404         GlobalSettings().save_display_settings(self._plot.display_settings)
405         event.accept()
406     else:
407         event.ignore()
408
409 def keyPressEvent(self, event: QKeyEvent) -> None:
410     """Handle a :class:`QKeyEvent` by scrolling through expression history."""
411     key = event.key()
412
413     # Load previous expression
414     if key == Qt.Key_Up:
415         if self._expression_history_index is None:
416             if len(self._expression_history) == 0:
417                 event.ignore()
418                 return
419
420             # If the index is none and we've got a history, set the index to -1
421             self._expression_history_index = -1
422
423             # If the index is in range of the list (the index is always negative), then decrement it
424             elif self._expression_history_index > -len(self._expression_history):
425                 self._expression_history_index -= 1
426
427             self._linedit_expression_box.setText(self._expression_history[self._expression_history_index])
428
429     # Load next expression
430     elif key == Qt.Key_Down:
431         if self._expression_history_index is None:
432             event.ignore()
433             return
434
435             self._expression_history_index += 1
436
437             # The index is always negative, so if we've reached 0, then we need to stop
438             if self._expression_history_index == 0:
439                 self._expression_history_index = None
440                 self._linedit_expression_box.setText('')
441             else:
442                 self._linedit_expression_box.setText(self._expression_history[self._expression_history_index])
443
444     else:
445         event.ignore()
446         return
447
448     event.accept()
449
450 def _update_render_buttons(self) -> None:

```

```

451         """Enable or disable the render and animate buttons according to whether the matrix expression is valid."""
452         text = self._lineEdit_expression_box.text()
453
454         # Let's say that the user defines a non-singular matrix A, then defines B as A^-1
455         # If they then redefine A and make it singular, then we get a LinAlgError when
456         # trying to evaluate an expression with B in it
457         # To fix this, we just do naive validation rather than aware validation
458         if ',' in text:
459             self._button_render.setEnabled(False)
460
461             try:
462                 valid = all(self._matrix_wrapper.is_valid_expression(x) for x in text.split(','))
463             except LinAlgError:
464                 valid = all(validate_matrix_expression(x) for x in text.split(','))
465
466             self._button_animate.setEnabled(valid)
467
468         else:
469             try:
470                 valid = self._matrix_wrapper.is_valid_expression(text)
471             except LinAlgError:
472                 valid = validate_matrix_expression(text)
473
474             self._button_render.setEnabled(valid)
475             self._button_animate.setEnabled(valid)
476
477     def _extend_expression_history(self, text: str) -> None:
478         """Extend the expression history with the given expression."""
479         if len(self._expression_history) == 0 or self._expression_history[-1] != text:
480             self._expression_history.append(text)
481             self._expression_history_index = -1
482
483     @pyqtSlot()
484     def _reset_zoom(self) -> None:
485         """Reset the zoom level back to normal."""
486         self._plot.grid_spacing = self._plot.DEFAULT_GRID_SPACING
487         self._plot.update()
488
489     @pyqtSlot()
490     def _reset_transformation(self) -> None:
491         """Reset the visualized transformation back to the identity."""
492         if self._animating or self._animating_sequence:
493             self._reset_during_animation = True
494
495         self._animating = False
496         self._animating_sequence = False
497
498         self._plot.plot_matrix(self._matrix_wrapper['I'])
499         self._plot.update()
500
501     @pyqtSlot()
502     def _render_expression(self) -> None:
503         """Render the transformation given by the expression in the input box."""
504         try:
505             text = self._lineEdit_expression_box.text()
506             matrix = self._matrix_wrapper.evaluate_expression(text)
507
508             except LinAlgError:
509                 self._show_error_message('Singular matrix', 'Cannot take inverse of singular matrix.')
510                 return
511
512             self._extend_expression_history(text)
513
514             if self._is_matrix_too_big(matrix):
515                 return
516
517             self._plot.plot_matrix(matrix)
518             self._plot.update()
519
520     @pyqtSlot()
521     def _animate_expression(self) -> None:
522         """Animate from the current matrix to the matrix in the expression box."""
523         self._button_render.setEnabled(False)

```

```
524         self._button_animate.setEnabled(False)
525
526     matrix_start: MatrixType = np.array([
527         [self._plot.point_i[0], self._plot.point_j[0]],
528         [self._plot.point_i[1], self._plot.point_j[1]]
529     ])
530
531     text = self._lineEdit_expression_box.text()
532
533     self._extend_expression_history(text)
534
535     # If there's commas in the expression, then we want to animate each part at a time
536     if ',' in text:
537         current_matrix = matrix_start
538         self._animating_sequence = True
539
540         # For each expression in the list, right multiply it by the current matrix,
541         # and animate from the current matrix to that new matrix
542         for expr in text.split(',')[:-1]:
543             if not self._animating_sequence:
544                 break
545
546             try:
547                 new_matrix = self._matrix_wrapper.evaluate_expression(expr)
548
549                 if self._plot.display_settings.applicative_animation:
550                     new_matrix = new_matrix @ current_matrix
551
552                 # If we want a transitional animation and we're animating the same matrix, then restart the
553                 # animation. We use this check rather than equality because of small floating point errors
554                 elif (abs(current_matrix - new_matrix) < 1e-12).all():
555                     current_matrix = self._matrix_wrapper['I']
556
557                 # We pause here for 200 ms to make the animation look a bit nicer
558                 self._plot.plot_matrix(current_matrix)
559                 self._plot.update()
560                 QApplication.processEvents()
561                 QThread.msleep(200)
562
563             except LinAlgError:
564                 self._show_error_message('Singular matrix', 'Cannot take inverse of singular matrix.')
565                 return
566
567             self._animate_between_matrices(current_matrix, new_matrix)
568             current_matrix = new_matrix
569
570             # Here we just redraw and allow for other events to be handled while we pause
571             self._plot.update()
572             QApplication.processEvents()
573             QThread.msleep(self._plot.display_settings.animation_pause_length)
574
575         self._animating_sequence = False
576
577     # If there's no commas, then just animate directly from the start to the target
578     else:
579         # Get the target matrix and its determinant
580         try:
581             matrix_target = self._matrix_wrapper.evaluate_expression(text)
582
583         except LinAlgError:
584             self._show_error_message('Singular matrix', 'Cannot take inverse of singular matrix.')
585             return
586
587         # The concept of applicative animation is explained in /gui/settings.py
588         if self._plot.display_settings.applicative_animation:
589             matrix_target = matrix_target @ matrix_start
590
591         # If we want a transitional animation and we're animating the same matrix, then restart the animation
592         # We use this check rather than equality because of small floating point errors
593         elif (abs(matrix_start - matrix_target) < 1e-12).all():
594             matrix_start = self._matrix_wrapper['I']
595
596         # We pause here for 200 ms to make the animation look a bit nicer
```



```

597         self._plot.plot_matrix(matrix_start)
598         self._plot.update()
599         QApplication.processEvents()
600         QThread.sleep(200)
601
602         self._animate_between_matrices(matrix_start, matrix_target)
603
604     self._update_render_buttons()
605
606 def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
607     """Get the matrix to render for this frame of the animation.
608
609     This method will smoothen the determinant if that setting is enabled and if the determinant is positive.
610     It also animates rotation-like matrices using a logarithmic spiral to rotate around and scale continuously.
611     Essentially, it just makes things look good when animating.
612
613     :param MatrixType start: The starting matrix
614     :param MatrixType target: The target matrix
615     :param float proportion: How far we are through the loop
616     """
617     det_target = linalg.det(target)
618     det_start = linalg.det(start)
619
620     # This is the matrix that we're applying to get from start to target
621     # We want to check if it's rotation-like
622     if linalg.det(start) == 0:
623         matrix_application = None
624     else:
625         matrix_application = target @ linalg.inv(start)
626
627     # For a matrix to represent a rotation, it must have a positive determinant,
628     # its vectors must be perpendicular, the same length, and at right angles
629     # The checks for 'abs(value) < 1e-10' are to account for floating point error
630     if matrix_application is not None \
631         and self._plot.display_settings.smoothen_determinant \
632         and linalg.det(matrix_application) > 0 \
633         and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 1e-10 \
634         and abs(np.hypot(*matrix_application.T[0]) - np.hypot(*matrix_application.T[1])) < 1e-10:
635         rotation_vector: VectorType = matrix_application.T[0] # Take the i column
636         radius, angle = polar_coords(*rotation_vector)
637
638         # We want the angle to be in [-pi, pi), so we have to subtract 2pi from it if it's too big
639         if angle > np.pi:
640             angle -= 2 * np.pi
641
642         i: VectorType = start.T[0]
643         j: VectorType = start.T[1]
644
645         # Scale the coords with a list comprehension
646         # It's a bit janky, but rotate_coords() will always return a 2-tuple,
647         # so new_i and new_j will always be lists of length 2
648         scale = (radius - 1) * proportion + 1
649         new_i = [scale * c for c in rotate_coord(i[0], i[1], angle * proportion)]
650         new_j = [scale * c for c in rotate_coord(j[0], j[1], angle * proportion)]
651
652         return np.array(
653             [
654                 [new_i[0], new_j[0]],
655                 [new_i[1], new_j[1]]
656             ]
657         )
658
659     # matrix_a is the start matrix plus some part of the target, scaled by the proportion
660     # If we just used matrix_a, then things would animate, but the determinants would be weird
661     matrix_a = start + proportion * (target - start)
662
663     if not self._plot.display_settings.smoothen_determinant or det_start * det_target <= 0:
664         return matrix_a
665
666     # To fix the determinant problem, we get the determinant of matrix_a and use it to normalize
667     det_a = linalg.det(matrix_a)
668
669     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)

```

```

670     # We want  $B = cA$  such that  $\det(B) = \det(S)$ , where  $S$  is the start matrix,
671     # so then we can scale it with the animation, so we get
672     #  $\det(cA) = c^2 \det(A) = \det(S) \Rightarrow c = \sqrt{\text{abs}(\det(S) / \det(A))}$ 
673     # Then we scale  $A$  to get the determinant we want, and call that matrix_b
674     if det_a == 0:
675         c = 0
676     else:
677         c = np.sqrt(abs(det_start / det_a))
678
679     matrix_b = c * matrix_a
680     det_b = linalg.det(matrix_b)
681
682     # We want to return  $B$ , but we have to scale it over time to have the target determinant
683
684     # We want some  $C = dB$  such that  $\det(C)$  is some target determinant  $T$ 
685     #  $\det(dB) = d^2 \det(B) = T \Rightarrow d = \sqrt{\text{abs}(T / \det(B))}$ 
686
687     # We're also subtracting 1 and multiplying by the proportion and then adding one
688     # This just scales the determinant along with the animation
689
690     # That is all of course, if we can do that
691     # We'll crash if we try to do this with  $\det(B) == 0$ 
692     if det_b == 0:
693         return matrix_a
694
695     scalar: float = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
696     return scalar * matrix_b
697
698 def _animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType) -> None:
699     """Animate from the start matrix to the target matrix."""
700     self._animating = True
701
702     # Making steps depend on animation_time ensures a smooth animation without
703     # massive overheads for small animation times
704     steps = self._plot.display_settings.animation_time // 10
705
706     for i in range(0, steps + 1):
707         if not self._animating:
708             break
709
710         matrix_to_render = self._get_animation_frame(matrix_start, matrix_target, i / steps)
711
712         if self._is_matrix_too_big(matrix_to_render):
713             self._animating = False
714             self._animating_sequence = False
715             return
716
717         self._plot.plot_matrix(matrix_to_render)
718
719         # We schedule the plot to be updated, tell the event loop to
720         # process events, and asynchronously sleep for 10ms
721         # This allows for other events to be processed while animating, like zooming in and out
722         self._plot.update()
723         QApplication.processEvents()
724         QThread.sleep(self._plot.display_settings.animation_time // steps)
725
726     if not self._reset_during_animation:
727         self._plot.plot_matrix(matrix_target)
728     else:
729         self._plot.plot_matrix(self._matrix_wrapper['I'])
730
731     self._plot.update()
732
733     self._animating = False
734     self._reset_during_animation = False
735
736 @pyqtSlot()
737 def _open_info_panel(self) -> None:
738     """Open the info panel and register a callback to undefine matrices."""
739     dialog = InfoPanelDialog(self._matrix_wrapper, self)
740     dialog.open()
741     dialog.finished.connect(self._assign_matrix_wrapper)
742

```

```

743 @pyqtSlot(DefineMatrixDialog)
744 def _dialog_define_matrix(self, dialog_class: Type[DefineMatrixDialog]) -> None:
745     """Open a generic definition dialog to define a new matrix.
746
747     The class for the desired dialog is passed as an argument. We create an
748     instance of this class and the dialog is opened asynchronously and modally
749     (meaning it blocks interaction with the main window) with the proper method
750     connected to the :meth:`QDialog.accepted` signal.
751
752     .. note:: ``dialog_class`` must subclass
↪ :class:`~lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog`.
753
754     :param dialog_class: The dialog class to instantiate
755     :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog]
756     """
757     # We create a dialog with a deepcopy of the current matrix_wrapper
758     # This avoids the dialog mutating this one
759     dialog: DefineMatrixDialog
760
761     if dialog_class == DefineVisuallyDialog:
762         dialog = DefineVisuallyDialog(
763             self,
764             matrix_wrapper=deepcopy(self._matrix_wrapper),
765             display_settings=self._plot.display_settings,
766             polygon_points=self._plot.polygon_points,
767             input_vector=self._plot.point_input_vector
768         )
769     else:
770         dialog = dialog_class(self, matrix_wrapper=deepcopy(self._matrix_wrapper))
771
772     # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
773     dialog.open()
774
775     # So we have to use the accepted signal to call a method when the user accepts the dialog
776     dialog.accepted.connect(self._assign_matrix_wrapper)
777
778 @pyqtSlot()
779 def _assign_matrix_wrapper(self) -> None:
780     """Assign a new value to ``self._matrix_wrapper`` and give the expression box focus."""
781     self._matrix_wrapper = self.sender().matrix_wrapper
782     self._lineEdit_expression_box.setFocus()
783     self._update_render_buttons()
784
785     self.setWindowModified(True)
786     self._update_window_title()
787
788 @pyqtSlot()
789 def _dialog_change_global_settings(self) -> None:
790     """Open the dialog to change the global settings."""
791     dialog = GlobalSettingsDialog(self)
792     dialog.open()
793     dialog.accepted.connect(self._plot.update)
794
795 @pyqtSlot()
796 def _dialog_change_display_settings(self) -> None:
797     """Open the dialog to change the display settings."""
798     dialog = DisplaySettingsDialog(self, display_settings=self._plot.display_settings)
799     dialog.open()
800     dialog.accepted.connect(self._assign_display_settings)
801
802 @pyqtSlot()
803 def _assign_display_settings(self) -> None:
804     """Assign a new value to ``self._plot.display_settings`` and give the expression box focus."""
805     self._plot.display_settings = self.sender().display_settings
806     self._plot.update()
807     self._lineEdit_expression_box.setFocus()
808     self._update_render_buttons()
809
810 @pyqtSlot()
811 def _dialog_define_polygon(self) -> None:
812     """Open the dialog to define a polygon."""
813     dialog = DefinePolygonDialog(self, polygon_points=self._plot.polygon_points)
814     dialog.open()

```

```

815         dialog.accepted.connect(self._assign_polygon_points)
816
817     @pyqtSlot()
818     def _assign_polygon_points(self) -> None:
819         """Assign a new value to ``self._plot.polygon_points`` and give the expression box focus."""
820         self._plot.polygon_points = self.sender().polygon_points
821         self._plot.update()
822         self._lineEdit_expression_box.setFocus()
823         self._update_render_buttons()
824
825         self.setWindowModified(True)
826         self._update_window_title()
827
828     def _show_error_message(self, title: str, text: str, info: str | None = None, *, warning: bool = False) -> None:
829         """Show an error message in a dialog box.
830
831         :param str title: The window title of the dialog box
832         :param str text: The simple error message
833         :param info: The more informative error message
834         :type info: Optional[str]
835         """
836         dialog = QMessageBox(self)
837         dialog.setWindowTitle(title)
838         dialog.setText(text)
839
840         if warning:
841             dialog.setIcon(QMessageBox.Warning)
842         else:
843             dialog.setIcon(QMessageBox.Critical)
844
845         if info is not None:
846             dialog.setInformativeText(info)
847
848         dialog.open()
849
850         # This is `finished` rather than `accepted` because we want to update the buttons no matter what
851         dialog.finished.connect(self._update_render_buttons)
852
853     def _is_matrix_too_big(self, matrix: MatrixType) -> bool:
854         """Check if the given matrix will actually fit on the grid.
855
856         We're checking against a 1000x1000 grid here, which is far less than the actual space we have available.
857         But even when fully zoomed out 1080p monitor, the grid is only roughly 170x90, so 1000x1000 is plenty.
858
859         :param MatrixType matrix: The matrix to check
860         :returns bool: Whether the matrix is too big to fit on the canvas
861         """
862         for x, y in matrix.T:
863             if not (-1000 <= x <= 1000 and -1000 <= y <= 1000):
864                 self._show_error_message(
865                     'Matrix too big',
866                     'This matrix doesn't fit on the grid.',
867                     'This grid is only 1000x1000, and this matrix\n'
868                     f'[{int(matrix[0][0])} {int(matrix[0][1])}; {int(matrix[1][0])} {int(matrix[1][1])}]\n'
869                     " doesn't fit."
870                 )
871                 return True
872
873         return False
874
875     def _update_window_title(self) -> None:
876         """Update the window title to reflect whether the session has changed since it was last saved."""
877         if self._save_filename:
878             title = os.path.split(self._save_filename)[-1] + ' [*] - lintrans'
879         else:
880             title = ' [*] lintrans'
881
882         self.setWindowTitle(title)
883
884     def _reset_session(self) -> None:
885         """Ask the user if they want to reset the current session.
886
887         Resetting the session means setting the matrix wrapper to a new instance, and rendering I.

```

```

888         """
889         dialog = QMessageBox(self)
890         dialog.setIcon(QMessageBox.Question)
891         dialog.setWindowTitle('Reset the session?')
892         dialog.setText('Are you sure you want to reset the current session?')
893         dialog.setStandardButtons(QMessageBox.Yes | QMessageBox.No)
894         dialog.setDefaultButton(QMessageBox.No)
895
896         if dialog.exec() == QMessageBox.Yes:
897             self._matrix_wrapper = MatrixWrapper()
898             self._plot.polygon_points = []
899             self._plot.display_settings = GlobalSettings().get_display_settings()
900
901             self._reset_transformation()
902             self._expression_history = []
903             self._expression_history_index = None
904             self._lineedit_expression_box.setText('')
905             self._lineedit_expression_box.setFocus()
906             self._update_render_buttons()
907
908             self._save_filename = None
909             self.setWindowModified(False)
910             self._update_window_title()
911
912     def open_session_file(self, filename: str) -> None:
913         """Open the given session file.
914
915         If the selected file is not a valid lintrans session file, we just show an error message,
916         but if it's valid, we load it and set it as the default filename for saving.
917         """
918         try:
919             session, version, extra_attrs = Session.load_from_file(filename)
920
921             # load_from_file() can raise errors if the contents is not a valid pickled Python object,
922             # or if the pickled Python object is of the wrong type
923             except (AttributeError, EOFError, FileNotFoundError, ValueError, UnpicklingError):
924                 self._show_error_message(
925                     'Invalid file contents',
926                     'This is not a valid lintrans session file.',
927                     'Not all .lt files are lintrans session files. This file was probably created by an unrelated '
928                     'program.'
929                 )
930             return
931
932     missing_parts = False
933
934     if session.matrix_wrapper is not None:
935         self._matrix_wrapper = session.matrix_wrapper
936     else:
937         self._matrix_wrapper = MatrixWrapper() # type: ignore[unreachable]
938         missing_parts = True
939
940     if session.polygon_points is not None:
941         self._plot.polygon_points = session.polygon_points
942     else:
943         self._plot.polygon_points = [] # type: ignore[unreachable]
944         missing_parts = True
945
946     if session.display_settings is not None:
947         self._plot.display_settings = session.display_settings
948     else:
949         self._plot.display_settings = DisplaySettings() # type: ignore[unreachable]
950         missing_parts = True
951
952     if session.input_vector is not None:
953         self._plot.point_input_vector = session.input_vector
954     else:
955         self._plot.point_input_vector = (1, 1) # type: ignore[unreachable]
956         missing_parts = True
957
958     if missing_parts:
959         if version != lintrans.__version__:
960             info = f"This may be a version conflict. This file was saved with lintrans v{version} " \

```

```

961         f"but you're running lintrans v{lintrans.__version__}."
962     else:
963         info = None
964
965     self._show_error_message(
966         'Session file missing parts',
967         'This session file is missing certain elements. It may not work correctly.',
968         info,
969         warning=True
970     )
971     elif extra_attrs:
972         if version != lintrans.__version__:
973             info = f"This may be a version conflict. This file was saved with lintrans v{version} " \
974                 f"but you're running lintrans v{lintrans.__version__}."
975         else:
976             info = None
977
978     self._show_error_message(
979         'Session file has extra parts',
980         'This session file has more parts than expected. It will work correctly, '
981         'but you might be missing some features.',
982         info,
983         warning=True
984     )
985
986     self._reset_transformation()
987     self._expression_history = []
988     self._expression_history_index = None
989     self._linedit_expression_box.setText('')
990     self._linedit_expression_box.setFocus()
991     self._update_render_buttons()
992
993     # Set this as the default filename if we could read it properly
994     self._save_filename = filename
995     self.setWindowModified(False)
996     self._update_window_title()
997
998 @pyqtSlot()
999 def _ask_for_session_file(self) -> None:
1000     """Ask the user to select a session file, and then open it and load the session."""
1001     dialog = QFileDialog(
1002         self,
1003         'Open a session',
1004         GlobalSettings().get_save_directory(),
1005         'lintrans sessions (*.lt)'
1006     )
1007     dialog.setAcceptMode(QFileDialog.AcceptOpen)
1008     dialog.setFileMode(QFileDialog.ExistingFile)
1009     dialog.setViewMode(QFileDialog.List)
1010
1011     if dialog.exec():
1012         self.open_session_file(dialog.selectedFiles()[0])
1013
1014 @pyqtSlot()
1015 def _save_session(self) -> None:
1016     """Save the session to the given file.
1017
1018     If ``self._save_filename`` is ``None``, then call :meth:`_save_session_as` and return.
1019     """
1020     if self._save_filename is None:
1021         self._save_session_as()
1022         return
1023
1024     Session(
1025         matrix_wrapper=self._matrix_wrapper,
1026         polygon_points=self._plot.polygon_points,
1027         display_settings=self._plot.display_settings,
1028         input_vector=self._plot.point_input_vector,
1029     ).save_to_file(self._save_filename)
1030
1031     self.setWindowModified(False)
1032     self._update_window_title()
1033

```

```

1034 @pyqtSlot()
1035 def _save_session_as(self) -> None:
1036     """Ask the user for a file to save the session to, and then call :meth:`_save_session`.
1037
1038     .. note::
1039         If the user doesn't select a file to save the session to, then the session
1040         just doesn't get saved, and :meth:`_save_session` is never called.
1041     """
1042     dialog = FileSelectDialog(
1043         self,
1044         'Save this session',
1045         GlobalSettings().get_save_directory(),
1046         'lintrans sessions (*.lt)'
1047     )
1048     dialog.setAcceptMode(QFileDialog.AcceptSave)
1049     dialog.setFileMode(QFileDialog.AnyFile)
1050     dialog.setViewMode(QFileDialog.List)
1051     dialog.setDefaultSuffix('.lt')
1052
1053     if dialog.exec():
1054         filename = dialog.selectedFiles()[0]
1055         self._save_filename = filename
1056         self._save_session()
1057
1058 @pyqtSlot(str)
1059 def _prompt_update(self, version: str) -> None:
1060     """Open a modal dialog to prompt the user to update lintrans."""
1061     dialog = PromptUpdateDialog(self, new_version=version)
1062     dialog.open()
1063
1064 def check_for_updates_and_prompt(self) -> None:
1065     """Update lintrans depending on the user's choice of update type.
1066
1067     If they chose 'prompt', then this method will open a prompt dialog (after checking
1068     if a new version actually exists). See :meth:`_prompt_update`.
1069     """
1070     self._thread_updates.start()
1071
1072
1073 def main(filename: Optional[str]) -> NoReturn:
1074     """Run the GUI by creating and showing an instance of :class:`LintransMainWindow`.
1075
1076     :param Optional[str] filename: A session file to optionally open at startup
1077     """
1078     app = QApplication([])
1079     app.setApplicationName('lintrans')
1080     app.setApplicationVersion(lintrans.__version__)
1081
1082     qapp().setStyle(QStyleFactory.create('fusion'))
1083
1084     window = LintransMainWindow()
1085     window.show()
1086     window.check_for_updates_and_prompt()
1087
1088     if filename:
1089         window.open_session_file(filename)
1090
1091     sys.exit(app.exec())

```

## A.10 gui/\_\_init\_\_.py

```

1 # lintrans - The linear transformation visualizer
2 # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4 # This program is licensed under GNU GPLv3, available here:
5 # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7 """This package supplies the main GUI and associated dialogs for visualization."""
8
9 from . import dialogs, plots, session, settings, utility, validate

```

```

10 from .main_window import main
11
12 __all__ = ['dialogs', 'main', 'plots', 'session', 'settings', 'utility', 'validate']

```

## A.11 gui/session.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides the :class:`Session` class, which provides a way to save and load sessions."""
8
9  from __future__ import annotations
10
11  import os
12  import pathlib
13  import pickle
14  from collections import defaultdict
15  from typing import Any, DefaultDict, List, Tuple
16
17  import lintrans
18  from lintrans.gui.settings import DisplaySettings
19  from lintrans.matrices import MatrixWrapper
20
21
22  def _return_none() -> None:
23      """Return None.
24
25      This function only exists to make the defaultdict in :class:`Session` pickle-able.
26      """
27      return None
28
29
30  class Session:
31      """Hold information about a session and provide methods to save and load that data."""
32
33      __slots__ = ('matrix_wrapper', 'polygon_points', 'display_settings', 'input_vector')
34      matrix_wrapper: MatrixWrapper
35      polygon_points: List[Tuple[float, float]]
36      display_settings: DisplaySettings
37      input_vector: Tuple[float, float]
38
39      def __init__(
40          self,
41          *,
42          matrix_wrapper: MatrixWrapper,
43          polygon_points: List[Tuple[float, float]],
44          display_settings: DisplaySettings,
45          input_vector: Tuple[float, float],
46      ) -> None:
47          """Create a :class:`Session` object with the given data."""
48          self.matrix_wrapper = matrix_wrapper
49          self.polygon_points = polygon_points
50          self.display_settings = display_settings
51          self.input_vector = input_vector
52
53      def save_to_file(self, filename: str) -> None:
54          """Save the session state to a file, creating parent directories as needed."""
55          parent_dir = pathlib.Path(os.path.expanduser(filename)).parent.absolute()
56
57          if not os.path.isdir(parent_dir):
58              os.makedirs(parent_dir)
59
60          data_dict: DefaultDict[str, Any] = defaultdict(_return_none, lintrans=lintrans.__version__)
61          for attr in self.__slots__:
62              data_dict[attr] = getattr(self, attr)
63
64          with open(filename, 'wb') as f:

```



```

65         pickle.dump(data_dict, f, protocol=4)
66
67     @classmethod
68     def load_from_file(cls, filename: str) -> Tuple[Session, str, bool]:
69         """Return the session state that was previously saved to ``filename`` along with some extra information.
70
71         The tuple we return has the :class:`Session` object (with some possibly None arguments),
72         the lintrans version that the file was saved under, and whether the file had any extra
73         attributes that this version doesn't support.
74
75         :raises AttributeError: For specific older versions of :class:`Session` before it used ``__slots__``
76         :raises EOFError: If the file doesn't contain a pickled Python object
77         :raises FileNotFoundError: If the file doesn't exist
78         :raises ValueError: If the file contains a pickled object of the wrong type
79         """
80         with open(filename, 'rb') as f:
81             data_dict = pickle.load(f)
82
83         if not isinstance(data_dict, defaultdict):
84             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be defaultdict)')
85
86         session = cls(
87             matrix_wrapper=data_dict['matrix_wrapper'],
88             polygon_points=data_dict['polygon_points'],
89             display_settings=data_dict['display_settings'],
90             input_vector=data_dict['input_vector'],
91         )
92
93         # Check if the file has more attributes than we expect
94         # If it does, it's probably from a higher version of lintrans
95         extra_attrs = len(
96             set(data_dict.keys()).difference(
97                 set(['lintrans', *cls.__slots__])
98             )
99         ) != 0
100
101         return session, data_dict['lintrans'], extra_attrs

```

## A.12 gui/plots/classes.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides superclasses for plotting transformations."""
8
9  from __future__ import annotations
10
11  from abc import abstractmethod
12  from math import ceil, dist, floor
13  from typing import Iterable, List, Optional, Tuple
14
15  import numpy as np
16  from PyQt5.QtCore import QPoint, QPointF, QRectF, Qt
17  from PyQt5.QtGui import (QBrush, QColor, QFont, QMouseEvent, QPainter,
18                           QPainterPath, QPaintEvent, QPen, QPolygonF,
19                           QWheelEvent)
20  from PyQt5.QtWidgets import QWidget
21
22  from lintrans.global_settings import GlobalSettings
23  from lintrans.typing_ import MatrixType, VectorType
24
25
26  class BackgroundPlot(QWidget):
27      """This class provides a background for plotting, as well as setup for a Qt widget.
28
29      This class provides a background (untransformed) plane, and all the backend details
30      for a Qt application, but does not provide useful functionality. To be useful,

```

```

31         this class must be subclassed and behaviour must be implemented by the subclass.
32         """
33
34     DEFAULT_GRID_SPACING: int = 85
35     """This is the starting spacing between grid lines (in pixels)."""
36
37     _MINIMUM_GRID_SPACING: int = 5
38     """This is the minimum spacing between grid lines (in pixels)."""
39
40     _COLOUR_BACKGROUND_GRID: QColor = QColor('#808080')
41     """This is the colour of the background grid lines."""
42
43     _COLOUR_BACKGROUND_AXES: QColor = QColor('#000000')
44     """This is the colour of the background axes."""
45
46     _WIDTH_BACKGROUND_GRID: float = 0.3
47     """This is the width of the background grid lines, as a multiple of the :class:`QPainter` line width."""
48
49     _PEN_POLYGON: QPen = QPen(QColor('#000000'), 1.5)
50     """This is the pen used to draw the normal polygon."""
51
52     _BRUSH_SOLID_WHITE: QBrush = QBrush(QColor('FFFFFF'), Qt.SolidPattern)
53     """This brush is just solid white. Used to draw the insides of circles."""
54
55     def __init__(self, *args, **kwargs):
56         """Create the widget and setup backend stuff for rendering.
57
58         .. note:: ``*args`` and ``**kwargs`` are passed the superclass constructor (:class:`QWidget`).
59         """
60         super().__init__(*args, **kwargs)
61
62         self.setAutoFillBackground(True)
63
64         # Set the background to white
65         palette = self.palette()
66         palette.setColor(self.backgroundRole(), Qt.white)
67         self.setPalette(palette)
68
69         self.grid_spacing = self.DEFAULT_GRID_SPACING
70
71     @property
72     def _canvas_origin(self) -> Tuple[int, int]:
73         """Return the canvas coords of the grid origin.
74
75         The return value is intended to be unpacked and passed to a :meth:`QPainter.drawLine:iiii` call.
76
77         See :meth:`canvas_coords`.
78
79         :returns: The canvas coordinates of the grid origin
80         :rtype: Tuple[int, int]
81         """
82         return self.width() // 2, self.height() // 2
83
84     def _canvas_x(self, x: float) -> int:
85         """Convert an x coordinate from grid coords to canvas coords."""
86         return int(self._canvas_origin[0] + x * self.grid_spacing)
87
88     def _canvas_y(self, y: float) -> int:
89         """Convert a y coordinate from grid coords to canvas coords."""
90         return int(self._canvas_origin[1] - y * self.grid_spacing)
91
92     def canvas_coords(self, x: float, y: float) -> Tuple[int, int]:
93         """Convert a coordinate from grid coords to canvas coords.
94
95         This method is intended to be used like
96
97         .. code::
98
99             painter.drawLine(*self.canvas_coords(x1, y1), *self.canvas_coords(x2, y2))
100
101         or like
102
103         .. code::

```

```

104
105         painter.drawLine(*self._canvas_origin, *self.canvas_coords(x, y))
106
107     See :attr:`_canvas_origin`.
108
109     :param float x: The x component of the grid coordinate
110     :param float y: The y component of the grid coordinate
111     :returns: The resultant canvas coordinates
112     :rtype: Tuple[int, int]
113     """
114     return self._canvas_x(x), self._canvas_y(y)
115
116 def _grid_corner(self) -> Tuple[float, float]:
117     """Return the grid coords of the top right corner."""
118     return self.width() / (2 * self.grid_spacing), self.height() / (2 * self.grid_spacing)
119
120 def _grid_coors(self, x: int, y: int) -> Tuple[float, float]:
121     """Convert a coordinate from canvas coords to grid coords.
122
123     :param int x: The x component of the canvas coordinate
124     :param int y: The y component of the canvas coordinate
125     :returns: The resultant grid coordinates
126     :rtype: Tuple[float, float]
127     """
128     # We get the maximum grid coords and convert them into canvas coords
129     return (x - self._canvas_origin[0]) / self.grid_spacing, (-y + self._canvas_origin[1]) / self.grid_spacing
130
131 @abstractmethod
132 def paintEvent(self, event: QPaintEvent) -> None:
133     """Handle a :class:`QPaintEvent`.
134
135     .. note:: This method is abstract and must be overridden by all subclasses.
136     """
137
138 def _draw_background(self, painter: QPainter, draw_grid: bool) -> None:
139     """Draw the background grid.
140
141     .. note:: This method is just a utility method for subclasses to use to render the background grid.
142
143     :param QPainter painter: The painter to draw the background with
144     :param bool draw_grid: Whether to draw the grid lines
145     """
146     if draw_grid:
147         painter.setPen(QPen(self._COLOUR_BACKGROUND_GRID, self._WIDTH_BACKGROUND_GRID))
148
149         # Draw equally spaced vertical lines, starting in the middle and going out
150         # We loop up to half of the width. This is because we draw a line on each side in each iteration
151         for x in range(self.width() // 2 + self.grid_spacing, self.width(), self.grid_spacing):
152             painter.drawLine(x, 0, x, self.height())
153             painter.drawLine(self.width() - x, 0, self.width() - x, self.height())
154
155         # Same with the horizontal lines
156         for y in range(self.height() // 2 + self.grid_spacing, self.height(), self.grid_spacing):
157             painter.drawLine(0, y, self.width(), y)
158             painter.drawLine(0, self.height() - y, self.width(), self.height() - y)
159
160         # Now draw the axes
161         painter.setPen(QPen(self._COLOUR_BACKGROUND_AXES, self._WIDTH_BACKGROUND_GRID))
162         painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
163         painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
164
165 def wheelEvent(self, event: QWheelEvent) -> None:
166     """Handle a :class:`QWheelEvent` by zooming in or out of the grid."""
167     # angleDelta() returns a number of units equal to 8 times the number of degrees rotated
168     degrees = event.angleDelta() / 8
169
170     if degrees is not None:
171         new_spacing = max(1, self.grid_spacing + degrees.y())
172
173         if new_spacing >= self._MINIMUM_GRID_SPACING:
174             self.grid_spacing = new_spacing
175
176     event.accept()

```

```

177         self.update()
178
179
180 class InteractivePlot(BackgroundPlot):
181     """This class represents an interactive plot, which allows the user to click and/or drag point(s).
182
183     It declares the Qt methods needed for mouse cursor interaction to be abstract,
184     requiring all subclasses to implement these.
185     """
186
187     def _round_to_int_coord(self, point: Tuple[float, float]) -> Tuple[float, float]:
188         """Take a coordinate in grid coords and round it to an integer coordinate if it's within the snapping
189         ↪ distance.
190
191         If the point is not close enough, we just return the original point.
192         See :attr:`lintrans.global_settings.GlobalSettingsData.snap_dist`.
193         """
194         x, y = point
195
196         possible_snaps: List[Tuple[int, int]] = [
197             (floor(x), floor(y)),
198             (floor(x), ceil(y)),
199             (ceil(x), floor(y)),
200             (ceil(x), ceil(y))
201         ]
202
203         snap_distances: List[Tuple[float, Tuple[int, int]]] = [
204             (dist((x, y), coord), coord)
205             for coord in possible_snaps
206         ]
207
208         for snap_dist, coord in snap_distances:
209             if GlobalSettings().get_data().snap_to_int_coords and snap_dist < GlobalSettings().get_data().snap_dist:
210                 x, y = coord
211
212         return x, y
213
214     def _is_within_epsilon(self, cursor_pos: Tuple[float, float], point: Tuple[float, float]) -> bool:
215         """Check if the cursor position (in canvas coords) is within range of the given point."""
216         mx, my = cursor_pos
217         px, py = self.canvas_coords(*point)
218         cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
219         return (abs(px - mx) <= cursor_epsilon and abs(py - my) <= cursor_epsilon)
220
221     @abstractmethod
222     def mousePressEvent(self, event: QMouseEvent) -> None:
223         """Handle the mouse being pressed."""
224
225     @abstractmethod
226     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
227         """Handle the mouse being released."""
228
229     @abstractmethod
230     def mouseMoveEvent(self, event: QMouseEvent) -> None:
231         """Handle the mouse moving on the widget."""
232
233 class VectorGridPlot(BackgroundPlot):
234     """This class represents a background plot, with vectors and their grid drawn on top. It provides utility
235     ↪ methods.
236
237     .. note::
238         This is a simple superclass for vectors and is not for visualizing transformations.
239         See :class:`VisualizeTransformationPlot`.
240
241     This class should be subclassed to be used for visualization and matrix definition widgets.
242     All useful behaviour should be implemented by any subclass.
243
244     .. warning:: This class should never be directly instantiated, only subclassed.
245     """
246
247     _COLOUR_I = QColor('#0808d8')
248     """This is the colour of the `i` basis vector and associated transformed grid lines."""

```

```

248
249 _COLOUR_J = QColor('#e90000')
250 """This is the colour of the `j` basis vector and associated transformed grid lines."""
251
252 _COLOUR_TEXT = QColor('#000000')
253 """This is the colour of the text."""
254
255 _WIDTH_VECTOR_LINE = 1.8
256 """This is the width of the transformed basis vector lines, as a multiple of the :class:`QPainter` line
↳ width."""
257
258 _WIDTH_TRANSFORMED_GRID = 0.8
259 """This is the width of the transformed grid lines, as a multiple of the :class:`QPainter` line width."""
260
261 _ARROWHEAD_LENGTH = 0.15
262 """This is the minimum length (in grid coord size) of the arrowhead parts."""
263
264 _MAX_PARALLEL_LINES = 150
265 """This is the maximum number of parallel transformed grid lines that will be drawn.
266
267 The user can zoom out further, but we will stop drawing grid lines beyond this number.
268 """
269
270 def __init__(self, *args, **kwargs):
271     """Create the widget with ``point_i`` and ``point_j`` attributes.
272
273     .. note:: ``*args`` and ``**kwargs`` are passed to the superclass constructor (:class:`BackgroundPlot`).
274     """
275     super().__init__(*args, **kwargs)
276
277     self.point_i: Tuple[float, float] = (1., 0.)
278     self.point_j: Tuple[float, float] = (0., 1.)
279
280 @property
281 def _matrix(self) -> MatrixType:
282     """Return the assembled matrix of the basis vectors."""
283     return np.array([
284         [self.point_i[0], self.point_j[0]],
285         [self.point_i[1], self.point_j[1]]
286     ])
287
288 @property
289 def _det(self) -> float:
290     """Return the determinant of the assembled matrix."""
291     return float(np.linalg.det(self._matrix))
292
293 @property
294 def _eigs(self) -> 'Iterable[Tuple[float, VectorType]]':
295     """Return the eigenvalues and eigenvectors zipped together to be iterated over.
296
297     :rtype: Iterable[Tuple[float, VectorType]]
298     """
299     values, vectors = np.linalg.eig(self._matrix)
300     return zip(values, vectors.T)
301
302 @abstractmethod
303 def paintEvent(self, event: QPaintEvent) -> None:
304     """Handle a :class:`QPaintEvent`."""
305
306 def _draw_parallel_lines(self, painter: QPainter, vector: Tuple[float, float], point: Tuple[float, float]) ->
↳ None:
307     """Draw a set of evenly spaced grid lines parallel to ``vector`` intersecting ``point``.
308
309     :param QPainter painter: The painter to draw the lines with
310     :param vector: The vector to draw the grid lines parallel to
311     :type vector: Tuple[float, float]
312     :param point: The point for the lines to intersect with
313     :type point: Tuple[float, float]
314     """
315     max_x, max_y = self._grid_corner()
316     vector_x, vector_y = vector
317     point_x, point_y = point
318

```

```

319     # If the determinant is 0
320     if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
321         rank = np.linalg.matrix_rank(
322             np.array([
323                 [vector_x, point_x],
324                 [vector_y, point_y]
325             ])
326         )
327
328     # If the matrix is rank 1, then we can draw the column space line
329     if rank == 1:
330         # If the vector does not have a 0 x or y component, then we can just draw the line
331         if abs(vector_x) > 1e-12 and abs(vector_y) > 1e-12:
332             self._draw_oblique_line(painter, vector_y / vector_x, 0)
333
334         # Otherwise, we have to draw lines along the axes
335         elif abs(vector_x) > 1e-12 and abs(vector_y) < 1e-12:
336             painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
337
338         elif abs(vector_x) < 1e-12 and abs(vector_y) > 1e-12:
339             painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
340
341         # If the vector is (0, 0), then don't draw a line for it
342         else:
343             return
344
345     # If the rank is 0, then we don't draw any lines
346     else:
347         return
348
349     elif abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
350         # If both components of the vector are practically 0, then we can't render any grid lines
351         return
352
353     # Draw vertical lines
354     elif abs(vector_x) < 1e-12:
355         painter.drawLine(self._canvas_x(0), 0, self._canvas_x(0), self.height())
356
357         for i in range(min(abs(int(max_x / point_x)), self._MAX_PARALLEL_LINES)):
358             painter.drawLine(
359                 self._canvas_x((i + 1) * point_x),
360                 0,
361                 self._canvas_x((i + 1) * point_x),
362                 self.height()
363             )
364             painter.drawLine(
365                 self._canvas_x(-1 * (i + 1) * point_x),
366                 0,
367                 self._canvas_x(-1 * (i + 1) * point_x),
368                 self.height()
369             )
370
371     # Draw horizontal lines
372     elif abs(vector_y) < 1e-12:
373         painter.drawLine(0, self._canvas_y(0), self.width(), self._canvas_y(0))
374
375         for i in range(min(abs(int(max_y / point_y)), self._MAX_PARALLEL_LINES)):
376             painter.drawLine(
377                 0,
378                 self._canvas_y((i + 1) * point_y),
379                 self.width(),
380                 self._canvas_y((i + 1) * point_y)
381             )
382             painter.drawLine(
383                 0,
384                 self._canvas_y(-1 * (i + 1) * point_y),
385                 self.width(),
386                 self._canvas_y(-1 * (i + 1) * point_y)
387             )
388
389     # If the line is oblique, then we can use  $y = mx + c$ 
390     else:
391         m = vector_y / vector_x

```

```

392         c = point_y - m * point_x
393
394         self._draw_oblique_line(painter, m, 0)
395
396         # We don't want to overshoot the max number of parallel lines,
397         # but we should also stop looping as soon as we can't draw any more lines
398         for i in range(1, self._MAX_PARALLEL_LINES + 1):
399             if not self._draw_pair_of_oblique_lines(painter, m, i * c):
400                 break
401
402     def _draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
403         """Draw a pair of oblique lines, using the equation  $y = mx + c$ .
404
405         This method just calls :meth:`_draw_oblique_line` with ``c`` and ``-c``,
406         and returns True if either call returned True.
407
408         :param QPainter painter: The painter to draw the vectors and grid lines with
409         :param float m: The gradient of the lines to draw
410         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
411         :returns bool: Whether we were able to draw any lines on the canvas
412         """
413         return any([
414             self._draw_oblique_line(painter, m, c),
415             self._draw_oblique_line(painter, m, -c)
416         ])
417
418     def _draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
419         """Draw an oblique line, using the equation  $y = mx + c$ .
420
421         We only draw the part of the line that fits within the canvas, returning True if
422         we were able to draw a line within the boundaries, and False if we couldn't draw a line
423
424         :param QPainter painter: The painter to draw the vectors and grid lines with
425         :param float m: The gradient of the line to draw
426         :param float c: The y-intercept of the line to draw
427         :returns bool: Whether we were able to draw a line on the canvas
428         """
429         max_x, max_y = self._grid_corner()
430
431         # These variable names are shortened for convenience
432         # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
433         myi = (max_y - c) / m
434         mmyi = (-max_y - c) / m
435         mx_i = max_x * m + c
436         mmx_i = -max_x * m + c
437
438         # The inner list here is a list of coords, or None
439         # If an intersection fits within the bounds, then we keep its coord,
440         # else it is None, and then gets discarded from the points list
441         # By the end, points is a list of two coords, or an empty list
442         points: List[Tuple[float, float]] = [
443             x for x in [
444                 (myi, max_y) if -max_x < myi < max_x else None,
445                 (mmyi, -max_y) if -max_x < mmyi < max_x else None,
446                 (max_x, mx_i) if -max_y < mx_i < max_y else None,
447                 (-max_x, mmx_i) if -max_y < mmx_i < max_y else None
448             ] if x is not None
449         ]
450
451         # If no intersections fit on the canvas
452         if len(points) < 2:
453             return False
454
455         # If we can, then draw the line
456         else:
457             painter.drawLine(
458                 *self.canvas_coords(*points[0]),
459                 *self.canvas_coords(*points[1])
460             )
461             return True
462
463     def _draw_transformed_grid(self, painter: QPainter) -> None:
464         """Draw the transformed version of the grid, given by the basis vectors.

```

```

465
466         .. note:: This method draws the grid, but not the basis vectors. Use :meth:`_draw_basis_vectors` to draw
↳ them.
467
468         :param QPainter painter: The painter to draw the grid lines with
469         """
470         # Draw all the parallel lines
471         painter.setPen(QPen(self._COLOUR_I, self._WIDTH_TRANSFORMED_GRID))
472         self._draw_parallel_lines(painter, self.point_i, self.point_j)
473         painter.setPen(QPen(self._COLOUR_J, self._WIDTH_TRANSFORMED_GRID))
474         self._draw_parallel_lines(painter, self.point_j, self.point_i)
475
476     def _draw_arrowhead_away_from_origin(self, painter: QPainter, point: Tuple[float, float]) -> None:
477         """Draw an arrowhead at `point`, pointing away from the origin.
478
479         :param QPainter painter: The painter to draw the arrowhead with
480         :param point: The point to draw the arrowhead at, given in grid coords
481         :type point: Tuple[float, float]
482         """
483         # This algorithm was adapted from a C# algorithm found at
484         # http://csharpshelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
485
486         # Get the x and y coords of the point, and then normalize them
487         # We have to normalize them, or else the size of the arrowhead will
488         # scale with the distance of the point from the origin
489         x, y = point
490         vector_length = np.sqrt(x * x + y * y)
491
492         if vector_length < 1e-12:
493             return
494
495         nx = x / vector_length
496         ny = y / vector_length
497
498         # We choose a length and find the steps in the x and y directions
499         length = min(
500             self._ARROWHEAD_LENGTH * self.DEFAULT_GRID_SPACING / self.grid_spacing,
501             vector_length
502         )
503         dx = length * (-nx - ny)
504         dy = length * (nx - ny)
505
506         # Then we just plot those lines
507         painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x + dx, y + dy))
508         painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x - dy, y + dx))
509
510     def _draw_position_vector(self, painter: QPainter, point: Tuple[float, float], colour: QColor) -> None:
511         """Draw a vector from the origin to the given point.
512
513         :param QPainter painter: The painter to draw the position vector with
514         :param point: The tip of the position vector in grid coords
515         :type point: Tuple[float, float]
516         :param QColor colour: The colour to draw the position vector in
517         """
518         painter.setPen(QPen(colour, self._WIDTH_VECTOR_LINE))
519         painter.drawLine(*self._canvas_origin, *self.canvas_coords(*point))
520         self._draw_arrowhead_away_from_origin(painter, point)
521
522     def _draw_basis_vectors(self, painter: QPainter) -> None:
523         """Draw arrowheads at the tips of the basis vectors.
524
525         :param QPainter painter: The painter to draw the basis vectors with
526         """
527         self._draw_position_vector(painter, self.point_i, self._COLOUR_I)
528         self._draw_position_vector(painter, self.point_j, self._COLOUR_J)
529
530     def _draw_basis_vector_labels(self, painter: QPainter) -> None:
531         """Label the basis vectors with `i` and `j`."""
532         font = self.font()
533         font.setItalic(True)
534         font.setStyleHint(QFont.Serif)
535
536         self._draw_text_at_vector_tip(painter, self.point_i, 'i', font)

```



```

537         self._draw_text_at_vector_tip(painter, self.point_j, 'j', font)
538
539     def _draw_text_at_vector_tip(
540         self,
541         painter: QPainter,
542         point: Tuple[float, float],
543         text: str,
544         font: Optional[QFont] = None
545     ) -> None:
546         """Draw the given text at the point as if it were the tip of a vector, using the custom font if given."""
547         offset = 3
548         top_left: QPoint
549         bottom_right: QPoint
550         alignment_flags: int
551         x, y = point
552
553         if x >= 0 and y >= 0: # Q1
554             top_left = QPoint(self._canvas_x(x) + offset, 0)
555             bottom_right = QPoint(self.width(), self._canvas_y(y) - offset)
556             alignment_flags = Qt.AlignLeft | Qt.AlignBottom
557
558         elif x < 0 and y >= 0: # Q2
559             top_left = QPoint(0, 0)
560             bottom_right = QPoint(self._canvas_x(x) - offset, self._canvas_y(y) - offset)
561             alignment_flags = Qt.AlignRight | Qt.AlignBottom
562
563         elif x < 0 and y < 0: # Q3
564             top_left = QPoint(0, self._canvas_y(y) + offset)
565             bottom_right = QPoint(self._canvas_x(x) - offset, self.height())
566             alignment_flags = Qt.AlignRight | Qt.AlignTop
567
568         else: # Q4
569             top_left = QPoint(self._canvas_x(x) + offset, self._canvas_y(y) + offset)
570             bottom_right = QPoint(self.width(), self.height())
571             alignment_flags = Qt.AlignLeft | Qt.AlignTop
572
573         original_font = painter.font()
574
575         if font is not None:
576             painter.setFont(font)
577
578         painter.setPen(QPen(self._COLOUR_TEXT, 1))
579         painter.drawText(QRectF(top_left, bottom_right), alignment_flags, text)
580
581         painter.setFont(original_font)
582
583
584     class VisualizeTransformationPlot(VectorGridPlot):
585         """This class is a superclass for visualizing transformations. It provides utility methods."""
586
587         _COLOUR_EIGEN = QColor('#13cf00')
588         """This is the colour of the eigenvectors and eigenlines (the spans of the eigenvectors)."""
589
590         @abstractmethod
591         def paintEvent(self, event: QPaintEvent) -> None:
592             """Handle a :class:`QPaintEvent`."""
593
594         def _draw_determinant_parallelogram(self, painter: QPainter) -> None:
595             """Draw the parallelogram of the determinant of the matrix.
596
597             :param QPainter painter: The painter to draw the parallelogram with
598             """
599             if self._det == 0:
600                 return
601
602             path = QPainterPath()
603             path.moveTo(*self._canvas_origin)
604             path.lineTo(*self.canvas_coords(*self.point_i))
605             path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
606             path.lineTo(*self.canvas_coords(*self.point_j))
607
608             color = (16, 235, 253) if self._det > 0 else (253, 34, 16)
609             brush = QBrush(QColor(*color, alpha=128), Qt.SolidPattern)

```

```

610 painter.fillPath(path, brush)
611
612
613 def _draw_determinant_text(self, painter: QPainter) -> None:
614     """Write the string value of the determinant in the middle of the parallelogram.
615
616     :param QPainter painter: The painter to draw the determinant text with
617     """
618     painter.setPen(QPen(self._COLOUR_TEXT, self._WIDTH_VECTOR_LINE))
619
620     # We're building a QRect that encloses the determinant parallelogram
621     # Then we can center the text in this QRect
622     coords: List[Tuple[float, float]] = [
623         (0, 0),
624         self.point_i,
625         self.point_j,
626         (
627             self.point_i[0] + self.point_j[0],
628             self.point_i[1] + self.point_j[1]
629         )
630     ]
631
632     xs = [t[0] for t in coords]
633     ys = [t[1] for t in coords]
634
635     top_left = QPoint(*self.canvas_coords(min(xs), max(ys)))
636     bottom_right = QPoint(*self.canvas_coords(max(xs), min(ys)))
637
638     rect = QRectF(top_left, bottom_right)
639
640     painter.drawText(
641         rect,
642         Qt.AlignHCenter | Qt.AlignVCenter,
643         f'{self._det:.2f}'
644     )
645
646 def _draw_eigenvectors(self, painter: QPainter) -> None:
647     """Draw the eigenvectors of the displayed matrix transformation.
648
649     :param QPainter painter: The painter to draw the eigenvectors with
650     """
651     for value, vector in self._eigs:
652         x = value * vector[0]
653         y = value * vector[1]
654
655         if x.imag != 0 or y.imag != 0:
656             continue
657
658         self._draw_position_vector(painter, (x, y), self._COLOUR_EIGEN)
659         self._draw_text_at_vector_tip(painter, (x, y), f'{value:.2f}')
660
661 def _draw_eigenlines(self, painter: QPainter) -> None:
662     """Draw the eigenlines. These are the invariant lines, or the spans of the eigenvectors.
663
664     :param QPainter painter: The painter to draw the eigenlines with
665     """
666     painter.setPen(QPen(self._COLOUR_EIGEN, self._WIDTH_TRANSFORMED_GRID))
667
668     for value, vector in self._eigs:
669         if value.imag != 0:
670             continue
671
672         x, y = vector
673
674         if x == 0:
675             x_mid = int(self.width() / 2)
676             painter.drawLine(x_mid, 0, x_mid, self.height())
677
678         elif y == 0:
679             y_mid = int(self.height() / 2)
680             painter.drawLine(0, y_mid, self.width(), y_mid)
681
682     else:

```

```

683         self._draw_oblique_line(painter, y / x, 0)
684
685     def _draw_polygon_from_points(self, painter: QPainter, points: List[Tuple[float, float]]) -> None:
686         """Draw a polygon from a given list of points.
687
688         This is a helper method for :meth:`_draw_untransformed_polygon` and :meth:`_draw_transformed_polygon`.
689         """
690         if len(points) > 2:
691             painter.drawPolygon(QPolygonF(
692                 [QPointF(*self.canvas_coords(*p)) for p in points]
693             ))
694         elif len(points) == 2:
695             painter.drawLine(
696                 *self.canvas_coords(*points[0]),
697                 *self.canvas_coords(*points[1])
698             )
699
700     def _draw_untransformed_polygon(self, painter: QPainter) -> None:
701         """Draw the original untransformed polygon with a dashed line."""
702         pen = QPen(self._PEN_POLYGON)
703         pen.setDashPattern([4, 4])
704         painter.setPen(pen)
705
706         self._draw_polygon_from_points(painter, self.polygon_points)
707
708     def _draw_transformed_polygon(self, painter: QPainter) -> None:
709         """Draw the transformed version of the polygon."""
710         if len(self.polygon_points) == 0:
711             return
712
713         painter.setPen(self._PEN_POLYGON)
714
715         # This transpose trick lets us do one matrix multiplication to transform every point in the polygon
716         # I learned this from Phil. Thanks Phil
717         self._draw_polygon_from_points(
718             painter,
719             (self._matrix @ np.array(self.polygon_points).T).T
720         )

```

## A.13 gui/plots/widgets.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides the actual widgets that can be used to visualize transformations in the GUI."""
8
9  from __future__ import annotations
10
11  import operator
12  from abc import abstractmethod
13  from copy import copy
14  from math import dist
15  from typing import List, Optional, Tuple
16
17  from PyQt5.QtCore import QPointF, Qt, pyqtSlot
18  from PyQt5.QtGui import QBrush, QColor, QMouseEvent, QPainter, QPaintEvent,
19      QPen, QPolygonF
20
21  from lintrans.global_settings import GlobalSettings
22  from lintrans.gui.settings import DisplaySettings
23  from lintrans.typing_ import MatrixType
24
25  from .classes import InteractivePlot, VisualizeTransformationPlot
26
27
28  class VisualizeTransformationWidget(VisualizeTransformationPlot):
29      """This widget is used in the main window to visualize transformations.

```

```

30
31 It handles all the rendering itself, and the only method that the user needs to care about
32 is :meth:`plot_matrix`, which allows you to visualize the given matrix transformation.
33 """
34
35 _COLOUR_OUTPUT_VECTOR = QColor('#f7c216')
36
37 def __init__(self, *args, display_settings: DisplaySettings, polygon_points: List[Tuple[float, float]],
38 ↪ **kwargs):
39     """Create the widget and assign its display settings, passing ``*args`` and ``**kwargs`` to super."""
40     super().__init__(*args, **kwargs)
41
42     self.display_settings = display_settings
43     self.polygon_points = polygon_points
44
45 def plot_matrix(self, matrix: MatrixType) -> None:
46     """Plot the given matrix on the grid by setting the basis vectors.
47
48     .. warning:: This method does not call :meth:`QWidget.update()`. This must be done by the caller.
49
50     :param MatrixType matrix: The matrix to plot
51     """
52     self.point_i = (matrix[0][0], matrix[1][0])
53     self.point_j = (matrix[0][1], matrix[1][1])
54
55 def _draw_scene(self, painter: QPainter) -> None:
56     """Draw the default scene of the transformation.
57
58     This method exists to make it easier to split the main viewport from visual definitions while
59     not using multiple :class:`QPainter` objects from a single :meth:`paintEvent` call in a subclass.
60     """
61     painter.setRenderHint(QPainter.Antialiasing)
62     painter.setBrush(Qt.NoBrush)
63
64     self._draw_background(painter, self.display_settings.draw_background_grid)
65
66     if self.display_settings.draw_eigenlines:
67         self._draw_eigenlines(painter)
68
69     if self.display_settings.draw_eigenvectors:
70         self._draw_eigenvectors(painter)
71
72     if self.display_settings.draw_determinant_parallelogram:
73         self._draw_determinant_parallelogram(painter)
74
75         if self.display_settings.show_determinant_value:
76             self._draw_determinant_text(painter)
77
78     if self.display_settings.draw_transformed_grid:
79         self._draw_transformed_grid(painter)
80
81     if self.display_settings.draw_basis_vectors:
82         self._draw_basis_vectors(painter)
83
84         if self.display_settings.label_basis_vectors:
85             self._draw_basis_vector_labels(painter)
86
87     if self.display_settings.draw_untransformed_polygon:
88         self._draw_untransformed_polygon(painter)
89
90     if self.display_settings.draw_transformed_polygon:
91         self._draw_transformed_polygon(painter)
92
93 @abstractmethod
94 def paintEvent(self, event: QPaintEvent) -> None:
95     """Paint the scene of the transformation."""
96
97 class MainViewportWidget(VisualizeTransformationWidget, InteractivePlot):
98     """This is the widget for the main viewport.
99
100     It extends :class:`VisualizeTransformationWidget` with input and output vectors.
101     """

```

```
102
103 def __init__(self, *args, **kwargs):
104     """Create the main viewport widget with its input point."""
105     super().__init__(*args, **kwargs)
106
107     self.point_input_vector: Tuple[float, float] = (1, 1)
108     self._dragging_vector: bool = False
109
110 def _draw_input_vector(self, painter: QPainter) -> None:
111     """Draw the input vector."""
112     pen = QPen(QColor('#000000'), self._WIDTH_VECTOR_LINE)
113     painter.setPen(pen)
114
115     x, y = self.canvas_coords(*self.point_input_vector)
116     painter.drawLine(*self._canvas_origin, x, y)
117
118     painter.setBrush(self._BRUSH_SOLID_WHITE)
119     cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
120
121     painter.setPen(Qt.NoPen)
122     painter.drawPie(
123         x - cursor_epsilon,
124         y - cursor_epsilon,
125         2 * cursor_epsilon,
126         2 * cursor_epsilon,
127         0,
128         16 * 360
129     )
130
131     painter.setPen(pen)
132     painter.drawArc(
133         x - cursor_epsilon,
134         y - cursor_epsilon,
135         2 * cursor_epsilon,
136         2 * cursor_epsilon,
137         0,
138         16 * 360
139     )
140
141 def _draw_output_vector(self, painter: QPainter) -> None:
142     """Draw the output vector."""
143     painter.setPen(QPen(self._COLOUR_OUTPUT_VECTOR, self._WIDTH_VECTOR_LINE))
144     painter.setBrush(QBrush(self._COLOUR_OUTPUT_VECTOR, Qt.SolidPattern))
145
146     x, y = self.canvas_coords(*(self._matrix @ self.point_input_vector))
147     cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
148
149     painter.drawLine(*self._canvas_origin, x, y)
150     painter.drawPie(
151         x - cursor_epsilon,
152         y - cursor_epsilon,
153         2 * cursor_epsilon,
154         2 * cursor_epsilon,
155         0,
156         16 * 360
157     )
158
159 def paintEvent(self, event: QPaintEvent) -> None:
160     """Paint the scene by just calling :meth:`_draw_scene` and drawing the I/O vectors."""
161     painter = QPainter()
162     painter.begin(self)
163
164     self._draw_scene(painter)
165
166     if self.display_settings.draw_output_vector:
167         self._draw_output_vector(painter)
168
169     if self.display_settings.draw_input_vector:
170         self._draw_input_vector(painter)
171
172     painter.end()
173     event.accept()
174
```

```

175 def mousePressEvent(self, event: QMouseEvent) -> None:
176     """Check if the user has clicked on the input vector."""
177     cursor_pos = (event.x(), event.y())
178
179     if event.button() != Qt.LeftButton:
180         event.ignore()
181         return
182
183     if self._is_within_epsilon(cursor_pos, self.point_input_vector):
184         self._dragging_vector = True
185
186     event.accept()
187
188 def mouseReleaseEvent(self, event: QMouseEvent) -> None:
189     """Stop dragging the input vector."""
190     if event.button() == Qt.LeftButton:
191         self._dragging_vector = False
192         event.accept()
193     else:
194         event.ignore()
195
196 def mouseMoveEvent(self, event: QMouseEvent) -> None:
197     """Drag the input vector if the user has clicked on it."""
198     if not self._dragging_vector:
199         event.ignore()
200         return
201
202     x, y = self._round_to_int_coord(self._grid_coords(event.x(), event.y()))
203     self.point_input_vector = (x, y)
204
205     self.update()
206     event.accept()
207
208
209 class DefineMatrixVisuallyWidget(VisualizeTransformationWidget, InteractivePlot):
210     """This widget allows the user to visually define a matrix.
211
212     This is just the widget itself. If you want the dialog, use
213     :class:`~lintrans.gui.dialogs.define_new_matrix.DefineVisuallyDialog`.
214     """
215
216     def __init__(
217         self,
218         *args,
219         display_settings: DisplaySettings,
220         polygon_points: List[Tuple[float, float]],
221         input_vector: Tuple[float, float],
222         **kwargs
223     ) -> None:
224         """Create the widget and enable mouse tracking. ``*args`` and ``**kwargs`` are passed to ``super()``."""
225         super().__init__(*args, display_settings=display_settings, polygon_points=polygon_points, **kwargs)
226
227         self._input_vector = input_vector
228         self._dragged_point: Tuple[float, float] | None = None
229
230     def _draw_input_vector(self, painter: QPainter) -> None:
231         """Draw the input vector."""
232         color = QColor('#000000')
233         color.setAlpha(0x88)
234         pen = QPen(color, self._WIDTH_VECTOR_LINE)
235         painter.setPen(pen)
236
237         x, y = self.canvas_coords(*self._input_vector)
238         painter.drawLine(*self._canvas_origin, x, y)
239
240         painter.setBrush(self._BRUSH_SOLID_WHITE)
241         cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
242
243         painter.setPen(Qt.NoPen)
244         painter.drawPie(
245             x - cursor_epsilon,
246             y - cursor_epsilon,
247             2 * cursor_epsilon,

```

```
248         2 * cursor_epsilon,
249         0,
250         16 * 360
251     )
252
253     painter.setPen(pen)
254     painter.drawArc(
255         x - cursor_epsilon,
256         y - cursor_epsilon,
257         2 * cursor_epsilon,
258         2 * cursor_epsilon,
259         0,
260         16 * 360
261     )
262
263     def _draw_output_vector(self, painter: QPainter) -> None:
264         """Draw the output vector."""
265         color = copy(self._COLOUR_OUTPUT_VECTOR)
266         color.setAlpha(0x88)
267         painter.setPen(QPen(color, self._WIDTH_VECTOR_LINE))
268         painter.setBrush(QBrush(self._COLOUR_OUTPUT_VECTOR, Qt.SolidPattern))
269
270         x, y = self.canvas_coords(*(self._matrix @ self._input_vector))
271         cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
272
273         painter.drawLine(*self._canvas_origin, x, y)
274         painter.drawPie(
275             x - cursor_epsilon,
276             y - cursor_epsilon,
277             2 * cursor_epsilon,
278             2 * cursor_epsilon,
279             0,
280             16 * 360
281         )
282
283     def paintEvent(self, event: QPaintEvent) -> None:
284         """Paint the scene by just calling :meth:`_draw_scene`."""
285         painter = QPainter()
286         painter.begin(self)
287
288         self._draw_scene(painter)
289
290         if self.display_settings.draw_output_vector:
291             self._draw_output_vector(painter)
292
293         if self.display_settings.draw_input_vector:
294             self._draw_input_vector(painter)
295
296         painter.end()
297         event.accept()
298
299     def mousePressEvent(self, event: QMouseEvent) -> None:
300         """Set the dragged point if the cursor is within the cursor epsilon.
301
302         See :attr:`lintrans.global_settings.GlobalSettingsData.cursor_epsilon`.
303         """
304         cursor_pos = (event.x(), event.y())
305
306         if event.button() != Qt.LeftButton:
307             event.ignore()
308             return
309
310         for point in (self.point_i, self.point_j):
311             if self._is_within_epsilon(cursor_pos, point):
312                 self._dragged_point = point[0], point[1]
313
314         event.accept()
315
316     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
317         """Handle the mouse click being released by unsetting the dragged point."""
318         if event.button() == Qt.LeftButton:
319             self._dragged_point = None
320             event.accept()
```

```

321         else:
322             event.ignore()
323
324     def mouseMoveEvent(self, event: QMouseEvent) -> None:
325         """Handle the mouse moving on the canvas."""
326         if self._dragged_point is None:
327             event.ignore()
328             return
329
330         x, y = self._round_to_int_coord(self._grid_coords(event.x(), event.y()))
331
332         if self._dragged_point == self.point_i:
333             self.point_i = x, y
334
335         elif self._dragged_point == self.point_j:
336             self.point_j = x, y
337
338         self._dragged_point = x, y
339
340         self.update()
341         event.accept()
342
343
344     class DefinePolygonWidget(InteractivePlot):
345         """This widget allows the user to define a polygon by clicking and dragging points on the canvas."""
346
347         def __init__(self, *args, polygon_points: List[Tuple[float, float]], **kwargs):
348             """Create the widget with a list of points and a dragged point index."""
349             super().__init__(*args, **kwargs)
350
351             self._dragged_point_index: Optional[int] = None
352             self.points = polygon_points.copy()
353
354         @pyqtSlot()
355         def reset_polygon(self) -> None:
356             """Reset the polygon and update the widget."""
357             self.points = []
358             self.update()
359
360         def mousePressEvent(self, event: QMouseEvent) -> None:
361             """Handle the mouse being clicked by adding a point or setting the dragged point index to an existing
↩ point."""
362             if event.button() not in (Qt.LeftButton, Qt.RightButton):
363                 event.ignore()
364                 return
365
366             canvas_pos = (event.x(), event.y())
367             grid_pos = self._grid_coords(*canvas_pos)
368
369             if event.button() == Qt.LeftButton:
370                 for i, point in enumerate(self.points):
371                     if self._is_within_epsilon(canvas_pos, point):
372                         self._dragged_point_index = i
373                         event.accept()
374                         return
375
376             new_point = self._round_to_int_coord(grid_pos)
377
378             if len(self.points) < 2:
379                 self.points.append(new_point)
380                 self._dragged_point_index = -1
381             else:
382                 # FIXME: This algorithm doesn't work very well when the new point is far away
383                 # from the existing polygon; it just picks the longest side
384
385                 # Get a list of line segments and a list of their lengths
386                 line_segments = list(zip(self.points, self.points[1:])) + [(self.points[-1], self.points[0])]
387                 segment_lengths = map(lambda t: dist(*t), line_segments)
388
389                 # Get the distance from each point in the polygon to the new point
390                 distances_to_point = [dist(p, new_point) for p in self.points]
391
392                 # For each pair of list-adjacent points, zip their distances to

```



```

393         # the new point into a tuple, and add them together
394         # This gives us the lengths of the catheti of the triangles that
395         # connect the new point to each pair of adjacent points
396         dist_to_point_pairs = list(zip(distances_to_point, distances_to_point[1:])) + \
397             [(distances_to_point[-1], distances_to_point[0])]
398
399         # mypy doesn't like the use of sum for some reason. Just ignore it
400         point_triangle_lengths = map(sum, dist_to_point_pairs) # type: ignore[arg-type]
401
402         # The normalized distance is the sum of the distances to the ends of the line segment
403         # (point_triangle_lengths) divided by the length of the segment
404         normalized_distances = list(map(operator.truediv, point_triangle_lengths, segment_lengths))
405
406         # Get the best distance and insert this new point just after the point with that index
407         # This will put it in the middle of the closest line segment
408         best_distance = min(normalized_distances)
409         index = 1 + normalized_distances.index(best_distance)
410
411         self.points.insert(index, new_point)
412         self._dragged_point_index = index
413
414     elif event.button() == Qt.RightButton:
415         for i, point in enumerate(self.points):
416             if self._is_within_epsilon(canvas_pos, point):
417                 self.points.pop(i)
418                 break
419
420     self.update()
421     event.accept()
422
423     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
424         """Handle the mouse click being released by unsetting the dragged point index."""
425         if event.button() == Qt.LeftButton:
426             self._dragged_point_index = None
427             event.accept()
428         else:
429             event.ignore()
430
431     def mouseMoveEvent(self, event: QMouseEvent) -> None:
432         """Handle mouse movement by dragging the selected point."""
433         if self._dragged_point_index is None:
434             event.ignore()
435             return
436
437         x, y = self._round_to_int_coord(self._grid_coords(event.x(), event.y()))
438
439         self.points[self._dragged_point_index] = x, y
440
441         self.update()
442
443         event.accept()
444
445     def _draw_polygon(self, painter: QPainter) -> None:
446         """Draw the polygon with circles at its vertices."""
447         painter.setPen(self._PEN_POLYGON)
448
449         if len(self.points) > 2:
450             painter.drawPolygon(QPolygonF(
451                 [QPointF(*self.canvas_coords(*p)) for p in self.points]
452             ))
453         elif len(self.points) == 2:
454             painter.drawLine(
455                 *self.canvas_coords(*self.points[0]),
456                 *self.canvas_coords(*self.points[1])
457             )
458
459         painter.setBrush(self._BRUSH_SOLID_WHITE)
460         cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
461
462         for point in self.points:
463             x, y = self.canvas_coords(*point)
464
465             painter.setPen(Qt.NoPen)

```

```

466         painter.drawPie(
467             x - cursor_epsilon,
468             y - cursor_epsilon,
469             2 * cursor_epsilon,
470             2 * cursor_epsilon,
471             0,
472             16 * 360
473         )
474
475         painter.setPen(self._PEN_POLYGON)
476         painter.drawArc(
477             x - cursor_epsilon,
478             y - cursor_epsilon,
479             2 * cursor_epsilon,
480             2 * cursor_epsilon,
481             0,
482             16 * 360
483         )
484
485         painter.setBrush(Qt.NoBrush)
486
487     def paintEvent(self, event: QPaintEvent) -> None:
488         """Draw the polygon on the canvas."""
489         painter = QPainter()
490         painter.begin(self)
491
492         painter.setRenderHint(QPainter.Antialiasing)
493         painter.setBrush(Qt.NoBrush)
494
495         self._draw_background(painter, True)
496
497         self._draw_polygon(painter)
498
499         painter.end()
500         event.accept()

```

## A.14 gui/plots/\_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This package provides widgets for the visualization plot in the main window and the visual definition dialog."""
8
9  from .classes import (BackgroundPlot, VectorGridPlot,
10                       VisualizeTransformationPlot)
11  from .widgets import (DefineMatrixVisuallyWidget, DefinePolygonWidget,
12                       MainViewportWidget, VisualizeTransformationWidget)
13
14  __all__ = ['BackgroundPlot', 'DefinePolygonWidget', 'DefineMatrixVisuallyWidget', 'MainViewportWidget',
15            'VectorGridPlot', 'VisualizeTransformationPlot', 'VisualizeTransformationWidget']

```

## A.15 gui/dialogs/define\_new\_matrix.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides an abstract :class:`DefineMatrixDialog` class and subclasses."""
8
9  from __future__ import annotations
10
11  import abc
12  from typing import List, Tuple

```

```

13
14 from numpy import array, eye
15 from PyQt5 import QtWidgets
16 from PyQt5.QtCore import pyqtSlot
17 from PyQt5.QtGui import QDoubleValidator, QKeySequence
18 from PyQt5.QtWidgets import (QGridLayout, QHBoxLayout, QLabel, QLineEdit,
19                               QPushButton, QShortcut, QSizePolicy, QSpacerItem,
20                               QVBoxLayout)
21
22 from lintrans.gui.dialogs.misc import FixedSizeDialog
23 from lintrans.gui.plots import DefineMatrixVisuallyWidget
24 from lintrans.gui.settings import DisplaySettings
25 from lintrans.gui.validate import MatrixExpressionValidator
26 from lintrans.matrices import MatrixWrapper
27 from lintrans.matrices.utility import is_valid_float, round_float
28 from lintrans.typing_ import MatrixType
29
30 _ALPHABET_NO_I = 'ABCDEFGHJKLMNPOQRSTUVWXYZ'
31
32
33 def get_first_undefined_matrix(wrapper: MatrixWrapper) -> str:
34     """Return the letter of the first undefined matrix in the given wrapper, or ``A`` if all matrices are
35     ↩ defined."""
36     defined_matrices = [x for x, _ in wrapper.get_defined_matrices()]
37     for letter in _ALPHABET_NO_I:
38         if letter not in defined_matrices:
39             return letter
40
41     return 'A'
42
43 class DefineMatrixDialog(FixedSizeDialog):
44     """An abstract superclass for definitions dialogs.
45
46     .. warning:: This class should never be directly instantiated, only subclassed.
47     """
48
49     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
50         """Create the widgets and layout of the dialog.
51
52         .. note:: ``*args`` and ``**kwargs`` are passed to the super constructor (:class:`QDialog`).
53
54         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
55         """
56         super().__init__(*args, **kwargs)
57
58         self.matrix_wrapper = matrix_wrapper
59         self.setWindowTitle('Define a matrix')
60
61         # === Create the widgets
62
63         self._button_confirm = QPushButton(self)
64         self._button_confirm.setText('Confirm')
65         self._button_confirm.setEnabled(False)
66         self._button_confirm.clicked.connect(self._confirm_matrix)
67         self._button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
68         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_confirm.click)
69
70         button_cancel = QPushButton(self)
71         button_cancel.setText('Cancel')
72         button_cancel.clicked.connect(self.reject)
73         button_cancel.setToolTip('Cancel this definition<br><b>(Escape)</b>')
74
75         label_equals = QLabel(self)
76         label_equals.setText('=')
77
78         self._combobox_letter = QtWidgets.QComboBox(self)
79
80         for letter in _ALPHABET_NO_I:
81             self._combobox_letter.addItem(letter)
82
83         self._combobox_letter.activated.connect(self._load_matrix)
84         self._combobox_letter.setCurrentText(get_first_undefined_matrix(self.matrix_wrapper))

```

```

85
86     # == Arrange the widgets
87
88     self.setContentsMargins(10, 10, 10, 10)
89
90     self._hlay_buttons = QHBoxLayout()
91     self._hlay_buttons.setSpacing(20)
92     self._hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
93     self._hlay_buttons.addWidget(button_cancel)
94     self._hlay_buttons.addWidget(self._button_confirm)
95
96     self._hlay_definition = QHBoxLayout()
97     self._hlay_definition.setSpacing(20)
98     self._hlay_definition.addWidget(self._combobox_letter)
99     self._hlay_definition.addWidget(label_equals)
100
101     # All subclasses have to manually add the hlay layouts to _vlay_all
102     # This is because the subclasses add their own widgets and if we add
103     # the layout here, then these new widgets won't be included
104     self._vlay_all = QVBoxLayout()
105     self._vlay_all.setSpacing(20)
106
107     self.setLayout(self._vlay_all)
108
109     @property
110     def _selected_letter(self) -> str:
111         """Return the letter currently selected in the combo box."""
112         return str(self._combobox_letter.currentText())
113
114     @abc.abstractmethod
115     @pyqtSlot()
116     def _update_confirm_button(self) -> None:
117         """Enable the confirm button if it should be enabled, else, disable it."""
118
119     @pyqtSlot(int)
120     def _load_matrix(self, index: int) -> None:
121         """Load the selected matrix into the dialog.
122
123         This method is optionally able to be overridden. If it is not overridden,
124         then no matrix is loaded when selecting a name.
125
126         We have this method in the superclass so that we can define it as the slot
127         for the :meth:`QComboBox.activated` signal in this constructor, rather than
128         having to define that in the constructor of every subclass.
129         """
130
131     @abc.abstractmethod
132     @pyqtSlot()
133     def _confirm_matrix(self) -> None:
134         """Confirm the inputted matrix and assign it.
135
136         .. note:: When subclassing, this method should mutate ``self.matrix_wrapper`` and then call
137         ↪ ``self.accept()``.
138         """
139
140     class DefineVisuallyDialog(DefineMatrixDialog):
141         """The dialog class that allows the user to define a matrix visually."""
142
143         def __init__(
144             self,
145             *args,
146             matrix_wrapper: MatrixWrapper,
147             display_settings: DisplaySettings,
148             polygon_points: List[Tuple[float, float]],
149             input_vector: Tuple[float, float],
150             **kwargs
151         ):
152             """Create the widgets and layout of the dialog.
153
154             :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
155             """
156             super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)

```

```

157
158         self.setMinimumSize(700, 550)
159
160         # === Create the widgets
161
162         self._plot = DefineMatrixVisuallyWidget(
163             self,
164             display_settings=display_settings,
165             polygon_points=polygon_points,
166             input_vector=input_vector
167         )
168
169         # === Arrange the widgets
170
171         self._hlay_definition.addWidget(self._plot)
172         self._hlay_definition.setStretchFactor(self._plot, 1)
173
174         self._vlay_all.addLayout(self._hlay_definition)
175         self._vlay_all.addLayout(self._hlay_buttons)
176
177         # We load the default matrix A into the plot
178         self._load_matrix(0)
179
180         # We also enable the confirm button, because any visually defined matrix is valid
181         self._button_confirm.setEnabled(True)
182
183     @pyqtSlot()
184     def _update_confirm_button(self) -> None:
185         """Enable the confirm button.
186
187         .. note::
188             The confirm button is always enabled in this dialog and this method is never actually used,
189             so it's got an empty body. It's only here because we need to implement the abstract method.
190         """
191
192     @pyqtSlot(int)
193     def _load_matrix(self, index: int) -> None:
194         """Show the selected matrix on the plot. If the matrix is None, show the identity."""
195         matrix = self.matrix_wrapper[self._selected_letter]
196
197         if matrix is None:
198             self._plot.plot_matrix(eye(2))
199         else:
200             self._plot.plot_matrix(matrix)
201
202         self._plot.update()
203
204     @pyqtSlot()
205     def _confirm_matrix(self) -> None:
206         """Confirm the matrix that's been defined visually."""
207         matrix: MatrixType = array([
208             [self._plot.point_i[0], self._plot.point_j[0]],
209             [self._plot.point_i[1], self._plot.point_j[1]]
210         ])
211
212         self.matrix_wrapper[self._selected_letter] = matrix
213         self.accept()
214
215     class DefineNumericallyDialog(DefineMatrixDialog):
216         """The dialog class that allows the user to define a new matrix numerically."""
217
218         def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
219             """Create the widgets and layout of the dialog.
220
221             :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
222             """
223             super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
224
225             # === Create the widgets
226
227             # tl = top left, br = bottom right, etc.
228             self._element_tl = QLineEdit(self)
229

```

```

230     self._element_tl.textChanged.connect(self._update_confirm_button)
231     self._element_tl.setValidator(QDoubleValidator())
232
233     self._element_tr = QLineEdit(self)
234     self._element_tr.textChanged.connect(self._update_confirm_button)
235     self._element_tr.setValidator(QDoubleValidator())
236
237     self._element_bl = QLineEdit(self)
238     self._element_bl.textChanged.connect(self._update_confirm_button)
239     self._element_bl.setValidator(QDoubleValidator())
240
241     self._element_br = QLineEdit(self)
242     self._element_br.textChanged.connect(self._update_confirm_button)
243     self._element_br.setValidator(QDoubleValidator())
244
245     self._matrix_elements = (self._element_tl, self._element_tr, self._element_bl, self._element_br)
246
247     font_parens = self.font()
248     font_parens.setPointSize(int(font_parens.pointSize() * 5))
249     font_parens.setWeight(int(font_parens.weight() / 5))
250
251     label_paren_left = QLabel(self)
252     label_paren_left.setText('(')
253     label_paren_left.setFont(font_parens)
254
255     label_paren_right = QLabel(self)
256     label_paren_right.setText(')')
257     label_paren_right.setFont(font_parens)
258
259     # === Arrange the widgets
260
261     grid_matrix = QGridLayout()
262     grid_matrix.setSpacing(20)
263     grid_matrix.addWidget(label_paren_left, 0, 0, -1, 1)
264     grid_matrix.addWidget(self._element_tl, 0, 1)
265     grid_matrix.addWidget(self._element_tr, 0, 2)
266     grid_matrix.addWidget(self._element_bl, 1, 1)
267     grid_matrix.addWidget(self._element_br, 1, 2)
268     grid_matrix.addWidget(label_paren_right, 0, 3, -1, 1)
269
270     self._hlay_definition.addLayout(grid_matrix)
271
272     self._vlay_all.addLayout(self._hlay_definition)
273     self._vlay_all.addLayout(self._hlay_buttons)
274
275     # We load the default matrix A into the boxes
276     self._load_matrix(0)
277
278     self._element_tl.setFocus()
279
280 @pyqtSlot()
281 def _update_confirm_button(self) -> None:
282     """Enable the confirm button if there are valid floats in every box."""
283     for elem in self._matrix_elements:
284         if not is_valid_float(elem.text()):
285             # If they're not all numbers, then we can't confirm it
286             self._button_confirm.setEnabled(False)
287             return
288
289     # If we didn't find anything invalid
290     self._button_confirm.setEnabled(True)
291
292 @pyqtSlot(int)
293 def _load_matrix(self, index: int) -> None:
294     """If the selected matrix is defined, load its values into the boxes."""
295     matrix = self.matrix_wrapper[self._selected_letter]
296
297     if matrix is None:
298         for elem in self._matrix_elements:
299             elem.setText('')
300
301     else:
302         self._element_tl.setText(round_float(matrix[0][0]))

```

```

303         self._element_tr.setText(round_float(matrix[0][1]))
304         self._element_bl.setText(round_float(matrix[1][0]))
305         self._element_br.setText(round_float(matrix[1][1]))
306
307     self._update_confirm_button()
308
309 @pyqtSlot()
310 def _confirm_matrix(self) -> None:
311     """Confirm the matrix in the boxes and assign it to the name in the combo box."""
312     matrix: MatrixType = array([
313         [float(self._element_tl.text()), float(self._element_tr.text())],
314         [float(self._element_bl.text()), float(self._element_br.text())]
315     ])
316
317     self.matrix_wrapper[self._selected_letter] = matrix
318     self.accept()
319
320
321 class DefineAsExpressionDialog(DefineMatrixDialog):
322     """The dialog class that allows the user to define a matrix as an expression of other matrices."""
323
324     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
325         """Create the widgets and layout of the dialog.
326
327         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
328         """
329         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
330
331         self.setMinimumWidth(450)
332
333         # === Create the widgets
334
335         self._lineEdit_expression_box = QLineEdit(self)
336         self._lineEdit_expression_box.setPlaceholderText('Enter matrix expression...')
337         self._lineEdit_expression_box.textChanged.connect(self._update_confirm_button)
338         self._lineEdit_expression_box.setValidator(MatrixExpressionValidator())
339
340         # === Arrange the widgets
341
342         self._hlay_definition.addWidget(self._lineEdit_expression_box)
343
344         self._vlay_all.addLayout(self._hlay_definition)
345         self._vlay_all.addLayout(self._hlay_buttons)
346
347         # Load the matrix if it's defined as an expression
348         self._load_matrix(0)
349
350         self._lineEdit_expression_box.setFocus()
351
352 @pyqtSlot()
353 def _update_confirm_button(self) -> None:
354     """Enable the confirm button if the matrix expression is valid in the wrapper."""
355     text = self._lineEdit_expression_box.text()
356     valid_expression = self.matrix_wrapper.is_valid_expression(text)
357
358     self._button_confirm.setEnabled(
359         valid_expression
360         and self._selected_letter not in text
361         and self._selected_letter not in self.matrix_wrapper.get_expression_dependencies(text)
362     )
363
364 @pyqtSlot(int)
365 def _load_matrix(self, index: int) -> None:
366     """If the selected matrix is defined an expression, load that expression into the box."""
367     if (expr := self.matrix_wrapper.get_expression(self._selected_letter)) is not None:
368         self._lineEdit_expression_box.setText(expr)
369     else:
370         self._lineEdit_expression_box.setText('')
371
372 @pyqtSlot()
373 def _confirm_matrix(self) -> None:
374     """Evaluate the matrix expression and assign its value to the name in the combo box."""
375     self.matrix_wrapper[self._selected_letter] = self._lineEdit_expression_box.text()

```

```
376         self.accept()
```

## A.16 gui/dialogs/settings.py

```
1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides dialogs to edit settings within the app."""
8
9  from __future__ import annotations
10
11  import abc
12  from typing import Dict
13
14  from PyQt5 import QtWidgets
15  from PyQt5.QtCore import Qt
16  from PyQt5.QtGui import (QDoubleValidator, QIntValidator, QKeyEvent,
17                           QKeySequence)
18  from PyQt5.QtWidgets import (QCheckBox, QGroupBox, QHBoxLayout, QLabel,
19                              QLayout, QLineEdit, QRadioButton, QShortcut,
20                              QSizePolicy, QSpacerItem, QVBoxLayout)
21
22  from lintrans.global_settings import (GlobalSettings, GlobalSettingsData,
23                                       UpdateType)
24  from lintrans.gui.dialogs.misc import FixedSizeDialog
25  from lintrans.gui.settings import DisplaySettings
26
27
28  class SettingsDialog(FixedSizeDialog):
29      """An abstract superclass for other simple dialogs."""
30
31      def __init__(self, *args, resettable: bool, **kwargs):
32          """Create the widgets and layout of the dialog, passing ``*args`` and ``**kwargs`` to super."""
33          super().__init__(*args, **kwargs)
34
35          # === Create the widgets
36
37          self._button_confirm = QtWidgets.QPushButton(self)
38          self._button_confirm.setText('Confirm')
39          self._button_confirm.clicked.connect(self._confirm_settings)
40          self._button_confirm.setToolTip('Confirm these new settings<br><b>(Ctrl + Enter)</b>')
41          QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_confirm.click)
42
43          self._button_cancel = QtWidgets.QPushButton(self)
44          self._button_cancel.setText('Cancel')
45          self._button_cancel.clicked.connect(self.reject)
46          self._button_cancel.setToolTip('Revert these settings<br><b>(Escape)</b>')
47
48          if resettable:
49              self._button_reset = QtWidgets.QPushButton(self)
50              self._button_reset.setText('Reset to defaults')
51              self._button_reset.clicked.connect(self._reset_settings)
52              self._button_reset.setToolTip('Reset these settings to their defaults<br><b>(Ctrl + R)</b>')
53              QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(self._button_reset.click)
54
55          # === Arrange the widgets
56
57          self.setContentsMargins(10, 10, 10, 10)
58
59          self._hlay_buttons = QHBoxLayout()
60          self._hlay_buttons.setSpacing(20)
61
62          if resettable:
63              self._hlay_buttons.addWidget(self._button_reset)
64
65          self._hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
66          self._hlay_buttons.addWidget(self._button_cancel)
```



```

67         self._hlay_buttons.addWidget(self._button_confirm)
68
69     def _setup_layout(self, options_layout: QLayout) -> None:
70         """Set the layout of the settings widget.
71
72         .. note:: This method must be called at the end of :meth:`__init__`
73            in subclasses to setup the layout properly.
74         """
75         vlay_all = QVBoxLayout()
76         vlay_all.setSpacing(20)
77         vlay_all.addLayout(options_layout)
78         vlay_all.addLayout(self._hlay_buttons)
79
80         self.setLayout(vlay_all)
81
82     @abc.abstractmethod
83     def _load_settings(self) -> None:
84         """Load the current settings into the widgets."""
85
86     @abc.abstractmethod
87     def _confirm_settings(self) -> None:
88         """Confirm the settings chosen in the dialog."""
89
90     def _reset_settings(self) -> None:
91         """Reset the settings.
92
93         .. note:: This method is empty but not abstract because not all subclasses will need to implement it.
94         """
95
96
97     class DisplaySettingsDialog(SettingsDialog):
98         """The dialog to allow the user to edit the display settings."""
99
100     def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
101         """Create the widgets and layout of the dialog.
102
103         :param DisplaySettings display_settings: The :class:`~lintrans.gui.settings.DisplaySettings` object to
104         ↪ mutate
105         """
106         super().__init__(*args, resettable=True, **kwargs)
107
108         self.display_settings = display_settings
109         self.setWindowTitle('Change display settings')
110
111         self._dict_checkboxes: Dict[str, QCheckBox] = {}
112
113         # === Create the widgets
114
115         # Basic stuff
116
117         self._checkbox_draw_background_grid = QCheckBox(self)
118         self._checkbox_draw_background_grid.setText('Draw &background grid')
119         self._checkbox_draw_background_grid.setToolTip(
120             'Draw the background grid (axes are always drawn)'
121         )
122         self._dict_checkboxes['b'] = self._checkbox_draw_background_grid
123
124         self._checkbox_draw_transformed_grid = QCheckBox(self)
125         self._checkbox_draw_transformed_grid.setText('Draw t&transformed grid')
126         self._checkbox_draw_transformed_grid.setToolTip(
127             'Draw the transformed grid (vectors are handled separately)'
128         )
129         self._dict_checkboxes['r'] = self._checkbox_draw_transformed_grid
130
131         self._checkbox_draw_basis_vectors = QCheckBox(self)
132         self._checkbox_draw_basis_vectors.setText('Draw basis &vectors')
133         self._checkbox_draw_basis_vectors.setToolTip(
134             'Draw the transformed basis vectors'
135         )
136         self._checkbox_draw_basis_vectors.clicked.connect(self._update_gui)
137         self._dict_checkboxes['v'] = self._checkbox_draw_basis_vectors
138
139         self._checkbox_label_basis_vectors = QCheckBox(self)

```

```

139     self._checkbox_label_basis_vectors.setText('Label the basis vectors')
140     self._checkbox_label_basis_vectors.setToolTip(
141         'Label the transformed i and j basis vectors'
142     )
143     self._dict_checkboxes['i'] = self._checkbox_label_basis_vectors
144
145     # Animations
146
147     self._checkbox_smooththen_determinant = QCheckBox(self)
148     self._checkbox_smooththen_determinant.setText('&Smoothen determinant')
149     self._checkbox_smooththen_determinant.setToolTip(
150         'Smoothly animate the determinant transition during animation (if possible)'
151     )
152     self._dict_checkboxes['s'] = self._checkbox_smooththen_determinant
153
154     self._checkbox_applicative_animation = QCheckBox(self)
155     self._checkbox_applicative_animation.setText('&Applicative animation')
156     self._checkbox_applicative_animation.setToolTip(
157         'Animate the new transformation applied to the current one,\n'
158         'rather than just that transformation on its own'
159     )
160     self._dict_checkboxes['a'] = self._checkbox_applicative_animation
161
162     label_animation_time = QLabel(self)
163     label_animation_time.setText('Total animation length (ms)')
164     label_animation_time.setToolTip(
165         'How long it takes for an animation to complete'
166     )
167
168     self._lineEdit_animation_time = QLineEdit(self)
169     self._lineEdit_animation_time.setValidator(QIntValidator(1, 9999, self))
170     self._lineEdit_animation_time.textChanged.connect(self._update_gui)
171
172     label_animation_pause_length = QLabel(self)
173     label_animation_pause_length.setText('Animation pause length (ms)')
174     label_animation_pause_length.setToolTip(
175         'How many milliseconds to pause for in comma-separated animations'
176     )
177
178     self._lineEdit_animation_pause_length = QLineEdit(self)
179     self._lineEdit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
180
181     # Matrix info
182
183     self._checkbox_draw_determinant_parallelogram = QCheckBox(self)
184     self._checkbox_draw_determinant_parallelogram.setText('Draw &determinant parallelogram')
185     self._checkbox_draw_determinant_parallelogram.setToolTip(
186         'Shade the parallelogram representing the determinant of the matrix'
187     )
188     self._checkbox_draw_determinant_parallelogram.clicked.connect(self._update_gui)
189     self._dict_checkboxes['d'] = self._checkbox_draw_determinant_parallelogram
190
191     self._checkbox_show_determinant_value = QCheckBox(self)
192     self._checkbox_show_determinant_value.setText('Show determinant value')
193     self._checkbox_show_determinant_value.setToolTip(
194         'Show the value of the determinant inside the parallelogram'
195     )
196     self._dict_checkboxes['t'] = self._checkbox_show_determinant_value
197
198     self._checkbox_draw_eigenvectors = QCheckBox(self)
199     self._checkbox_draw_eigenvectors.setText('Draw &eigenvectors')
200     self._checkbox_draw_eigenvectors.setToolTip('Draw the eigenvectors of the transformations')
201     self._dict_checkboxes['e'] = self._checkbox_draw_eigenvectors
202
203     self._checkbox_draw_eigenlines = QCheckBox(self)
204     self._checkbox_draw_eigenlines.setText('Draw eigenlines')
205     self._checkbox_draw_eigenlines.setToolTip('Draw the eigenlines (invariant lines) of the transformations')
206     self._dict_checkboxes['l'] = self._checkbox_draw_eigenlines
207
208     # Polygon
209
210     self._checkbox_draw_untransformed_polygon = QCheckBox(self)
211     self._checkbox_draw_untransformed_polygon.setText('&Untransformed polygon')

```

```

212 self._checkbox_draw_untransformed_polygon.setToolTip('Draw the untransformed version of the polygon')
213 self._dict_checkboxes['u'] = self._checkbox_draw_untransformed_polygon
214
215 self._checkbox_draw_transformed_polygon = QCheckBox(self)
216 self._checkbox_draw_transformed_polygon.setText('Transformed &polygon')
217 self._checkbox_draw_transformed_polygon.setToolTip('Draw the transformed version of the polygon')
218 self._dict_checkboxes['p'] = self._checkbox_draw_transformed_polygon
219
220 # Input/output vectors
221
222 self._checkbox_draw_input_vector = QCheckBox(self)
223 self._checkbox_draw_input_vector.setText('Draw the i&input vector')
224 self._checkbox_draw_input_vector.setToolTip('Draw the input vector (only in the viewport)')
225 self._dict_checkboxes['n'] = self._checkbox_draw_input_vector
226
227 self._checkbox_draw_output_vector = QCheckBox(self)
228 self._checkbox_draw_output_vector.setText('Draw the &output vector')
229 self._checkbox_draw_output_vector.setToolTip('Draw the output vector (only in the viewport)')
230 self._dict_checkboxes['o'] = self._checkbox_draw_output_vector
231
232 # == Arrange the widgets in QGroupBoxes
233
234 # Basic stuff
235
236 vlay_groupbox_basic_stuff = QVBoxLayout()
237 vlay_groupbox_basic_stuff.setSpacing(20)
238 vlay_groupbox_basic_stuff.addWidget(self._checkbox_draw_background_grid)
239 vlay_groupbox_basic_stuff.addWidget(self._checkbox_draw_transformed_grid)
240 vlay_groupbox_basic_stuff.addWidget(self._checkbox_draw_basis_vectors)
241 vlay_groupbox_basic_stuff.addWidget(self._checkbox_label_basis_vectors)
242
243 groupbox_basic_stuff = QGroupBox('Basic stuff', self)
244 groupbox_basic_stuff.setLayout(vlay_groupbox_basic_stuff)
245
246 # Animations
247
248 hlay_animation_time = QHBoxLayout()
249 hlay_animation_time.addWidget(label_animation_time)
250 hlay_animation_time.addWidget(self._linedit_animation_time)
251
252 hlay_animation_pause_length = QHBoxLayout()
253 hlay_animation_pause_length.addWidget(label_animation_pause_length)
254 hlay_animation_pause_length.addWidget(self._linedit_animation_pause_length)
255
256 vlay_groupbox_animations = QVBoxLayout()
257 vlay_groupbox_animations.setSpacing(20)
258 vlay_groupbox_animations.addWidget(self._checkbox_smooththen_determinant)
259 vlay_groupbox_animations.addWidget(self._checkbox_applicative_animation)
260 vlay_groupbox_animations.addLayout(hlay_animation_time)
261 vlay_groupbox_animations.addLayout(hlay_animation_pause_length)
262
263 groupbox_animations = QGroupBox('Animations', self)
264 groupbox_animations.setLayout(vlay_groupbox_animations)
265
266 # Matrix info
267
268 vlay_groupbox_matrix_info = QVBoxLayout()
269 vlay_groupbox_matrix_info.setSpacing(20)
270 vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_determinant_parallelogram)
271 vlay_groupbox_matrix_info.addWidget(self._checkbox_show_determinant_value)
272 vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_eigenvectors)
273 vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_eigenlines)
274
275 groupbox_matrix_info = QGroupBox('Matrix info', self)
276 groupbox_matrix_info.setLayout(vlay_groupbox_matrix_info)
277
278 # Polygon
279
280 vlay_groupbox_polygon = QVBoxLayout()
281 vlay_groupbox_polygon.setSpacing(20)
282 vlay_groupbox_polygon.addWidget(self._checkbox_draw_untransformed_polygon)
283 vlay_groupbox_polygon.addWidget(self._checkbox_draw_transformed_polygon)
284

```

```

285     groupbox_polygon = QGroupBox('Polygon', self)
286     groupbox_polygon.setLayout(vlay_groupbox_polygon)
287
288     # Input/output vectors
289
290     vlay_groupbox_io_vectors = QVBoxLayout()
291     vlay_groupbox_io_vectors.setSpacing(20)
292     vlay_groupbox_io_vectors.addWidget(self._checkbox_draw_input_vector)
293     vlay_groupbox_io_vectors.addWidget(self._checkbox_draw_output_vector)
294
295     groupbox_io_vectors = QGroupBox('Input/output vectors', self)
296     groupbox_io_vectors.setLayout(vlay_groupbox_io_vectors)
297
298     # Now arrange the groupboxes
299     vlay_left = QVBoxLayout()
300     vlay_left.setSpacing(20)
301     vlay_left.addWidget(groupbox_basic_stuff)
302     vlay_left.addWidget(groupbox_animations)
303
304     vlay_right = QVBoxLayout()
305     vlay_right.setSpacing(20)
306     vlay_right.addWidget(groupbox_matrix_info)
307     vlay_right.addWidget(groupbox_polygon)
308     vlay_right.addWidget(groupbox_io_vectors)
309
310     options_layout = QHBoxLayout()
311     options_layout.setSpacing(20)
312     options_layout.addLayout(vlay_left)
313     options_layout.addLayout(vlay_right)
314
315     self._setup_layout(options_layout)
316
317     # Finally, we load the current settings and update the GUI
318     self._load_settings()
319     self._update_gui()
320
321 def _load_settings(self) -> None:
322     """Load the current display settings into the widgets."""
323     # Basic stuff
324     self._checkbox_draw_background_grid.setChecked(self.display_settings.draw_background_grid)
325     self._checkbox_draw_transformed_grid.setChecked(self.display_settings.draw_transformed_grid)
326     self._checkbox_draw_basis_vectors.setChecked(self.display_settings.draw_basis_vectors)
327     self._checkbox_label_basis_vectors.setChecked(self.display_settings.label_basis_vectors)
328
329     # Animations
330     self._checkbox_smooththen_determinant.setChecked(self.display_settings.smoothen_determinant)
331     self._checkbox_applicative_animation.setChecked(self.display_settings.applicative_animation)
332     self._lineEdit_animation_time.setText(str(self.display_settings.animation_time))
333     self._lineEdit_animation_pause_length.setText(str(self.display_settings.animation_pause_length))
334
335     # Matrix info
336     self._checkbox_draw_determinant_parallelogram.setChecked(
337         ↪ self.display_settings.draw_determinant_parallelogram)
338     self._checkbox_show_determinant_value.setChecked(self.display_settings.show_determinant_value)
339     self._checkbox_draw_eigenvectors.setChecked(self.display_settings.draw_eigenvectors)
340     self._checkbox_draw_eigenlines.setChecked(self.display_settings.draw_eigenlines)
341
342     # Polygon
343     self._checkbox_draw_untransformed_polygon.setChecked(self.display_settings.draw_untransformed_polygon)
344     self._checkbox_draw_transformed_polygon.setChecked(self.display_settings.draw_transformed_polygon)
345
346     # Input/output vectors
347     self._checkbox_draw_input_vector.setChecked(self.display_settings.draw_input_vector)
348     self._checkbox_draw_output_vector.setChecked(self.display_settings.draw_output_vector)
349
350 def _confirm_settings(self) -> None:
351     """Build a :class:`~lintrans.gui.settings.DisplaySettings` object and assign it."""
352     # Basic stuff
353     self.display_settings.draw_background_grid = self._checkbox_draw_background_grid.isChecked()
354     self.display_settings.draw_transformed_grid = self._checkbox_draw_transformed_grid.isChecked()
355     self.display_settings.draw_basis_vectors = self._checkbox_draw_basis_vectors.isChecked()
356     self.display_settings.label_basis_vectors = self._checkbox_label_basis_vectors.isChecked()

```

```

357         # Animations
358         self.display_settings.smoothen_determinant = self._checkboxbox_smoothen_determinant.isChecked()
359         self.display_settings.applicative_animation = self._checkboxbox_applicative_animation.isChecked()
360         self.display_settings.animation_time = int(self._lineedit_animation_time.text())
361         self.display_settings.animation_pause_length = int(self._lineedit_animation_pause_length.text())
362
363         # Matrix info
364         self.display_settings.draw_determinant_parallelogram =
365             ⇨ self._checkboxbox_draw_determinant_parallelogram.isChecked()
366         self.display_settings.show_determinant_value = self._checkboxbox_show_determinant_value.isChecked()
367         self.display_settings.draw_eigenvectors = self._checkboxbox_draw_eigenvectors.isChecked()
368         self.display_settings.draw_eigenlines = self._checkboxbox_draw_eigenlines.isChecked()
369
370         # Polygon
371         self.display_settings.draw_untransformed_polygon = self._checkboxbox_draw_untransformed_polygon.isChecked()
372         self.display_settings.draw_transformed_polygon = self._checkboxbox_draw_transformed_polygon.isChecked()
373
374         # Input/output vectors
375         self.display_settings.draw_input_vector = self._checkboxbox_draw_input_vector.isChecked()
376         self.display_settings.draw_output_vector = self._checkboxbox_draw_output_vector.isChecked()
377
378         self.accept()
379
380     def _reset_settings(self) -> None:
381         """Reset the display settings to their defaults."""
382         self.display_settings = DisplaySettings()
383         self._load_settings()
384         self._update_gui()
385
386     def _update_gui(self) -> None:
387         """Update the GUI according to other widgets in the GUI.
388
389         For example, this method updates which checkboxes are enabled based on the values of other checkboxes.
390         """
391         self._checkboxbox_show_determinant_value.setEnabled(self._checkboxbox_draw_determinant_parallelogram.isChecked())
392         self._checkboxbox_label_basis_vectors.setEnabled(self._checkboxbox_draw_basis_vectors.isChecked())
393
394         try:
395             self._button_confirm.setEnabled(int(self._lineedit_animation_time.text()) >= 10)
396         except ValueError:
397             self._button_confirm.setEnabled(False)
398
399     def keyPressEvent(self, event: QKeyEvent) -> None:
400         """Handle a :class:`QKeyEvent` by manually activating toggling checkboxes.
401
402         Qt handles these shortcuts automatically and allows the user to do ``Alt + Key``
403         to activate a simple shortcut defined with ``&``. However, I like to be able to
404         just hit ``Key`` and have the shortcut activate.
405         """
406         letter = event.text().lower()
407         key = event.key()
408
409         if letter in self._dict_checkboxes:
410             self._dict_checkboxes[letter].animateClick()
411
412         # Return or keypad enter
413         elif key == Qt.Key_Return or key == Qt.Key_Enter:
414             self._button_confirm.click()
415
416         # Escape
417         elif key == Qt.Key_Escape:
418             self._button_cancel.click()
419
420         else:
421             event.ignore()
422             return
423
424         event.accept()
425
426 class GlobalSettingsDialog(SettingsDialog):
427     """The dialog to allow the user to edit the display settings."""
428

```

```

429 def __init__(self, *args, **kwargs):
430     """Create the widgets and layout of the dialog."""
431     super().__init__(*args, resettable=True, **kwargs)
432
433     self._data: GlobalSettingsData = GlobalSettings().get_data()
434     self.setWindowTitle('Change global settings')
435
436     # === Create the widgets
437
438     groupbox_update_types = QGroupBox('Update prompt type', self)
439     self._radio_button_auto = QRadioButton('Always update automatically', groupbox_update_types)
440     self._radio_button_prompt = QRadioButton('Always ask to update', groupbox_update_types)
441     self._radio_button_never = QRadioButton('Never update', groupbox_update_types)
442
443     label_cursor_epsilon = QLabel(self)
444     label_cursor_epsilon.setText('Cursor drag proximity (pixels)')
445     label_cursor_epsilon.setToolTip(
446         'The maximum distance (in pixels) from a draggable point before it will be dragged'
447     )
448
449     self._lineedit_cursor_epsilon = QLineEdit(self)
450     self._lineedit_cursor_epsilon.setValidator(QIntValidator(1, 99, self))
451     self._lineedit_cursor_epsilon.setText(str(self._data.cursor_epsilon))
452     self._lineedit_cursor_epsilon.textChanged.connect(self._update_gui)
453
454     self._checkbox_snap_to_int_coords = QCheckBox(self)
455     self._checkbox_snap_to_int_coords.setText('Snap to integer coordinates')
456     self._checkbox_snap_to_int_coords.setToolTip(
457         'Whether vectors should snap the integer coordinates when dragging them'
458     )
459     self._checkbox_snap_to_int_coords.clicked.connect(self._update_gui)
460
461     label_snap_dist = QLabel(self)
462     label_snap_dist.setText('Snap distance (grid units)')
463     label_snap_dist.setToolTip(
464         'The minimum distacne (in grid units) that a draggable point '
465         'must be from an integer coordinate to snap to it'
466     )
467
468     self._lineedit_snap_dist = QLineEdit(self)
469     self._lineedit_snap_dist.setValidator(QDoubleValidator(0.0, 0.99, 2, self))
470     self._lineedit_snap_dist.setText(str(self._data.snap_dist))
471     self._lineedit_snap_dist.textChanged.connect(self._update_gui)
472
473     # === Arrange the widgets
474
475     vlay_update_type = QVBoxLayout()
476     vlay_update_type.addWidget(self._radio_button_auto)
477     vlay_update_type.addWidget(self._radio_button_prompt)
478     vlay_update_type.addWidget(self._radio_button_never)
479     groupbox_update_types.setLayout(vlay_update_type)
480
481     hlay_cursor_epsilon = QHBoxLayout()
482     hlay_cursor_epsilon.addWidget(label_cursor_epsilon)
483     hlay_cursor_epsilon.addWidget(self._lineedit_cursor_epsilon)
484
485     hlay_snap_dist = QHBoxLayout()
486     hlay_snap_dist.addWidget(label_snap_dist)
487     hlay_snap_dist.addWidget(self._lineedit_snap_dist)
488
489     vlay_dist = QVBoxLayout()
490     vlay_dist.setSpacing(20)
491     vlay_dist.addLayout(hlay_cursor_epsilon)
492     vlay_dist.addWidget(self._checkbox_snap_to_int_coords)
493     vlay_dist.addLayout(hlay_snap_dist)
494
495     groupbox_dist = QGroupBox('Distances', self)
496     groupbox_dist.setLayout(vlay_dist)
497
498     options_layout = QVBoxLayout()
499     options_layout.setSpacing(20)
500     options_layout.addWidget(groupbox_update_types)
501     options_layout.addWidget(groupbox_dist)

```

```

502         self._load_settings()
503         self._update_gui()
504         self._setup_layout(options_layout)
505
506
507     def _update_gui(self) -> None:
508         """Update the GUI according to other widgets in the GUI."""
509         if self._lineEdit_cursor_epsilon.text() == '':
510             cursor_epsilon = False
511         else:
512             cursor_epsilon = 0 <= int(self._lineEdit_cursor_epsilon.text()) <= 99
513
514         if self._lineEdit_snap_dist.text() == '':
515             snap_dist = False
516         else:
517             snap_dist = 0.0 <= float(self._lineEdit_snap_dist.text()) <= 1.0
518
519         self._lineEdit_snap_dist.setEnabled(self._checkbox_snap_to_int_coords.isChecked())
520         self._button_confirm.setEnabled(cursor_epsilon and snap_dist)
521
522     def _load_settings(self) -> None:
523         """Load the current display settings into the widgets."""
524         if self._data.update_type == UpdateType.auto:
525             self._radio_button_auto.setChecked(True)
526         elif self._data.update_type == UpdateType.prompt:
527             self._radio_button_prompt.setChecked(True)
528         elif self._data.update_type == UpdateType.never:
529             self._radio_button_never.setChecked(True)
530
531         self._lineEdit_cursor_epsilon.setText(str(self._data.cursor_epsilon))
532         self._checkbox_snap_to_int_coords.setChecked(self._data.snap_to_int_coords)
533         self._lineEdit_snap_dist.setText(str(self._data.snap_dist))
534
535     def _confirm_settings(self) -> None:
536         """Set the global settings."""
537         if self._radio_button_auto.isChecked():
538             self._data.update_type = UpdateType.auto
539         elif self._radio_button_prompt.isChecked():
540             self._data.update_type = UpdateType.prompt
541         elif self._radio_button_never.isChecked():
542             self._data.update_type = UpdateType.never
543
544         self._data.cursor_epsilon = int(self._lineEdit_cursor_epsilon.text())
545         self._data.snap_to_int_coords = self._checkbox_snap_to_int_coords.isChecked()
546         self._data.snap_dist = float(self._lineEdit_snap_dist.text())
547
548         GlobalSettings().set_data(self._data)
549
550         self.accept()
551
552     def _reset_settings(self) -> None:
553         """Reset the internal data values to their defaults."""
554         self._data = GlobalSettingsData()
555         self._load_settings()
556         self._update_gui()

```

## A.17 gui/dialogs/\_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This package provides separate dialogs for the main GUI.
8
9  These dialogs are for defining new matrices in different ways and editing settings.
10 """
11
12 from .define_new_matrix import (DefineAsExpressionDialog, DefineMatrixDialog,

```

```

13         DefineNumericallyDialog, DefineVisuallyDialog)
14 from .misc import (AboutDialog, DefinePolygonDialog, FileSelectDialog,
15                   InfoPanelDialog, PromptUpdateDialog)
16 from .settings import DisplaySettingsDialog
17
18 __all__ = ['AboutDialog', 'DefineAsExpressionDialog', 'DefineMatrixDialog',
19           'DefineNumericallyDialog', 'DefinePolygonDialog', 'DefineVisuallyDialog',
20           'DisplaySettingsDialog', 'FileSelectDialog', 'InfoPanelDialog', 'PromptUpdateDialog']

```

## A.18 gui/dialogs/misc.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides miscellaneous dialog classes like :class:`AboutDialog`."""
8
9  from __future__ import annotations
10
11  import os
12  import platform
13  from typing import Dict, List, Optional, Tuple, Union
14
15  from PyQt5.QtCore import PYQT_VERSION_STR, QT_VERSION_STR, Qt, pyqtSlot
16  from PyQt5.QtGui import QKeySequence
17  from PyQt5.QtWidgets import (QDialog, QFileDialog, QGridLayout, QGroupBox,
18                              QHBoxLayout, QLabel, QPushButton, QRadioButton,
19                              QShortcut, QSizePolicy, QSpacerItem,
20                              QStackedLayout, QVBoxLayout, QWidget)
21
22  import lintrans
23  from lintrans.global_settings import GlobalSettings, UpdateType
24  from lintrans.gui.plots import DefinePolygonWidget
25  from lintrans.matrices import MatrixWrapper
26  from lintrans.matrices.utility import round_float
27  from lintrans.typing import MatrixType, is_matrix_type
28  from lintrans.updating import update_lintrans_in_background
29
30
31  class FixedSizeDialog(QDialog):
32      """A simple superclass to create modal dialog boxes with fixed size.
33
34      We override the :meth:`open` method to set the fixed size as soon as the dialog is opened modally.
35      """
36
37      def __init__(self, *args, **kwargs) -> None:
38          """Set the :cpp:enum:`Qt::WA_DeleteOnClose` attribute to ensure deletion of dialog."""
39          super().__init__(*args, **kwargs)
40          self.setAttribute(Qt.WA_DeleteOnClose)
41          self.setWindowFlag(Qt.WindowContextHelpButtonHint, False)
42
43      def open(self) -> None:
44          """Override :meth:`QDialog.open` to set the dialog to a fixed size."""
45          super().open()
46          self.setFixedSize(self.size())
47
48
49  class AboutDialog(FixedSizeDialog):
50      """A simple dialog class to display information about the app to the user.
51
52      It only has an :meth:`__init__` method because it only has label widgets, so no other methods are necessary
53      ↪ here.
54      """
55
56      def __init__(self, *args, **kwargs):
57          """Create an :class:`AboutDialog` object with all the label widgets."""
58          super().__init__(*args, **kwargs)

```



```

59         self.setWindowTitle('About lintrans')
60
61         # === Create the widgets
62
63         label_title = QLabel(self)
64         label_title.setText(f'lintrans (version {lintrans.__version__})')
65         label_title.setAlignment(Qt.AlignCenter)
66
67         font_title = label_title.font()
68         font_title.setPointSize(font_title.pointSize() * 2)
69         label_title.setFont(font_title)
70
71         label_version_info = QLabel(self)
72         label_version_info.setText(
73             f'With Python version {platform.python_version()}\n'
74             f'Qt version {QT_VERSION_STR} and PyQt5 version {PYQT_VERSION_STR}\n'
75             f'Running on {platform.platform()}'
76         )
77         label_version_info.setAlignment(Qt.AlignCenter)
78
79         label_info = QLabel(self)
80         label_info.setText(
81             'lintrans is a program designed to help visualise<br>'
82             '2D linear transformations represented with matrices.<br><br>'
83             "It's designed for teachers and students and all feedback<br>"
84             'is greatly appreciated. Go to <em>Help</em> &gt; <em>Give feedback</em><br>'
85             'to report a bug or suggest a new feature, or you can<br>email me directly at '
86             '<a href="mailto:dyson.dyson@icloud.com" style="color: black;">dyson.dyson@icloud.com</a>.'
87         )
88         label_info.setAlignment(Qt.AlignCenter)
89         label_info.setTextFormat(Qt.RichText)
90         label_info.setOpenExternalLinks(True)
91
92         label_copyright = QLabel(self)
93         label_copyright.setText(
94             'This program is free software.<br>Copyright 2021-2022 D. Dyson (DoctorDalek1963).<br>'
95             'This program is licensed under GPLv3, which can be found '
96             '<a href="https://www.gnu.org/licenses/gpl-3.0.html" style="color: black;">here</a>.'
97         )
98         label_copyright.setAlignment(Qt.AlignCenter)
99         label_copyright.setTextFormat(Qt.RichText)
100        label_copyright.setOpenExternalLinks(True)
101
102        # === Arrange the widgets
103
104        self.setContentsMargins(10, 10, 10, 10)
105
106        vlay = QVBoxLayout()
107        vlay.setSpacing(20)
108        vlay.addWidget(label_title)
109        vlay.addWidget(label_version_info)
110        vlay.addWidget(label_info)
111        vlay.addWidget(label_copyright)
112
113        self.setLayout(vlay)
114
115
116    class InfoPanelDialog(FixedSizeDialog):
117        """A simple dialog class to display an info panel that shows all currently defined matrices."""
118
119        def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
120            """Create the dialog box with all the widgets needed to show the information."""
121            super().__init__(*args, **kwargs)
122            self.matrix_wrapper = matrix_wrapper
123
124            self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
125                name: value
126                for name, value in self.matrix_wrapper.get_defined_matrices()
127            }
128
129            self.setWindowTitle('Defined matrices')
130            self.setContentsMargins(10, 10, 10, 10)
131

```

```

132         self._stacked_layout = QStackedLayout(self)
133         self.setLayout(self._stacked_layout)
134
135         self._draw_ui()
136
137     def _draw_ui(self) -> None:
138         grid_layout = QGridLayout()
139         grid_layout.setSpacing(20)
140
141         for i, (name, value) in enumerate(self._matrices.items()):
142             if value is None:
143                 continue
144
145             grid_layout.addWidget(
146                 self._get_full_matrix_widget(name, value),
147                 i % 4,
148                 i // 4,
149                 Qt.AlignCenter
150             )
151
152         container = QWidget(self)
153         container.setLayout(grid_layout)
154         self._stacked_layout.setCurrentIndex(self._stacked_layout.addWidget(container))
155
156     def _undefine_matrix(self, name: str) -> None:
157         """Undefine the given matrix and redraw the dialog."""
158         for x in self.matrix_wrapper.undefine_matrix(name):
159             self._matrices[x] = None
160
161         self._draw_ui()
162
163     def _get_full_matrix_widget(self, name: str, value: Union[MatrixType, str]) -> QWidget:
164         """Return a :class:`QWidget` containing the whole matrix widget composition.
165
166         Each defined matrix will get a widget group. Each group will be a label for the name,
167         a label for '=', and a container widget to either show the matrix numerically, or to
168         show the expression that it's defined as.
169
170         See :meth:`_get_matrix_data_widget`.
171         """
172         bold_font = self.font()
173         bold_font.setBold(True)
174
175         label_name = QLabel(self)
176         label_name.setText(name)
177         label_name.setFont(bold_font)
178
179         widget_matrix = self._get_matrix_data_widget(value)
180
181         hlay = QHBoxLayout()
182         hlay.setSpacing(10)
183         hlay.addWidget(label_name)
184         hlay.addWidget(QLabel('=', self))
185         hlay.addWidget(widget_matrix)
186
187         vlay = QVBoxLayout()
188         vlay.setSpacing(10)
189         vlay.addLayout(hlay)
190
191         if name != 'I':
192             button_undefine = QPushButton(self)
193             button_undefine.setText('Undefine')
194             button_undefine.clicked.connect(lambda: self._undefine_matrix(name))
195
196             vlay.addWidget(button_undefine)
197
198         groupbox = QGroupBox(self)
199         groupbox.setContentsMargins(10, 10, 10, 10)
200         groupbox.setLayout(vlay)
201
202         lay = QVBoxLayout()
203         lay.setSpacing(0)
204         lay.addWidget(groupbox)

```

```

205         container = QWidget(self)
206         container.setLayout(layout)
207
208         return container
209
210
211     def _get_matrix_data_widget(self, matrix: Union[MatrixType, str]) -> QWidget:
212         """Return a :class:`QWidget` containing the value of the matrix.
213
214         If the matrix is defined as an expression, it will be a simple :class:`QLabel`.
215         If the matrix is defined as a matrix, it will be a :class:`QWidget` container
216         with multiple :class:`QLabel` objects in it.
217         """
218         if isinstance(matrix, str):
219             label = QLabel(self)
220             label.setText(matrix)
221             return label
222
223         elif is_matrix_type(matrix):
224             # tl = top left, br = bottom right, etc.
225             label_tl = QLabel(self)
226             label_tl.setText(round_float(matrix[0][0]))
227
228             label_tr = QLabel(self)
229             label_tr.setText(round_float(matrix[0][1]))
230
231             label_bl = QLabel(self)
232             label_bl.setText(round_float(matrix[1][0]))
233
234             label_br = QLabel(self)
235             label_br.setText(round_float(matrix[1][1]))
236
237             # The parens need to be bigger than the numbers, but increasing the font size also
238             # makes the font thicker, so we have to reduce the font weight by the same factor
239             font_parens = self.font()
240             font_parens.setPointSize(int(font_parens.pointSize() * 2.5))
241             font_parens.setWeight(int(font_parens.weight() / 2.5))
242
243             label_paren_left = QLabel(self)
244             label_paren_left.setText('(')
245             label_paren_left.setFont(font_parens)
246
247             label_paren_right = QLabel(self)
248             label_paren_right.setText(')')
249             label_paren_right.setFont(font_parens)
250
251             container = QWidget(self)
252             grid_layout = QGridLayout()
253
254             grid_layout.addWidget(label_paren_left, 0, 0, -1, 1)
255             grid_layout.addWidget(label_tl, 0, 1)
256             grid_layout.addWidget(label_tr, 0, 2)
257             grid_layout.addWidget(label_bl, 1, 1)
258             grid_layout.addWidget(label_br, 1, 2)
259             grid_layout.addWidget(label_paren_right, 0, 3, -1, 1)
260
261             container.setLayout(grid_layout)
262
263             return container
264
265         raise ValueError('Matrix was not MatrixType or str')
266
267
268     class FileSelectDialog(QFileDialog):
269         """A subclass of :class:`QFileDialog` that fixes an issue with the default suffix on UNIX platforms."""
270
271         def selectedFiles(self) -> List[str]:
272             """Return a list of strings containing the absolute paths of the selected files in the dialog.
273
274             There is an issue on UNIX platforms where a hidden directory will be recognised as a suffix.
275             For example, ``/home/dyson/.lintrans/saves/test`` should have ``.lt`` appended, but
276             ``.lintrans/saves/test`` gets recognised as the suffix, so the default suffix is not added.
277

```

```

278         To fix this, we just look at the basename and see if it needs a suffix added. We do this for
279         every name in the list, but there should be just one name, since this class is only intended
280         to be used for saving files. We still return the full list of filenames.
281         """
282         selected_files: List[str] = []
283
284         for filename in super().selectedFiles():
285             # path will be the full path of the file, without the extension
286             # This method understands hidden directories on UNIX platforms
287             path, ext = os.path.splitext(filename)
288
289             if ext == '':
290                 ext = '.' + self.defaultSuffix()
291
292             selected_files.append(''.join((path, ext)))
293
294         return selected_files
295
296
297 class DefinePolygonDialog(FixedSizeDialog):
298     """This dialog class allows the use to define a polygon with :class:`DefinePolygonWidget`."""
299
300     def __init__(self, *args, polygon_points: List[Tuple[float, float]], **kwargs) -> None:
301         """Create the dialog with the :class:`DefinePolygonWidget` widget."""
302         super().__init__(*args, **kwargs)
303
304         self.setWindowTitle('Define a polygon')
305         self.setMinimumSize(700, 550)
306
307         self.polygon_points = polygon_points
308
309         # === Create the widgets
310
311         self._polygon_widget = DefinePolygonWidget(polygon_points=polygon_points)
312
313         button_confirm = QPushButton(self)
314         button_confirm.setText('Confirm')
315         button_confirm.clicked.connect(self._confirm_polygon)
316         button_confirm.setToolTip('Confirm this polygon<br><b>(Ctrl + Enter)</b>')
317         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(button_confirm.click)
318
319         button_cancel = QPushButton(self)
320         button_cancel.setText('Cancel')
321         button_cancel.clicked.connect(self.reject)
322         button_cancel.setToolTip('Discard this polygon<br><b>(Escape)</b>')
323
324         button_reset = QPushButton(self)
325         button_reset.setText('Reset polygon')
326         button_reset.clicked.connect(self._polygon_widget.reset_polygon)
327         button_reset.setToolTip('Remove all points of the polygon<br><b>(Ctrl + R)</b>')
328         QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(button_reset.click)
329
330         # === Arrange the widgets
331
332         self.setContentsMargins(10, 10, 10, 10)
333
334         hlay_buttons = QHBoxLayout()
335         hlay_buttons.setSpacing(20)
336         hlay_buttons.addWidget(button_reset)
337         hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
338         hlay_buttons.addWidget(button_cancel)
339         hlay_buttons.addWidget(button_confirm)
340
341         vlay = QVBoxLayout()
342         vlay.setSpacing(20)
343         vlay.addWidget(self._polygon_widget)
344         vlay.addLayout(hlay_buttons)
345
346         self.setLayout(vlay)
347
348     @pyqtSlot()
349     def _confirm_polygon(self) -> None:
350         """Confirm the polygon that the user has defined."""

```

```

351         self.polygon_points = self._polygon_widget.points
352         self.accept()
353
354
355 class PromptUpdateDialog(FixedSizeDialog):
356     """A simple dialog to ask the user if they want to upgrade their lintrans installation."""
357
358     def __init__(self, *args, new_version: str, **kwargs) -> None:
359         """Create the dialog with all its widgets."""
360         super().__init__(*args, **kwargs)
361
362         if new_version.startswith('v'):
363             new_version = new_version[1:]
364
365         self.setWindowTitle('Update available')
366
367         # === Create the widgets
368
369         label_info = QLabel(self)
370         label_info.setText(
371             'A new version of lintrans is available!\n'
372             f'({lintrans.__version__} -> {new_version})\n\n'
373             'Would you like to update now?'
374         )
375         label_info.setAlignment(Qt.AlignCenter)
376
377         label_explanation = QLabel(self)
378         label_explanation.setText(
379             'The update will run silently in the background, so you can keep using lintrans uninterrupted.\n'
380             'You can change your choice at any time in File > Settings.'
381         )
382         label_explanation.setAlignment(Qt.AlignCenter)
383
384         font = label_explanation.font()
385         font.setPointSize(int(0.9 * font.pointSize()))
386         font.setItalic(True)
387         label_explanation.setFont(font)
388
389         groupbox_radio_buttons = QGroupBox(self)
390
391         self._radio_button_auto = QRadioButton('Always update automatically', groupbox_radio_buttons)
392         self._radio_button_prompt = QRadioButton('Always ask to update', groupbox_radio_buttons)
393         self._radio_button_never = QRadioButton('Never update', groupbox_radio_buttons)
394
395         # If this prompt is even appearing, then the update type must be 'prompt'
396         self._radio_button_prompt.setChecked(True)
397
398         button_remind_me_later = QPushButton('Remind me later', self)
399         button_remind_me_later.clicked.connect(lambda: self._save_choice_and_update(False))
400         button_remind_me_later.setShortcut(Qt.Key_Escape)
401         button_remind_me_later.setFocus()
402
403         button_update_now = QPushButton('Update now', self)
404         button_update_now.clicked.connect(lambda: self._save_choice_and_update(True))
405
406         # === Arrange the widgets
407
408         self.setContentsMargins(10, 10, 10, 10)
409
410         hlay_buttons = QHBoxLayout()
411         hlay_buttons.setSpacing(20)
412         hlay_buttons.addWidget(button_remind_me_later)
413         hlay_buttons.addWidget(button_update_now)
414
415         vlay = QVBoxLayout()
416         vlay.setSpacing(20)
417         vlay.addWidget(label_info)
418
419         vlay_radio_buttons = QVBoxLayout()
420         vlay_radio_buttons.setSpacing(10)
421         vlay_radio_buttons.addWidget(self._radio_button_auto)
422         vlay_radio_buttons.addWidget(self._radio_button_prompt)
423         vlay_radio_buttons.addWidget(self._radio_button_never)

```

```

424
425         groupbox_radio_buttons.setLayout(vlay_radio_buttons)
426
427         vlay.addWidget(groupbox_radio_buttons)
428         vlay.addWidget(label_explanation)
429         vlay.addLayout(hlay_buttons)
430
431         self.setLayout(vlay)
432
433     def _save_choice_and_update(self, update_now: bool) -> None:
434         """Save the user's choice of how to update and optionally trigger an update now."""
435         gs = GlobalSettings()
436         if self._radio_button_auto.isChecked():
437             gs.set_update_type(UpdateType.auto)
438
439         elif self._radio_button_prompt.isChecked():
440             gs.set_update_type(UpdateType.prompt)
441
442         elif self._radio_button_never.isChecked():
443             gs.set_update_type(UpdateType.never)
444
445         if update_now:
446             # We don't need to check because we'll only get here if we know a new version is available
447             update_lintrans_in_background(check=False)
448             self.accept()
449         else:
450             self.reject()

```

## A.19 matrices/utility.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides simple utility methods for matrix and vector manipulation."""
8
9  from __future__ import annotations
10
11  import math
12  from typing import Tuple
13
14  import numpy as np
15
16  from lintrans.typing_ import MatrixType
17
18
19  def polar_coords(x: float, y: float, *, degrees: bool = False) -> Tuple[float, float]:
20      r"""Return the polar coordinates of a given (x, y) Cartesian coordinate.
21
22      .. note:: We're returning the angle in the range :math:`[0, 2\pi)`
23      """
24      radius = math.hypot(x, y)
25
26      # PyCharm complains about np.angle taking a complex argument even though that's what it's designed for
27      # noinspection PyTypeChecker
28      angle = float(np.angle(x + y * 1j, degrees))
29
30      if angle < 0:
31          angle += 2 * np.pi
32
33      return radius, angle
34
35
36  def rect_coords(radius: float, angle: float, *, degrees: bool = False) -> Tuple[float, float]:
37      r"""Return the rectilinear coordinates of a given polar coordinate."""
38      if degrees:
39          angle = np.radians(angle)
40

```

```

41     return radius * np.cos(angle), radius * np.sin(angle)
42
43
44 def rotate_coord(x: float, y: float, angle: float, *, degrees: bool = False) -> Tuple[float, float]:
45     """Rotate a rectilinear coordinate by the given angle."""
46     if degrees:
47         angle = np.radians(angle)
48
49     r, theta = polar_coords(x, y, degrees=degrees)
50     theta = (theta + angle) % (2 * np.pi)
51
52     return rect_coords(r, theta, degrees=degrees)
53
54
55 def create_rotation_matrix(angle: float, *, degrees: bool = True) -> MatrixType:
56     """Create a matrix representing a rotation (anticlockwise) by the given angle.
57
58     :Example:
59
60     >>> create_rotation_matrix(30)
61     array([[ 0.8660254, -0.5      ],
62            [ 0.5      ,  0.8660254]])
63     >>> create_rotation_matrix(45)
64     array([[ 0.70710678, -0.70710678],
65            [ 0.70710678,  0.70710678]])
66     >>> create_rotation_matrix(np.pi / 3, degrees=False)
67     array([[ 0.5      , -0.8660254],
68            [ 0.8660254,  0.5      ]])
69
70     :param float angle: The angle to rotate anticlockwise by
71     :param bool degrees: Whether to interpret the angle as degrees (True) or radians (False)
72     :returns MatrixType: The resultant matrix
73     """
74     rad = np.deg2rad(angle % 360) if degrees else angle % (2 * np.pi)
75     return np.array([
76         [np.cos(rad), -1 * np.sin(rad)],
77         [np.sin(rad), np.cos(rad)]
78     ])
79
80
81 def is_valid_float(string: str) -> bool:
82     """Check if the string is a valid float (or anything that can be cast to a float, such as an int).
83
84     This function simply checks that ``float(string)`` doesn't raise an error.
85
86     .. note:: An empty string is not a valid float, so will return False.
87
88     :param str string: The string to check
89     :returns bool: Whether the string is a valid float
90     """
91     try:
92         float(string)
93         return True
94     except ValueError:
95         return False
96
97
98 def round_float(num: float, precision: int = 5) -> str:
99     """Round a floating point number to a given number of decimal places for pretty printing.
100
101     :param float num: The number to round
102     :param int precision: The number of decimal places to round to
103     :returns str: The rounded number for pretty printing
104     """
105     # Round to ``precision`` number of decimal places
106     string = str(round(num, precision))
107
108     # Cut off the potential final zero
109     if string.endswith('.0'):
110         return string[:-2]
111
112     elif 'e' in string: # Scientific notation
113         split = string.split('e')

```

```

114         # The leading 0 only happens when the exponent is negative, so we know there'll be a minus sign
115         return split[0] + 'e-' + split[1][1:].rstrip('0')
116
117     else:
118         return string

```

## A.20 matrices/wrapper.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module contains the main :class:`MatrixWrapper` class and a function to create a matrix from an angle."""
8
9  from __future__ import annotations
10
11  import re
12  from copy import copy
13  from functools import reduce
14  from operator import add, matmul
15  from typing import Any, Dict, List, Optional, Set, Tuple, Union
16
17  import numpy as np
18
19  from lintrans.typing_ import MatrixType, is_matrix_type
20
21  from .parse import (get_matrix_identifiers, parse_matrix_expression,
22                      validate_matrix_expression)
23  from .utility import create_rotation_matrix
24
25  _ALPHABET_NO_I = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
26
27
28  class MatrixWrapper:
29      """A wrapper class to hold all possible matrices and allow access to them.
30
31      .. note::
32          When defining a custom matrix, its name must be a capital letter and cannot be ``I``.
33
34      The contained matrices can be accessed and assigned to using square bracket notation.
35
36      :Example:
37
38      >>> wrapper = MatrixWrapper()
39      >>> wrapper['I']
40      array([[1., 0.],
41            [0., 1.]])
42      >>> wrapper['M'] # Returns None
43      >>> wrapper['M'] = np.array([[1, 2], [3, 4]])
44      >>> wrapper['M']
45      array([[1., 2.],
46            [3., 4.]])
47      """
48
49      def __init__(self):
50          """Initialize a :class:`MatrixWrapper` object with a dictionary of matrices which can be accessed."""
51          self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
52              'A': None, 'B': None, 'C': None, 'D': None,
53              'E': None, 'F': None, 'G': None, 'H': None,
54              'I': np.eye(2), # I is always defined as the identity matrix
55              'J': None, 'K': None, 'L': None, 'M': None,
56              'N': None, 'O': None, 'P': None, 'Q': None,
57              'R': None, 'S': None, 'T': None, 'U': None,
58              'V': None, 'W': None, 'X': None, 'Y': None,
59              'Z': None
60          }
61
62      def __repr__(self) -> str:

```



```

63         """Return a nice string repr of the :class:`MatrixWrapper` for debugging."""
64         defined_matrices = ''.join([k for k, v in self._matrices.items() if v is not None])
65         return f'<{self.__class__.__module__}.{self.__class__.__name__} object with ' \
66             f'{len(defined_matrices)} defined matrices: '{defined_matrices}'>'
67
68     def __eq__(self, other: Any) -> bool:
69         """Check for equality in wrappers by comparing dictionaries.
70
71         :param Any other: The object to compare this wrapper to
72         """
73         if not isinstance(other, self.__class__):
74             return NotImplemented
75
76         # We loop over every matrix and check if every value is equal in each
77         for name in self._matrices:
78             s_matrix = self[name]
79             o_matrix = other[name]
80
81             if s_matrix is None and o_matrix is None:
82                 continue
83
84             elif (s_matrix is None and o_matrix is not None) or \
85                 (s_matrix is not None and o_matrix is None):
86                 return False
87
88             # This is mainly to satisfy mypy, because we know these must be matrices
89             elif not is_matrix_type(s_matrix) or not is_matrix_type(o_matrix):
90                 return False
91
92             # Now we know they're both NumPy arrays
93             elif np.array_equal(s_matrix, o_matrix):
94                 continue
95
96             else:
97                 return False
98
99         return True
100
101     def __hash__(self) -> int:
102         """Return the hash of the matrices dictionary."""
103         return hash(self._matrices)
104
105     def __getitem__(self, name: str) -> Optional[MatrixType]:
106         """Get the matrix with the given identifier.
107
108         If it is a simple name, it will just be fetched from the dictionary. If the identifier is ``rot(x)`, with
109         a given angle in degrees, then we return a new matrix representing a rotation by that angle. If the
110         ↪ identifier
111         is something like ``[1 2;3 4]`, then we will evaluate this matrix (we assume it will have whitespace
112         ↪ exactly
113         like the example; see :func:`lintrans.matrices.parse.strip_whitespace`).
114
115         .. note::
116             If the named matrix is defined as an expression, then this method will return its evaluation.
117             If you want the expression itself, use :meth:`get_expression`.
118
119         :param str name: The name of the matrix to get
120         :returns Optional[MatrixType]: The value of the matrix (could be None)
121
122         :raises NameError: If there is no matrix with the given name
123         """
124         # Return a new rotation matrix
125         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
126             return create_rotation_matrix(float(match.group(1)))
127
128         if (match := re.match(
129             r'\((-?\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?);(-?\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?))\]',
130             name
131         )) is not None:
132             a = float(match.group(1))
133             b = float(match.group(2))
134             c = float(match.group(3))
135             d = float(match.group(4))

```

```

134         return np.array([[a, b], [c, d]])
135
136     if name not in self._matrices:
137         if validate_matrix_expression(name):
138             return self.evaluate_expression(name)
139
140         raise NameError(f'Unrecognised matrix name "{name}"')
141
142     # We copy the matrix before we return it so the user can't accidentally mutate the matrix
143     matrix = copy(self._matrices[name])
144
145     if isinstance(matrix, str):
146         return self.evaluate_expression(matrix)
147
148     return matrix
149
150 def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:
151     """Set the value of matrix ``name`` with the new_matrix.
152
153     The new matrix may be a simple 2x2 NumPy array, or it could be a string, representing an
154     expression in terms of other, previously defined matrices.
155
156     :param str name: The name of the matrix to set the value of
157     :param Optional[Union[MatrixType, str]] new_matrix: The value of the new matrix (could be None)
158
159     :raises NameError: If the name isn't a legal matrix name
160     :raises TypeError: If the matrix isn't a valid 2x2 NumPy array or expression in terms of other defined
161     ↪ matrices
162     :raises ValueError: If you attempt to define a matrix in terms of itself
163     """
164     if not (name in self._matrices and name != 'I'):
165         raise NameError('Matrix name is illegal')
166
167     if new_matrix is None:
168         self._matrices[name] = None
169         return
170
171     if isinstance(new_matrix, str):
172         if self.is_valid_expression(new_matrix):
173             if name not in new_matrix and \
174                 name not in self.get_expression_dependencies(new_matrix):
175                 self._matrices[name] = new_matrix
176                 return
177             else:
178                 raise ValueError('Cannot define a matrix recursively')
179
180     if not is_matrix_type(new_matrix):
181         raise TypeError('Matrix must be a 2x2 NumPy array')
182
183     # All matrices must have float entries
184     a = float(new_matrix[0][0])
185     b = float(new_matrix[0][1])
186     c = float(new_matrix[1][0])
187     d = float(new_matrix[1][1])
188
189     self._matrices[name] = np.array([[a, b], [c, d]])
190
191 def get_matrix_dependencies(self, matrix_name: str) -> Set[str]:
192     """Return all the matrices (as identifiers) that the given matrix (indirectly) depends on.
193
194     If A depends on nothing, B directly depends on A, and C directly depends on B,
195     then we say C depends on B 'and' A.
196     """
197     expression = self.get_expression(matrix_name)
198     if expression is None:
199         return set()
200
201     s = set()
202     identifiers = get_matrix_identifiers(expression)
203     for identifier in identifiers:
204         s.add(identifier)
205         s.update(self.get_matrix_dependencies(identifier))

```

```

206         return s
207
208     def get_expression_dependencies(self, expression: str) -> Set[str]:
209         """Return all the matrices that the given expression depends on.
210
211         This method just calls :meth:`get_matrix_dependencies` on each matrix
212         identifier in the expression. See that method for details.
213
214         If an expression contains a matrix that has no dependencies, then the
215         expression is `not` considered to depend on that matrix. But it `is`
216         considered to depend on any matrix that has its own dependencies.
217         """
218         s = set()
219         for iden in get_matrix_identifiers(expression):
220             s.update(self.get_matrix_dependencies(iden))
221         return s
222
223     def get_expression(self, name: str) -> Optional[str]:
224         """If the named matrix is defined as an expression, return that expression, else return None.
225
226         :param str name: The name of the matrix
227         :returns Optional[str]: The expression that the matrix is defined as, or None
228
229         :raises NameError: If the name is invalid
230         """
231         if name not in self._matrices:
232             raise NameError('Matrix must have a legal name')
233
234         matrix = self._matrices[name]
235         if isinstance(matrix, str):
236             return matrix
237
238         return None
239
240     def is_valid_expression(self, expression: str) -> bool:
241         """Check if the given expression is valid, using the context of the wrapper.
242
243         This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
244         ensures that all the matrices in the expression are defined in the wrapper.
245
246         :param str expression: The expression to validate
247         :returns bool: Whether the expression is valid in this wrapper
248
249         :raises LinAlgError: If a matrix is defined in terms of the inverse of a singular matrix
250         """
251         # Get rid of the transposes to check all capital letters
252         new_expression = expression.replace('^T', '').replace('^T}', '')
253
254         # Make sure all the referenced matrices are defined
255         for matrix in [x for x in new_expression if re.match('[A-Z]', x)]:
256             if self[matrix] is None:
257                 return False
258
259             if (expr := self.get_expression(matrix)) is not None:
260                 if not self.is_valid_expression(expr):
261                     return False
262
263         return validate_matrix_expression(expression)
264
265     def evaluate_expression(self, expression: str) -> MatrixType:
266         """Evaluate a given expression and return the matrix evaluation.
267
268         :param str expression: The expression to be parsed
269         :returns MatrixType: The matrix result of the expression
270
271         :raises ValueError: If the expression is invalid
272         """
273         if not self.is_valid_expression(expression):
274             raise ValueError('The expression is invalid')
275
276         parsed_result = parse_matrix_expression(expression)
277         final_groups: List[List[MatrixType]] = []
278

```

```

279     for group in parsed_result:
280         f_group: List[MatrixType] = []
281
282         for multiplier, identifier, index in group:
283             if index == 'T':
284                 m = self[identifier]
285
286                 # This assertion is just so mypy doesn't complain
287                 # We know this won't be None, because we know that this matrix is defined in this wrapper
288                 assert m is not None
289                 matrix_value = m.T
290
291             else:
292                 # Again, this assertion is just for mypy
293                 # We know this will be a matrix, but since upgrading from NumPy 1.21 to 1.23
294                 # (to fix a bug with GH Actions on Windows), mypy complains about matrix_power()
295                 base_matrix = self[identifier]
296                 assert is_matrix_type(base_matrix)
297
298                 matrix_value = np.linalg.matrix_power(base_matrix, 1 if index == 'I' else int(index))
299
300                 matrix_value *= 1 if multiplier == '1' else float(multiplier)
301                 f_group.append(matrix_value)
302
303         final_groups.append(f_group)
304
305     return reduce(add, [reduce(matmul, group) for group in final_groups])
306
307 def get_defined_matrices(self) -> List[Tuple[str, Union[MatrixType, str]]]:
308     """Return a list of tuples containing the name and value of all defined matrices in the wrapper.
309
310     :returns: A list of tuples where the first element is the name, and the second element is the value
311     :rtype: List[Tuple[str, Union[MatrixType, str]]]
312     """
313     matrices = []
314
315     for name, value in self._matrices.items():
316         if value is not None:
317             matrices.append((name, value))
318
319     return matrices
320
321 def undefine_matrix(self, name: str) -> Set[str]:
322     """Safely undefine the given matrix by also undefining any matrices that depend on it."""
323     if not (name in self._matrices and name != 'I'):
324         raise NameError('Matrix name is illegal')
325
326     # This maps each matrix to all the matrices that depend on it
327     dependents_map = {
328         x: set(y for y in _ALPHABET_NO_I if x in self.get_matrix_dependencies(y))
329         for x in _ALPHABET_NO_I
330     }
331
332     s: Set[str] = set(name)
333     self[name] = None
334     for x in dependents_map[name]:
335         s.update(self.undefine_matrix(x))
336
337     return s

```

## A.21 matrices/\_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This package supplies classes and functions to parse, evaluate, and wrap matrices."""
8

```

```

9  from . import parse, utility
10 from .utility import create_rotation_matrix
11 from .wrapper import MatrixWrapper
12
13 __all__ = ['create_rotation_matrix', 'MatrixWrapper', 'parse', 'utility']

```

## A.22 matrices/parse.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides functions to parse and validate matrix expressions."""
8
9  from __future__ import annotations
10
11  import re
12  from dataclasses import dataclass
13  from typing import List, Pattern, Set, Tuple
14
15  from lintrans.typing import MatrixParseList
16
17  _ALPHABET = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
18
19  NAIVE_CHARACTER_CLASS = r'[-+\sA-Z0-9.rot()\[\]\;:]'
20  """This is a RegEx character class that just holds all the valid characters for an expression.
21
22  See :func:`validate_matrix_expression` to actually validate matrix expressions.
23  """
24
25
26  class MatrixParseError(Exception):
27      """A simple exception to be raised when an error is found when parsing."""
28
29
30  def compile_naive_expression_pattern() -> Pattern[str]:
31      """Compile the single RegEx pattern that will match a valid matrix expression."""
32      digit_no_zero = '[123456789]'
33      digits = '\\d+'
34      integer_no_zero = digit_no_zero + '(' + digits + ')?'
35      real_number = f'({integer_no_zero}(\\.\\{digits}\\)?|0\\.\\{digits}\\)?)'
36
37      anonymous_matrix = r'\\[(-?\\d+(?:\\.\\d+)?)(-?\\d+(?:\\.\\d+)?);(-?\\d+(?:\\.\\d+)?)(-?\\d+(?:\\.\\d+)?\\)]'
38
39      index_content = f'(-?{integer_no_zero}|T)'
40      index = f'\\^{{{index_content}}}|\\^{index_content}'
41      matrix_identifier = f'([A-Z]|rot\\((-?{real_number}\\)|{anonymous_matrix}|\\({NAIVE_CHARACTER_CLASS}\\+\\))'
42      matrix = '(' + real_number + '?' + matrix_identifier + index + '?)'
43      expression = f'~?{matrix}+((\\+~?|-){matrix}+)*$'
44
45      return re.compile(expression)
46
47
48  # This is an expensive pattern to compile, so we compile it when this module is initialized
49  _naive_expression_pattern = compile_naive_expression_pattern()
50
51
52  def find_sub_expressions(expression: str) -> List[str]:
53      """Find all the sub-expressions in the given expression.
54
55      This function only goes one level deep, so may return strings like ``A(BC)D``.
56
57      :raises MatrixParseError: If there are unbalanced parentheses
58      """
59      sub_expressions: List[str] = []
60      string = ''
61      paren_depth = 0
62      pointer = 0

```

```

63
64 expression = strip_whitespace(expression)
65
66 while True:
67     char = expression[pointer]
68
69     if char == '(' and expression[pointer - 3:pointer] != 'rot':
70         paren_depth += 1
71
72         # This is a bit of a manual bodge, but it eliminates extraneous parens
73         if paren_depth == 1:
74             pointer += 1
75             continue
76
77     elif char == ')' and re.match(f'{{NAIVE_CHARACTER_CLASS}}*?rot\\([\\-\\.d.]+$', expression[:pointer]) is None:
78         paren_depth -= 1
79
80     if paren_depth > 0:
81         string += char
82
83     if paren_depth == 0 and string:
84         sub_expressions.append(string)
85         string = ''
86
87     pointer += 1
88
89     if pointer >= len(expression):
90         break
91
92 if paren_depth != 0:
93     raise MatrixParseError('Unbalanced parentheses in expression')
94
95 return sub_expressions
96
97
98 def strip_whitespace(expression: str) -> str:
99     """Strip the whitespace from the given expression, preserving whitespace in anonymous matrices.
100
101     Whitespace in anonymous matrices is preserved such that there is exactly one space in the middle of each pair of
102     numbers, but no space after the semi-colon, like so: `[1 -2;3.4 5]`.
103     """
104     # We replace the necessary whitespace with null bytes to preserve it
105     expression = re.sub(
106         r'\\s*(-?\\d+(?:\\.\\d+)?)\\s+(-?\\d+(?:\\.\\d+)?)\\s*;\\s*(-?\\d+(?:\\.\\d+)?)\\s+(-?\\d+(?:\\.\\d+)?)\\s*\\s*',
107         r'[\\g<1> \\g<2>;\\g<3> \\g<4>]'.replace(' ', '\\x00'),
108         expression
109     )
110
111     expression = re.sub(r'\\s', '', expression)
112     return re.sub('\\x00', ' ', expression)
113
114
115 def validate_matrix_expression(expression: str) -> bool:
116     """Validate the given matrix expression.
117
118     This function simply checks the expression against the BNF schema documented in
119     :ref:`expression-syntax-docs`. It is not aware of which matrices are actually defined
120     in a wrapper. For an aware version of this function, use the
121     :meth:`~lintrans.matrices.wrapper.MatrixWrapper.is_valid_expression` method on
122     :class:`~lintrans.matrices.wrapper.MatrixWrapper`.
123
124     :param str expression: The expression to be validated
125     :returns bool: Whether the expression is valid according to the schema
126     """
127     # Remove all whitespace
128     expression = strip_whitespace(expression)
129     match = _naive_expression_pattern.match(expression)
130
131     if match is None:
132         return False
133
134     if re.search(r'\\^-?\\d*\\.\\d+', expression) is not None:
135         return False

```

```

136
137     # Check that the whole expression was matched against
138     if expression != match.group(0):
139         return False
140
141     try:
142         sub_expressions = find_sub_expressions(expression)
143     except MatrixParseError:
144         return False
145
146     if len(sub_expressions) == 0:
147         return True
148
149     return all(validate_matrix_expression(m) for m in sub_expressions)
150
151
152 @dataclass
153 class MatrixToken:
154     """A simple dataclass to hold information about a matrix token being parsed."""
155
156     multiplier: str = ''
157     identifier: str = ''
158     exponent: str = ''
159
160     @property
161     def tuple(self) -> Tuple[str, str, str]:
162         """Create a tuple of the token for parsing."""
163         return self.multiplier, self.identifier, self.exponent
164
165
166 class ExpressionParser:
167     """A class to hold state during parsing.
168
169     Most of the methods in this class are class-internal and should not be used from outside.
170
171     This class should be used like this:
172
173     >>> ExpressionParser('3A~1B').parse()
174     [[('3', 'A', '-1'), ('', 'B', '')]]
175     >>> ExpressionParser('4(M^TA^2)^-2').parse()
176     [[('4', 'M{T}A^{2}', '-2')]]
177     """
178
179     def __init__(self, expression: str):
180         """Create an instance of the parser with the given expression and initialise variables to use during
181         ↪ parsing."""
182         # Remove all whitespace
183         expression = strip_whitespace(expression)
184
185         # Check if it's valid
186         if not validate_matrix_expression(expression):
187             raise MatrixParseError('Invalid expression')
188
189         # Wrap all exponents and transposition powers with {}
190         expression = re.sub(r'(?<=^)(-?\d+|T)(?=[^}]|$\d+)', r'{\g<0>}', expression)
191
192         # Remove any standalone minuses
193         expression = re.sub(r'-(?=[A-Z]|\d+)', '-1', expression)
194
195         # Replace subtractions with additions
196         expression = re.sub(r'-(?=[A-Z]|T)\d+([A-Z]|rot|T)', '+-', expression)
197
198         # Get rid of a potential leading + introduced by the last step
199         expression = re.sub(r'^+', '', expression)
200
201         self._expression = expression
202         self._pointer: int = 0
203
204         self._current_token = MatrixToken()
205         self._current_group: List[Tuple[str, str, str]] = []
206
207         self._final_list: MatrixParseList = []

```

```

208     def __repr__(self) -> str:
209         """Return a simple repr containing the expression."""
210         return f'{self.__class__.__module__}.{self.__class__.__name__}("{self._expression}")'
211
212     @property
213     def _char(self) -> str:
214         """Return the character pointed to by the pointer."""
215         return self._expression[self._pointer]
216
217     def parse(self) -> MatrixParseList:
218         """Fully parse the instance's matrix expression and return the :attr:`~lintrans.typing_.MatrixParseList`.
219
220         This method uses all the private methods of this class to parse the
221         expression in parts. All private methods mutate the instance variables.
222
223         :returns: The parsed expression
224         :rtype: :attr:`~lintrans.typing_.MatrixParseList`
225         """
226         self._parse_multiplication_group()
227
228         while self._pointer < len(self._expression):
229             if self._expression[self._pointer] != '+':
230                 raise MatrixParseError('Expected "+" between multiplication groups')
231
232             self._pointer += 1
233             self._parse_multiplication_group()
234
235         return self._final_list
236
237     def _parse_multiplication_group(self) -> None:
238         """Parse a group of matrices to be multiplied together.
239
240         This method just parses matrices until we get to a ``+``.
241         """
242         # This loop continues to parse matrices until we fail to do so
243         while self._parse_matrix():
244             # Once we get to the end of the multiplication group, we add it the final list and reset the group list
245             if self._pointer >= len(self._expression) or self._char == '+':
246                 self._final_list.append(self._current_group)
247                 self._current_group = []
248                 self._pointer += 1
249
250     def _parse_matrix(self) -> bool:
251         """Parse a full matrix using :meth:`~_parse_matrix_part`.
252
253         This method will parse an optional multiplier, an identifier, and an optional exponent. If we
254         do this successfully, we return True. If we fail to parse a matrix (maybe we've reached the
255         end of the current multiplication group and the next char is ``+``), then we return False.
256
257         :returns bool: Success or failure
258         """
259         self._current_token = MatrixToken()
260
261         while self._parse_matrix_part():
262             pass # The actual execution is taken care of in the loop condition
263
264         if self._current_token.identifier == '':
265             return False
266
267         self._current_group.append(self._current_token.tuple)
268         return True
269
270     def _parse_matrix_part(self) -> bool:
271         """Parse part of a matrix (multiplier, identifier, or exponent).
272
273         Which part of the matrix we parse is dependent on the current value of the pointer and the expression.
274         This method will parse whichever part of matrix token that it can. If it can't parse a part of a matrix,
275         or it's reached the next matrix, then we just return False. If we succeeded to parse a matrix part, then
276         we return True.
277
278         :returns bool: Success or failure
279         :raises MatrixParseError: If we fail to parse this part of the matrix
280         """

```



```

281         if self._pointer >= len(self._expression):
282             return False
283
284         if self._char.isdigit() or self._char == '-':
285             if self._current_token.multiplier != '' \
286                 or (self._current_token.multiplier == '' and self._current_token.identifier != ''):
287                 return False
288
289             self._parse_multiplier()
290
291         elif self._char.isalpha() and self._char.isupper():
292             if self._current_token.identifier != '':
293                 return False
294
295             self._current_token.identifier = self._char
296             self._pointer += 1
297
298         elif self._char == 'r':
299             if self._current_token.identifier != '':
300                 return False
301
302             self._parse_rot_identifier()
303
304         elif self._char == '[':
305             if self._current_token.identifier != '':
306                 return False
307
308             self._parse_anonymous_identifier()
309
310         elif self._char == '(':
311             if self._current_token.identifier != '':
312                 return False
313
314             self._parse_sub_expression()
315
316         elif self._char == '^':
317             if self._current_token.exponent != '':
318                 return False
319
320             self._parse_exponent()
321
322         elif self._char == '+':
323             return False
324
325         else:
326             raise MatrixParseError(f'Unrecognised character "{self._char}" in matrix expression')
327
328         return True
329
330     def _parse_multiplier(self) -> None:
331         """Parse a multiplier from the expression and pointer.
332
333         This method just parses a numerical multiplier, which can include
334         zero or one ``.`` character and optionally a ``-`` at the start.
335
336         :raises MatrixParseError: If we fail to parse this part of the matrix
337         """
338         multiplier = ''
339
340         while self._char.isdigit() or self._char in ('.', '-'):
341             multiplier += self._char
342             self._pointer += 1
343
344         try:
345             float(multiplier)
346         except ValueError as e:
347             raise MatrixParseError(f'Invalid multiplier "{multiplier}"') from e
348
349         self._current_token.multiplier = multiplier
350
351     def _parse_rot_identifier(self) -> None:
352         """Parse a ``rot()``-style identifier from the expression and pointer.
353

```

```

354     This method will just parse something like ``rot(12.5)``. The angle number must be a real number.
355
356     :raises MatrixParseError: If we fail to parse this part of the matrix
357     """
358     if match := re.match(r'rot\(([^\d.-]+\d+)\)', self._expression[self._pointer:]):
359         # Ensure that the number in brackets is a valid float
360         try:
361             float(match.group(1))
362         except ValueError as e:
363             raise MatrixParseError(f'Invalid angle number "{match.group(1)}" in rot-identifier') from e
364
365         self._current_token.identifier = match.group(0)
366         self._pointer += len(match.group(0))
367     else:
368         raise MatrixParseError(
369             f'Invalid rot-identifier "{self._expression[self._pointer : self._pointer + 15]}..."
370         )
371
372     def _parse_anonymous_idenfiter(self) -> None:
373         """Parse an anonymous matrix, including the square brackets."""
374         if match := re.match(
375             r'^\[(?!\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?);(-?\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?)\]',
376             self._expression[self._pointer:]
377         ):
378             for n in range(1, 4 + 1):
379                 try:
380                     float(match.group(n))
381                 except ValueError as e:
382                     raise MatrixParseError(f'Invalid matrix entry "{match.group(1)}" in anonymous matrix') from e
383
384             self._current_token.identifier = match.group(0)
385             self._pointer += len(match.group(0))
386         else:
387             raise MatrixParseError(
388                 f'Invalid anonymous matrix "{self._expression[self._pointer : self._pointer + 15]}..."
389             )
390
391     def _parse_sub_expression(self) -> None:
392         """Parse a parenthesized sub-expression as the identifier.
393
394         This method will also validate the expression in the parentheses.
395
396         :raises MatrixParseError: If we fail to parse this part of the matrix
397         """
398         if self._char != '(':
399             raise MatrixParseError('Sub-expression must start with "("')
400
401         self._pointer += 1
402         paren_depth = 1
403         identifier = ''
404
405         while paren_depth > 0:
406             if self._char == '(':
407                 paren_depth += 1
408             elif self._char == ')':
409                 paren_depth -= 1
410
411             if paren_depth == 0:
412                 self._pointer += 1
413                 break
414
415             identifier += self._char
416             self._pointer += 1
417
418         if not validate_matrix_expression(identifier):
419             raise MatrixParseError(f'Invalid sub-expression identifier "{identifier}"')
420
421         self._current_token.identifier = identifier
422
423     def _parse_exponent(self) -> None:
424         """Parse a matrix exponent from the expression and pointer.
425
426         The exponent must be an integer or ``T`` for transpose.

```

```

427
428         :raises MatrixParseError: If we fail to parse this part of the token
429         """
430         if match := re.match(r'^{(-?\d+|T)\}', self._expression[self._pointer:]):
431             exponent = match.group(1)
432
433             try:
434                 if exponent != 'T':
435                     int(exponent)
436             except ValueError as e:
437                 raise MatrixParseError(f'Invalid exponent "{match.group(1)}"' from e
438
439             self._current_token.exponent = exponent
440             self._pointer += len(match.group(0))
441         else:
442             raise MatrixParseError(
443                 f'Invalid exponent "{self._expression[self._pointer : self._pointer + 10]}...'
444             )
445
446
447 def parse_matrix_expression(expression: str) -> MatrixParseList:
448     """Parse the matrix expression and return a :attr:`~lintrans.typing_.MatrixParseList`.
449
450     :Example:
451
452     >>> parse_matrix_expression('A')
453     [[(' ', 'A', ' ')]]
454     >>> parse_matrix_expression('-3M^2')
455     [[(' -3', 'M', '2')]]
456     >>> parse_matrix_expression('1.2rot(12)^{3}2B^T')
457     [[('1.2', 'rot(12)', '3'), ('2', 'B', 'T')]]
458     >>> parse_matrix_expression('A^2 + 3B')
459     [[(' ', 'A', '2')], [('3', 'B', ' ')]]
460     >>> parse_matrix_expression('-3A^{ -1}3B^T - 45M^2')
461     [[(' -3', 'A', ' -1'), ('3', 'B', 'T')], [(' -45', 'M', '2')]]
462     >>> parse_matrix_expression('5.3A^{4} 2.6B^{ -2} + 4.6D^T 8.9E^{ -1}')
463     [[('5.3', 'A', '4'), ('2.6', 'B', ' -2')], [('4.6', 'D', 'T'), ('8.9', 'E', ' -1')]]
464     >>> parse_matrix_expression('2(A+B^TC)^2D')
465     [[('2', 'A+B^TC', '2'), (' ', 'D', ' ')]]
466
467     :param str expression: The expression to be parsed
468     :returns: A list of parsed components
469     :rtype: :attr:`~lintrans.typing_.MatrixParseList`
470     """
471     return ExpressionParser(expression).parse()
472
473
474 def get_matrix_identifiers(expression: str) -> Set[str]:
475     """Return all the matrix identifiers used in the given expression.
476
477     This method works recursively with sub-expressions.
478     """
479     s = set()
480     top_level = [id for sublist in parse_matrix_expression(expression) for _, id, _ in sublist]
481
482     for body in top_level:
483         if body in _ALPHABET:
484             s.add(body)
485
486         elif re.match(r'rot\((\d+(\.\d+)?)\)', body):
487             continue
488
489         else:
490             s.update(get_matrix_identifiers(body))
491
492     return s

```

## A.23 typing\_/\_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This package supplies type aliases for linear algebra and transformations.
8
9  .. note::
10     This package is called ``typing_`` and not ``typing`` to avoid name collisions with the
11     builtin :mod:`typing`. I don't quite know how this collision occurs, but renaming
12     this module fixed the problem.
13 """
14
15 from __future__ import annotations
16
17 from sys import version_info
18 from typing import Any, List, Tuple
19
20 from nptyping import Float, NDArray, Shape
21 from numpy import ndarray
22
23 if version_info >= (3, 10):
24     from typing import TypeAlias, TypeGuard
25
26 __all__ = ['is_matrix_type', 'MatrixType', 'MatrixParseList', 'VectorType']
27
28 MatrixType: TypeAlias = NDArray[Shape['2', '2'], Float]
29 """This type represents a 2x2 matrix as a NumPy array."""
30
31 VectorType: TypeAlias = NDArray[Shape['2'], Float]
32 """This type represents a 2D vector as a NumPy array, for use with :attr:`MatrixType`."""
33
34 MatrixParseList: TypeAlias = List[List[Tuple[str, str, str]]]
35 """This is a list containing lists of tuples. Each tuple represents a matrix and is ``(multiplier,
36 matrix_identifier, index)`` where all of them are strings. These matrix-representing tuples are
37 contained in lists which represent multiplication groups. Every matrix in the group should be
38 multiplied together, in order. These multiplication group lists are contained by a top level list,
39 which is this type. Once these multiplication group lists have been evaluated, they should be summed.
40
41 In the tuples, the multiplier is a string representing a real number, the matrix identifier
42 is a capital letter or ``rot(x)`` where x is a real number angle, and the index is a string
43 representing an integer, or it's the letter ``T`` for transpose.
44 """
45
46
47 def is_matrix_type(matrix: Any) -> TypeGuard[MatrixType]:
48     """Check if the given value is a valid matrix type.
49
50     .. note::
51         This function is a TypeGuard, meaning if it returns True, then the
52         passed value must be a :attr:`MatrixType`.
53     """
54     return isinstance(matrix, ndarray) and matrix.shape == (2, 2)

```

## B Testing code

### B.1 conftest.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """A simple ``conftest.py`` containing some re-usable fixtures and functions."""
8
9  import numpy as np
10 import pytest
11
12 from lintrans.matrices import MatrixWrapper
13
14
15 def get_test_wrapper() -> MatrixWrapper:
16     """Return a new MatrixWrapper object with some preset values."""
17     wrapper = MatrixWrapper()
18
19     root_two_over_two = np.sqrt(2) / 2
20
21     wrapper['A'] = np.array([[1, 2], [3, 4]])
22     wrapper['B'] = np.array([[6, 4], [12, 9]])
23     wrapper['C'] = np.array([[-1, -3], [4, -12]])
24     wrapper['D'] = np.array([[13.2, 9.4], [-3.4, -1.8]])
25     wrapper['E'] = np.array([
26         [root_two_over_two, -1 * root_two_over_two],
27         [root_two_over_two, root_two_over_two]
28     ])
29     wrapper['F'] = np.array([[-1, 0], [0, 1]])
30     wrapper['G'] = np.array([[np.pi, np.e], [1729, 743.631]])
31
32     return wrapper
33
34
35 @pytest.fixture
36 def test_wrapper() -> MatrixWrapper:
37     """Return a new MatrixWrapper object with some preset values."""
38     return get_test_wrapper()
39
40
41 @pytest.fixture
42 def new_wrapper() -> MatrixWrapper:
43     """Return a new MatrixWrapper with no initialized values."""
44     return MatrixWrapper()

```

### B.2 backend/test\_session.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test the functionality of saving and loading sessions."""
8
9  from pathlib import Path
10
11 from conftest import get_test_wrapper
12
13 import lintrans
14 from lintrans.gui.session import Session
15 from lintrans.gui.settings import DisplaySettings
16 from lintrans.matrices.wrapper import MatrixWrapper
17

```

```

18
19 def test_save_and_load(tmp_path: Path, test_wrapper: MatrixWrapper) -> None:
20     """Test that sessions save and load and return the same matrix wrapper."""
21     points = [(1, 0), (-2, 3), (3.2, -10), (0, 0), (-2, -3), (2, -1.3)]
22     session = Session(
23         matrix_wrapper=test_wrapper,
24         polygon_points=points,
25         display_settings=DisplaySettings(),
26         input_vector=(2, 3)
27     )
28
29     path = str((tmp_path / 'test.lt').absolute())
30     session.save_to_file(path)
31
32     loaded_session, version, extra_attrs = Session.load_from_file(path)
33     assert loaded_session.matrix_wrapper == get_test_wrapper()
34     assert loaded_session.polygon_points == points
35     assert loaded_session.display_settings == DisplaySettings()
36     assert loaded_session.input_vector == (2, 3)
37
38     assert version == lintrans.__version__
39     assert not extra_attrs

```

### B.3 backend/matrices/test\_parse\_and\_validate\_expression.py

```

1 # lintrans - The linear transformation visualizer
2 # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4 # This program is licensed under GNU GPLv3, available here:
5 # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7 """Test the :mod:`matrices.parse` module validation and parsing."""
8
9 from typing import List, Tuple
10
11 import pytest
12
13 from lintrans.matrices.parse import (MatrixParseError, find_sub_expressions,
14                                     get_matrix_identifiers,
15                                     parse_matrix_expression, strip_whitespace,
16                                     validate_matrix_expression)
17 from lintrans.typing import MatrixParseList
18
19 expected_sub_expressions: List[Tuple[str, List[str]]] = [
20     ('2(AB)^-1', ['AB']),
21     ('-3(A+B)^2-C(B^TA)^-1', ['A+B', 'B^TA']),
22     ('rot(45)', []),
23     ('()', []),
24     ('()', ['()']),
25     ('2.3A^-1(AB)^-1+(BC)^2', ['AB', 'BC']),
26     ('(2.3A^-1(AB)^-1+(BC)^2)', ['2.3A^-1(AB)^-1+(BC)^2']),
27     ('(2.3 A^-1 (A B)^-1 + (B C)^2)', ['2.3A^-1(AB)^-1+(BC)^2']),
28     ('A([1 2; 3 4]M^T)^2', ['[1 2;3 4]M^T']),
29     ('[1 2; -3 -1]', []),
30 ]
31
32
33 def test_find_sub_expressions() -> None:
34     """Test the :func:`lintrans.matrices.parse.find_sub_expressions` function."""
35     for inp, output in expected_sub_expressions:
36         assert find_sub_expressions(inp) == output
37
38
39 expected_stripped_whitespace: List[Tuple[str, str]] = [
40     ('[ 1 2 ; 3 4 ]', '[1 2;3 4]'),
41     ('[-3.4 6; 1.2 -9 ]', '[-3.4 6;1.2 -9]'),
42     ('A    4 [ 43      -653.23    ; 32523    -4.3 ] Z^2', 'A4[43 -653.23;32523 -4.3]Z^2'),
43     ('[ 1 2; -4    3.64]    [-5 6; 8.3 2]', '[1 2;-4 3.64][-5 6;8.3 2]')
44 ]
45

```

```

46
47 def test_strip_whitespace() -> None:
48     """Test the :func:`lintrans.matrices.parse.strip_whitespace` function."""
49     for inp, output in expected_stripped_whitespace:
50         assert strip_whitespace(inp) == output
51
52
53 valid_inputs: List[str] = [
54     'A', 'AB', '3A', '1.2A', '-3.4A', 'A^2', 'A~-1', 'A^{-1}',
55     'A^12', 'A^T', 'A^{5}', 'A^{T}', '4.3A^7', '9.2A^{18}', '0.1A'
56
57     'rot(45)', 'rot(12.5)', '3rot(90)',
58     'rot(135)^3', 'rot(51)^T', 'rot(-34)^-1',
59
60     'A+B', 'A+2B', '4.3A+9B', 'A^2+B^T', '3A^7+0.8B^{16}',
61     'A-B', '3A-4B', '3.2A^3-16.79B^T', '4.752A^{17}-3.32B^{36}',
62     'A-1B', '-A', '-1A', 'A^{2}3.4B', 'A^{-1}2.3B',
63
64     '3A4B', 'A^TB', 'A^{T}B', '4A^6B^3',
65     '2A^{3}4B^5', '4rot(90)^3', 'rot(45)rot(13)',
66     'Arot(90)', 'AB^2', 'A^2B^2', '8.36A^T3.4B^12',
67
68     '3.5A^{4}5.6rot(19.2)^T-B^{-1}4.1C^5',
69
70     '(A)', '(AB)^-1', '2.3(3B^TA)^2', '-3.4(9D^{2}3F~-1)^T+C', '(AB)(C)',
71     '3(rot(34)^~7A)^-1+B', '3A^2B+4A(B+C)^-1D^T-A(C(D+E)B)',
72
73     '[1 2; 3 4]', '4[1 -2;12 5]^3', '[1 -2; 3.1 -4.1365]', 'A[1 -3; 4 5]^~1',
74     'rot(45)[-13.2 9;1.414 0]^2M^T', '([1 2; 3 4])', '3A^2(M-B^T)^{-1}18([13.2 -6.4; -11 0.2]+F)^2'
75 ]
76
77 invalid_inputs: List[str] = [
78     '', 'rot()', 'A^', 'A^1.2', 'A^2 3.4B', 'A^23.4B', 'A~-1 2.3B', 'A^{3.4}', '1,2A', 'ro(12)', '5', '12^2',
79     '^T', '^12}', '.1A', 'A^{13}', 'A^3}', 'A^A', '^2', 'A--B', '--A', '+A', '--1A', 'A--B', 'A--1B',
80     '.A', '1.A', '2.3AB^T', '(AB+)', '-4.6(9A', '-2(3.4A^{~-1}-C^)^2', '9.2)', '3A^2B+4A(B+C)^-1D^T-A(C(D+EB)',
81     '3)^~2', '4(your mum)^T', 'rot()', 'rot(10.1.1)', 'rot(--2)', '[ ]', '[1 2]', '[-1;3]', '[2 3; 5.6]',
82     '1 2; 3 4', '[1 2; 34]', '[1 2 3; 4 5]', '[1 2 3; 4 5 6]', '[;]', '[1; 2 3 4]',
83
84     'This is 100% a valid matrix expression, I swear'
85 ]
86
87
88 @pytest.mark.parametrize('inputs,output', [(valid_inputs, True), (invalid_inputs, False)])
89 def test_validate_matrix_expression(inputs: List[str], output: bool) -> None:
90     """Test the validate_matrix_expression() function."""
91     for inp in inputs:
92         assert validate_matrix_expression(inp) == output
93
94
95 expressions_and_parsed_expressions: List[Tuple[str, MatrixParseList]] = [
96     # Simple expressions
97     ('A', [[(' ', 'A', ' ')]]),
98     ('A^2', [[(' ', 'A', '2')]]),
99     ('A^{2}', [[(' ', 'A', '2')]]),
100     ('3A', [[('3', 'A', ' ')]]),
101     ('1.4A^3', [[('1.4', 'A', '3')]]),
102     ('0.1A', [[('0.1', 'A', ' ')]]),
103     ('0.1A', [[('0.1', 'A', ' ')]]),
104     ('A^12', [[(' ', 'A', '12')]]),
105     ('A^234', [[(' ', 'A', '234')]]),
106
107     # Multiplications
108     ('A 0.1B', [[(' ', 'A', ' '), ('0.1', 'B', ' ')]]),
109     ('A^2 3B', [[(' ', 'A', '23'), (' ', 'B', ' ')]]),
110     ('A^{2}3.4B', [[(' ', 'A', '2'), ('3.4', 'B', ' ')]]),
111     ('4A^{3} 6B^2', [[('4', 'A', '3'), ('6', 'B', '2')]]),
112     ('4.2A^{T} 6.1B~-1', [[('4.2', 'A', 'T'), ('6.1', 'B', '-1')]]),
113     ('-1.2A^2 rot(45)^2', [[('~-1.2', 'A', '2'), (' ', 'rot(45)', '2')]]),
114     ('3.2A^T 4.5B^{5} 9.6rot(121.3)', [[('3.2', 'A', 'T'), ('4.5', 'B', '5'), ('9.6', 'rot(121.3)', ' ')]]),
115     ('-1.18A^{~-2} 0.1B^{2} 9rot(-34.6)^-1', [[('~-1.18', 'A', '-2'), ('0.1', 'B', '2'), ('9', 'rot(-34.6)', '-1')]]),
116
117     # Additions
118     ('A + B', [[(' ', 'A', ' '), (' ', 'B', ' ')]]),

```

```

119 ('A + B - C', [[(' ', 'A', ''), (' ', 'B', ''), ('-1', 'C', '')]]),
120 ('A^2 + 0.5B', [[(' ', 'A', '2'), ('0.5', 'B', '')]]),
121 ('2A^3 + 8B^T - 3C^-1', [[('2', 'A', '3'), ('8', 'B', 'T'), ('-3', 'C', '-1')]]),
122 ('4.9A^2 - 3rot(134.2)^-1 + 7.6B^8', [[('4.9', 'A', '2'), ('-3', 'rot(134.2)', '-1'), ('7.6', 'B', '8')]]),
123 ('3A^2-3B', [[('3', 'A', '2'), ('-3', 'B', '')]]),
124 (
125     '3MA^2-15B^TT',
126     [
127         [ ('3', 'M', ''), (' ', 'A', '2') ],
128         [ ('-15', 'B', 'T'), (' ', 'T', '') ]
129     ]
130 ),
131
132 # Additions with multiplication
133 ('2.14A^3 4.5rot(14.5)^-1 + 8B^T - 3C^-1', [[('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'),
134                                             [ ('8', 'B', 'T'), ('-3', 'C', '-1') ] ]),
135 ('2.14A^3 4.5rot(14.5)^-1 + 8.5B^T 5.97C^14 - 3.14D^-1 6.7E^T',
136  [ [ ('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1') ], [ ('8.5', 'B', 'T'), ('5.97', 'C', '14') ],
137  [ ('-3.14', 'D', '-1'), ('6.7', 'E', 'T') ] ]),
138
139 # Parenthesized expressions
140 ('(AB)^-1', [[(' ', 'AB', '-1')]]),
141 ('-3(A+B)^2-C(B^TA)^-1', [[('3', 'A+B', '2'), ('-1', 'C', ''), (' ', 'B^TA', '-1')]]),
142 ('2.3(3B^TA)^2', [[('2.3', '3B^TA', '2')]]),
143 ('-3.4(9D^2)3F^-1)^T+C', [[('3.4', '9D^2)3F^-1', 'T'), (' ', 'C', '')]]),
144 ('2.39(3.1A^-1)2.3B(CD)^-1)^T + (AB^T)^-1', [[('2.39', '3.1A^-1)2.3B(CD)^-1', 'T'), (' ', 'AB^T',
145  ↳ '-1')]]),
146
147 # Anonymous matrices
148 ('[1 2; 3 4]', [[(' ', '[1 2; 3 4]', '')]]),
149 ('A[-3 4; 16.2 87.93]', [[(' ', 'A', ''), (' ', '[-3 4; 16.2 87.93]', '')]]),
150 (
151     '3A^2(M- [ 1 2 ; 5 4 ]^T)^-1 18([13.2 -6.4; -11 0.2]+F)^2+Z',
152     [
153         [ ('3', 'A', '2'), (' ', 'M+1[1 2; 5 4]^T', '-1'), ('18', '[13.2 -6.4; -11 0.2]+F', '2') ],
154         [ (' ', 'Z', '') ]
155     ]
156 ),
157 ('[1 2; -3 -1]^2', [[(' ', '[1 2; -3 -1]', '2')]]),
158 ('[1 2; -3 -1]^-1', [[(' ', '[1 2; -3 -1]', '-1')]]),
159 ('[1 2; -3 -1]^-1', [[(' ', '[1 2; -3 -1]', '-1')]]),
160 (
161     '3M[1 2; -3 -1]^2-[-5 6; 8.3 2]^TT',
162     [
163         [ ('3', 'M', ''), (' ', '[1 2; -3 -1]', '2') ],
164         [ ('-1', '[-5 6; 8.3 2]', 'T'), (' ', 'T', '') ]
165     ]
166 ),
167 (
168     '3M[1 2; -3 -1]^2-15[-5 6; 8.3 2]^TT',
169     [
170         [ ('3', 'M', ''), (' ', '[1 2; -3 -1]', '2') ],
171         [ ('-15', '[-5 6; 8.3 2]', 'T'), (' ', 'T', '') ]
172     ]
173 ),
174
175 def test_parse_matrix_expression() -> None:
176     """Test the parse_matrix_expression() function."""
177     for expression, parsed_expression in expressions_and_parsed_expressions:
178         # Test it with and without whitespace
179         assert parse_matrix_expression(expression) == parsed_expression
180         assert parse_matrix_expression(strip_whitespace(expression)) == parsed_expression
181
182     for expression in valid_inputs:
183         # Assert that it doesn't raise MatrixParseError
184         parse_matrix_expression(expression)
185
186
187 def test_parse_error() -> None:
188     """Test that parse_matrix_expression() raises a MatrixParseError."""
189     for expression in invalid_inputs:
190         with pytest.raises(MatrixParseError):

```



```

191         parse_matrix_expression(expression)
192
193
194 def test_get_matrix_identifiers() -> None:
195     """Test that matrix identifiers can be properly found."""
196     assert get_matrix_identifiers('M^T') == {'M'}
197     assert get_matrix_identifiers('ABCDEF') == {'A', 'B', 'C', 'D', 'E', 'F'}
198     assert get_matrix_identifiers('AB^{ -1}3Crot(45)2A(B^2C^{ -1})') == {'A', 'B', 'C'}
199     assert get_matrix_identifiers('A^{2}3A^{ -1}A^TA') == {'A'}
200     assert get_matrix_identifiers('rot(45)(rot(25)rot(20))^{2}') == set()
201
202     for expression in invalid_inputs:
203         with pytest.raises(MatrixParseError):
204             get_matrix_identifiers(expression)

```

## B.4 backend/matrices/utility/test\_coord\_conversion.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2022 D. Dyson (DoctorDalek1963)
3  #
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test conversion between polar and rectilinear coordinates in :mod:`lintrans.matrices.utility`."""
8
9  from typing import List, Tuple
10
11  from numpy import pi, sqrt
12  from pytest import approx
13
14  from lintrans.matrices.utility import polar_coords, rect_coords
15
16  expected_coords: List[Tuple[Tuple[float, float], Tuple[float, float]]] = [
17      ((0, 0), (0, 0)),
18      ((1, 1), (sqrt(2), pi / 4)),
19      ((0, 1), (1, pi / 2)),
20      ((1, 0), (1, 0)),
21      ((sqrt(2), sqrt(2)), (2, pi / 4)),
22      ((-3, 4), (5, 2.214297436)),
23      ((4, -3), (5, 5.639684198)),
24      ((5, -0.2), (sqrt(626) / 5, 6.24320662)),
25      ((-1.3, -10), (10.08414597, 4.583113976)),
26      ((23.4, 0), (23.4, 0)),
27      ((pi, -pi), (4.442882938, 1.75 * pi))
28  ]
29
30
31 def test_polar_coords() -> None:
32     """Test that :func:`lintrans.matrices.utility.polar_coords` works as expected."""
33     for rect, polar in expected_coords:
34         assert polar_coords(*rect) == approx(polar)
35
36
37 def test_rect_coords() -> None:
38     """Test that :func:`lintrans.matrices.utility.rect_coords` works as expected."""
39     for rect, polar in expected_coords:
40         assert rect_coords(*polar) == approx(rect)
41
42     assert rect_coords(1, 0) == approx((1, 0))
43     assert rect_coords(1, pi) == approx((-1, 0))
44     assert rect_coords(1, 2 * pi) == approx((1, 0))
45     assert rect_coords(1, 3 * pi) == approx((-1, 0))
46     assert rect_coords(1, 4 * pi) == approx((1, 0))
47     assert rect_coords(1, 5 * pi) == approx((-1, 0))
48     assert rect_coords(1, 6 * pi) == approx((1, 0))
49     assert rect_coords(20, 100) == approx(rect_coords(20, 100 % (2 * pi)))

```

## B.5 backend/matrices/utility/test\_float\_utility\_functions.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test the utility functions for GUI dialog boxes."""
8
9  from typing import List, Tuple
10
11  import numpy as np
12  import pytest
13
14  from lintrans.matrices.utility import is_valid_float, round_float
15
16  valid_floats: List[str] = [
17      '0', '1', '3', '-2', '123', '-208', '1.2', '-3.5', '4.252634', '-42362.352325',
18      '1e4', '-2.59e3', '4.13e-6', '-5.5244e-12'
19  ]
20
21  invalid_floats: List[str] = [
22      '', 'pi', 'e', '1.2.3', '1,2', '-', '.', 'None', 'no', 'yes', 'float'
23  ]
24
25
26  @pytest.mark.parametrize('inputs,output', [(valid_floats, True), (invalid_floats, False)])
27  def test_is_valid_float(inputs: List[str], output: bool) -> None:
28      """Test the is_valid_float() function."""
29      for inp in inputs:
30          assert is_valid_float(inp) == output
31
32
33  def test_round_float() -> None:
34      """Test the round_float() function."""
35      expected_values: List[Tuple[float, int, str]] = [
36          (1.0, 4, '1'), (1e-6, 4, '0'), (1e-5, 6, '1e-5'), (6.3e-8, 5, '0'), (3.2e-8, 10, '3.2e-8'),
37          (np.sqrt(2) / 2, 5, '0.70711'), (-1 * np.sqrt(2) / 2, 5, '-0.70711'),
38          (np.pi, 1, '3.1'), (np.pi, 2, '3.14'), (np.pi, 3, '3.142'), (np.pi, 4, '3.1416'), (np.pi, 5, '3.14159'),
39          (1.23456789, 2, '1.23'), (1.23456789, 3, '1.235'), (1.23456789, 4, '1.2346'), (1.23456789, 5, '1.23457'),
40          (12345.678, 1, '12345.7'), (12345.678, 2, '12345.68'), (12345.678, 3, '12345.678'),
41      ]
42
43      for num, precision, answer in expected_values:
44          assert round_float(num, precision) == answer

```

## B.6 backend/matrices/utility/test\_rotation\_matrices.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test functions for rotation matrices."""
8
9  from typing import List, Tuple
10
11  import numpy as np
12  import pytest
13
14  from lintrans.matrices import create_rotation_matrix
15  from lintrans.typing_ import MatrixType
16
17  angles_and_matrices: List[Tuple[float, float, MatrixType]] = [
18      (0, 0, np.array([[1, 0], [0, 1]])),
19      (90, np.pi / 2, np.array([[0, -1], [1, 0]])),
20      (180, np.pi, np.array([[ -1, 0], [0, -1]])),

```

```

21     (270, 3 * np.pi / 2, np.array([[0, 1], [-1, 0]])),
22     (360, 2 * np.pi, np.array([[1, 0], [0, 1]])),
23
24     (45, np.pi / 4, np.array([
25         [np.sqrt(2) / 2, -1 * np.sqrt(2) / 2],
26         [np.sqrt(2) / 2, np.sqrt(2) / 2]
27     ])),
28     (135, 3 * np.pi / 4, np.array([
29         [-1 * np.sqrt(2) / 2, -1 * np.sqrt(2) / 2],
30         [np.sqrt(2) / 2, -1 * np.sqrt(2) / 2]
31     ])),
32     (225, 5 * np.pi / 4, np.array([
33         [-1 * np.sqrt(2) / 2, np.sqrt(2) / 2],
34         [-1 * np.sqrt(2) / 2, -1 * np.sqrt(2) / 2]
35     ])),
36     (315, 7 * np.pi / 4, np.array([
37         [np.sqrt(2) / 2, np.sqrt(2) / 2],
38         [-1 * np.sqrt(2) / 2, np.sqrt(2) / 2]
39     ])),
40
41     (30, np.pi / 6, np.array([
42         [np.sqrt(3) / 2, -1 / 2],
43         [1 / 2, np.sqrt(3) / 2]
44     ])),
45     (60, np.pi / 3, np.array([
46         [1 / 2, -1 * np.sqrt(3) / 2],
47         [np.sqrt(3) / 2, 1 / 2]
48     ])),
49     (120, 2 * np.pi / 3, np.array([
50         [-1 / 2, -1 * np.sqrt(3) / 2],
51         [np.sqrt(3) / 2, -1 / 2]
52     ])),
53     (150, 5 * np.pi / 6, np.array([
54         [-1 * np.sqrt(3) / 2, -1 / 2],
55         [1 / 2, -1 * np.sqrt(3) / 2]
56     ])),
57     (210, 7 * np.pi / 6, np.array([
58         [-1 * np.sqrt(3) / 2, 1 / 2],
59         [-1 / 2, -1 * np.sqrt(3) / 2]
60     ])),
61     (240, 4 * np.pi / 3, np.array([
62         [-1 / 2, np.sqrt(3) / 2],
63         [-1 * np.sqrt(3) / 2, -1 / 2]
64     ])),
65     (300, 10 * np.pi / 6, np.array([
66         [1 / 2, np.sqrt(3) / 2],
67         [-1 * np.sqrt(3) / 2, 1 / 2]
68     ])),
69     (330, 11 * np.pi / 6, np.array([
70         [np.sqrt(3) / 2, 1 / 2],
71         [-1 / 2, np.sqrt(3) / 2]
72     ]))
73 ]
74
75
76 def test_create_rotation_matrix() -> None:
77     """Test that create_rotation_matrix() works with given angles and expected matrices."""
78     for degrees, radians, matrix in angles_and_matrices:
79         assert create_rotation_matrix(degrees, degrees=True) == pytest.approx(matrix)
80         assert create_rotation_matrix(radians, degrees=False) == pytest.approx(matrix)
81
82         assert create_rotation_matrix(-1 * degrees, degrees=True) == pytest.approx(np.linalg.inv(matrix))
83         assert create_rotation_matrix(-1 * radians, degrees=False) == pytest.approx(np.linalg.inv(matrix))
84
85     assert (create_rotation_matrix(-90, degrees=True) ==
86             create_rotation_matrix(270, degrees=True)).all()
87     assert (create_rotation_matrix(-0.5 * np.pi, degrees=False) ==
88             create_rotation_matrix(1.5 * np.pi, degrees=False)).all()

```

**B.7 backend/matrices/matrix\_wrapper/test\_evaluate\_expression.py**

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test the MatrixWrapper evaluate_expression() method."""
8
9  import numpy as np
10 import pytest
11 from confest import get_test_wrapper
12 from numpy import linalg as la
13 from pytest import approx
14
15 from lintrans.matrices import MatrixWrapper, create_rotation_matrix
16 from lintrans.typing_ import MatrixType
17
18
19 def test_simple_matrix_addition(test_wrapper: MatrixWrapper) -> None:
20     """Test simple addition and subtraction of two matrices."""
21     # NOTE: We assert that all of these values are not None just to stop mypy complaining
22     # These values will never actually be None because they're set in the wrapper() fixture
23     # There's probably a better way do this, because this method is a bit of a bodge, but this works for now
24     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
25         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
26         test_wrapper['G'] is not None
27
28     assert (test_wrapper.evaluate_expression('A+B') == test_wrapper['A'] + test_wrapper['B']).all()
29     assert (test_wrapper.evaluate_expression('E+F') == test_wrapper['E'] + test_wrapper['F']).all()
30     assert (test_wrapper.evaluate_expression('G+D') == test_wrapper['G'] + test_wrapper['D']).all()
31     assert (test_wrapper.evaluate_expression('C+C') == test_wrapper['C'] + test_wrapper['C']).all()
32     assert (test_wrapper.evaluate_expression('D+A') == test_wrapper['D'] + test_wrapper['A']).all()
33     assert (test_wrapper.evaluate_expression('B+C') == test_wrapper['B'] + test_wrapper['C']).all()
34
35     assert test_wrapper == get_test_wrapper()
36
37
38 def test_simple_two_matrix_multiplication(test_wrapper: MatrixWrapper) -> None:
39     """Test simple multiplication of two matrices."""
40     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
41         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
42         test_wrapper['G'] is not None
43
44     assert (test_wrapper.evaluate_expression('AB') == test_wrapper['A'] @ test_wrapper['B']).all()
45     assert (test_wrapper.evaluate_expression('BA') == test_wrapper['B'] @ test_wrapper['A']).all()
46     assert (test_wrapper.evaluate_expression('AC') == test_wrapper['A'] @ test_wrapper['C']).all()
47     assert (test_wrapper.evaluate_expression('DA') == test_wrapper['D'] @ test_wrapper['A']).all()
48     assert (test_wrapper.evaluate_expression('ED') == test_wrapper['E'] @ test_wrapper['D']).all()
49     assert (test_wrapper.evaluate_expression('FD') == test_wrapper['F'] @ test_wrapper['D']).all()
50     assert (test_wrapper.evaluate_expression('GA') == test_wrapper['G'] @ test_wrapper['A']).all()
51     assert (test_wrapper.evaluate_expression('CF') == test_wrapper['C'] @ test_wrapper['F']).all()
52     assert (test_wrapper.evaluate_expression('AG') == test_wrapper['A'] @ test_wrapper['G']).all()
53
54     assert test_wrapper.evaluate_expression('A2B') == approx((test_wrapper['A'] @ (2 * test_wrapper['B'])))
55     assert test_wrapper.evaluate_expression('2AB') == approx((2 * test_wrapper['A']) @ test_wrapper['B'])
56     assert test_wrapper.evaluate_expression('C3D') == approx((test_wrapper['C'] @ (3 * test_wrapper['D'])))
57     assert test_wrapper.evaluate_expression('4.2E1.2A') == approx((4.2 * test_wrapper['E']) @ (1.2 *
58         ↪ test_wrapper['A']))
59
60     assert test_wrapper == get_test_wrapper()
61
62
63 def test_identity_multiplication(test_wrapper: MatrixWrapper) -> None:
64     """Test that multiplying by the identity doesn't change the value of a matrix."""
65     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
66         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
67         test_wrapper['G'] is not None
68
69     assert (test_wrapper.evaluate_expression('I') == test_wrapper['I']).all()
70     assert (test_wrapper.evaluate_expression('AI') == test_wrapper['A']).all()

```

```

70     assert (test_wrapper.evaluate_expression('IA') == test_wrapper['A']).all()
71     assert (test_wrapper.evaluate_expression('GI') == test_wrapper['G']).all()
72     assert (test_wrapper.evaluate_expression('IG') == test_wrapper['G']).all()
73
74     assert (test_wrapper.evaluate_expression('EID') == test_wrapper['E'] @ test_wrapper['D']).all()
75     assert (test_wrapper.evaluate_expression('IED') == test_wrapper['E'] @ test_wrapper['D']).all()
76     assert (test_wrapper.evaluate_expression('EDI') == test_wrapper['E'] @ test_wrapper['D']).all()
77     assert (test_wrapper.evaluate_expression('IEIDI') == test_wrapper['E'] @ test_wrapper['D']).all()
78     assert (test_wrapper.evaluate_expression('EI^3D') == test_wrapper['E'] @ test_wrapper['D']).all()
79
80     assert test_wrapper == get_test_wrapper()
81
82
83 def test_simple_three_matrix_multiplication(test_wrapper: MatrixWrapper) -> None:
84     """Test simple multiplication of two matrices."""
85     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
86         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
87         test_wrapper['G'] is not None
88
89     assert (test_wrapper.evaluate_expression('ABC') == test_wrapper['A'] @ test_wrapper['B'] @
90         ↪ test_wrapper['C']).all()
91     assert (test_wrapper.evaluate_expression('ACB') == test_wrapper['A'] @ test_wrapper['C'] @
92         ↪ test_wrapper['B']).all()
93     assert (test_wrapper.evaluate_expression('BAC') == test_wrapper['B'] @ test_wrapper['A'] @
94         ↪ test_wrapper['C']).all()
95     assert (test_wrapper.evaluate_expression('EFG') == test_wrapper['E'] @ test_wrapper['F'] @
96         ↪ test_wrapper['G']).all()
97     assert (test_wrapper.evaluate_expression('DAC') == test_wrapper['D'] @ test_wrapper['A'] @
98         ↪ test_wrapper['C']).all()
99     assert (test_wrapper.evaluate_expression('GAE') == test_wrapper['G'] @ test_wrapper['A'] @
100         ↪ test_wrapper['E']).all()
101     assert (test_wrapper.evaluate_expression('FAG') == test_wrapper['F'] @ test_wrapper['A'] @
102         ↪ test_wrapper['G']).all()
103     assert (test_wrapper.evaluate_expression('GAF') == test_wrapper['G'] @ test_wrapper['A'] @
104         ↪ test_wrapper['F']).all()
105
106     assert test_wrapper == get_test_wrapper()
107
108
109 def test_matrix_inverses(test_wrapper: MatrixWrapper) -> None:
110     """Test the inverses of single matrices."""
111     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
112         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
113         test_wrapper['G'] is not None
114
115     assert (test_wrapper.evaluate_expression('A^{-1}') == la.inv(test_wrapper['A'])).all()
116     assert (test_wrapper.evaluate_expression('B^{-1}') == la.inv(test_wrapper['B'])).all()
117     assert (test_wrapper.evaluate_expression('C^{-1}') == la.inv(test_wrapper['C'])).all()
118     assert (test_wrapper.evaluate_expression('D^{-1}') == la.inv(test_wrapper['D'])).all()
119     assert (test_wrapper.evaluate_expression('E^{-1}') == la.inv(test_wrapper['E'])).all()
120     assert (test_wrapper.evaluate_expression('F^{-1}') == la.inv(test_wrapper['F'])).all()
121     assert (test_wrapper.evaluate_expression('G^{-1}') == la.inv(test_wrapper['G'])).all()
122
123     assert (test_wrapper.evaluate_expression('A^{-1}') == la.inv(test_wrapper['A'])).all()
124     assert (test_wrapper.evaluate_expression('B^{-1}') == la.inv(test_wrapper['B'])).all()
125     assert (test_wrapper.evaluate_expression('C^{-1}') == la.inv(test_wrapper['C'])).all()
126     assert (test_wrapper.evaluate_expression('D^{-1}') == la.inv(test_wrapper['D'])).all()
127     assert (test_wrapper.evaluate_expression('E^{-1}') == la.inv(test_wrapper['E'])).all()
128     assert (test_wrapper.evaluate_expression('F^{-1}') == la.inv(test_wrapper['F'])).all()
129     assert (test_wrapper.evaluate_expression('G^{-1}') == la.inv(test_wrapper['G'])).all()
130
131     assert test_wrapper == get_test_wrapper()
132
133
134 def test_matrix_powers(test_wrapper: MatrixWrapper) -> None:
135     """Test that matrices can be raised to integer powers."""
136     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
137         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
138         test_wrapper['G'] is not None
139
140     assert (test_wrapper.evaluate_expression('A^2') == la.matrix_power(test_wrapper['A'], 2)).all()
141     assert (test_wrapper.evaluate_expression('B^4') == la.matrix_power(test_wrapper['B'], 4)).all()
142     assert (test_wrapper.evaluate_expression('C^{12}') == la.matrix_power(test_wrapper['C'], 12)).all()

```

```

135     assert (test_wrapper.evaluate_expression('D^12') == la.matrix_power(test_wrapper['D'], 12)).all()
136     assert (test_wrapper.evaluate_expression('E^8') == la.matrix_power(test_wrapper['E'], 8)).all()
137     assert (test_wrapper.evaluate_expression('F^-6') == la.matrix_power(test_wrapper['F'], -6)).all()
138     assert (test_wrapper.evaluate_expression('G^-2') == la.matrix_power(test_wrapper['G'], -2)).all()
139
140     assert test_wrapper == get_test_wrapper()
141
142
143 def test_matrix_transpose(test_wrapper: MatrixWrapper) -> None:
144     """Test matrix transpositions."""
145     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
146            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
147            test_wrapper['G'] is not None
148
149     assert (test_wrapper.evaluate_expression('A^T') == test_wrapper['A'].T).all()
150     assert (test_wrapper.evaluate_expression('B^T') == test_wrapper['B'].T).all()
151     assert (test_wrapper.evaluate_expression('C^T') == test_wrapper['C'].T).all()
152     assert (test_wrapper.evaluate_expression('D^T') == test_wrapper['D'].T).all()
153     assert (test_wrapper.evaluate_expression('E^T') == test_wrapper['E'].T).all()
154     assert (test_wrapper.evaluate_expression('F^T') == test_wrapper['F'].T).all()
155     assert (test_wrapper.evaluate_expression('G^T') == test_wrapper['G'].T).all()
156
157     assert (test_wrapper.evaluate_expression('A^T') == test_wrapper['A'].T).all()
158     assert (test_wrapper.evaluate_expression('B^T') == test_wrapper['B'].T).all()
159     assert (test_wrapper.evaluate_expression('C^T') == test_wrapper['C'].T).all()
160     assert (test_wrapper.evaluate_expression('D^T') == test_wrapper['D'].T).all()
161     assert (test_wrapper.evaluate_expression('E^T') == test_wrapper['E'].T).all()
162     assert (test_wrapper.evaluate_expression('F^T') == test_wrapper['F'].T).all()
163     assert (test_wrapper.evaluate_expression('G^T') == test_wrapper['G'].T).all()
164
165     assert test_wrapper == get_test_wrapper()
166
167
168 def test_rotation_matrices(test_wrapper: MatrixWrapper) -> None:
169     """Test that 'rot(angle)' can be used in an expression."""
170     assert (test_wrapper.evaluate_expression('rot(90)') == create_rotation_matrix(90)).all()
171     assert (test_wrapper.evaluate_expression('rot(180)') == create_rotation_matrix(180)).all()
172     assert (test_wrapper.evaluate_expression('rot(270)') == create_rotation_matrix(270)).all()
173     assert (test_wrapper.evaluate_expression('rot(360)') == create_rotation_matrix(360)).all()
174     assert (test_wrapper.evaluate_expression('rot(45)') == create_rotation_matrix(45)).all()
175     assert (test_wrapper.evaluate_expression('rot(30)') == create_rotation_matrix(30)).all()
176
177     assert (test_wrapper.evaluate_expression('rot(13.43)') == create_rotation_matrix(13.43)).all()
178     assert (test_wrapper.evaluate_expression('rot(49.4)') == create_rotation_matrix(49.4)).all()
179     assert (test_wrapper.evaluate_expression('rot(-123.456)') == create_rotation_matrix(-123.456)).all()
180     assert (test_wrapper.evaluate_expression('rot(963.245)') == create_rotation_matrix(963.245)).all()
181     assert (test_wrapper.evaluate_expression('rot(-235.24)') == create_rotation_matrix(-235.24)).all()
182
183     assert test_wrapper == get_test_wrapper()
184
185
186 def test_multiplication_and_addition(test_wrapper: MatrixWrapper) -> None:
187     """Test multiplication and addition of matrices together."""
188     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
189            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
190            test_wrapper['G'] is not None
191
192     assert (test_wrapper.evaluate_expression('AB+C') ==
193            test_wrapper['A'] @ test_wrapper['B'] + test_wrapper['C']).all()
194     assert (test_wrapper.evaluate_expression('DE-D') ==
195            test_wrapper['D'] @ test_wrapper['E'] - test_wrapper['D']).all()
196     assert (test_wrapper.evaluate_expression('FD+AB') ==
197            test_wrapper['F'] @ test_wrapper['D'] + test_wrapper['A'] @ test_wrapper['B']).all()
198     assert (test_wrapper.evaluate_expression('BA-DE') ==
199            test_wrapper['B'] @ test_wrapper['A'] - test_wrapper['D'] @ test_wrapper['E']).all()
200
201     assert (test_wrapper.evaluate_expression('2AB+3C') ==
202            (2 * test_wrapper['A'] @ test_wrapper['B'] + (3 * test_wrapper['C'])).all()
203     assert (test_wrapper.evaluate_expression('4D7.9E-1.2A') ==
204            (4 * test_wrapper['D'] @ (7.9 * test_wrapper['E']) - (1.2 * test_wrapper['A'])).all()
205
206     assert test_wrapper == get_test_wrapper()
207

```

```

208
209 def test_complicated_expressions(test_wrapper: MatrixWrapper) -> None:
210     """Test evaluation of complicated expressions."""
211     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
212            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
213            test_wrapper['G'] is not None
214
215     assert (test_wrapper.evaluate_expression('-3.2A^T 4B^{-1} 6C^{-1} + 8.1D^{2} 3.2E^4') ==
216            (-3.2 * test_wrapper['A'].T) @ (4 * la.inv(test_wrapper['B'])) @ (6 * la.inv(test_wrapper['C']))
217            + (8.1 * la.matrix_power(test_wrapper['D'], 2)) @ (3.2 * la.matrix_power(test_wrapper['E'], 4))).all()
218
219     assert (test_wrapper.evaluate_expression('53.6D^{2} 3B^T - 4.9F^{2} 2D + A^3 B^{-1}') ==
220            (53.6 * la.matrix_power(test_wrapper['D'], 2)) @ (3 * test_wrapper['B'].T)
221            - (4.9 * la.matrix_power(test_wrapper['F'], 2)) @ (2 * test_wrapper['D'])
222            + la.matrix_power(test_wrapper['A'], 3) @ la.inv(test_wrapper['B'])).all()
223
224     assert test_wrapper == get_test_wrapper()
225
226
227 def test_parenthesized_expressions(test_wrapper: MatrixWrapper) -> None:
228     """Test evaluation of parenthesized expressions."""
229     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
230            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
231            test_wrapper['G'] is not None
232
233     assert (test_wrapper.evaluate_expression('(A^T)^2') == la.matrix_power(test_wrapper['A'].T, 2)).all()
234     assert (test_wrapper.evaluate_expression('(B^T)^3') == la.matrix_power(test_wrapper['B'].T, 3)).all()
235     assert (test_wrapper.evaluate_expression('(C^T)^4') == la.matrix_power(test_wrapper['C'].T, 4)).all()
236     assert (test_wrapper.evaluate_expression('(D^T)^5') == la.matrix_power(test_wrapper['D'].T, 5)).all()
237     assert (test_wrapper.evaluate_expression('(E^T)^6') == la.matrix_power(test_wrapper['E'].T, 6)).all()
238     assert (test_wrapper.evaluate_expression('(F^T)^7') == la.matrix_power(test_wrapper['F'].T, 7)).all()
239     assert (test_wrapper.evaluate_expression('(G^T)^8') == la.matrix_power(test_wrapper['G'].T, 8)).all()
240
241     assert (test_wrapper.evaluate_expression('(rot(45)^1)^T') == create_rotation_matrix(45).T).all()
242     assert (test_wrapper.evaluate_expression('(rot(45)^2)^T') == la.matrix_power(create_rotation_matrix(45),
243            ↪ 2).T).all()
244     assert (test_wrapper.evaluate_expression('(rot(45)^3)^T') == la.matrix_power(create_rotation_matrix(45),
245            ↪ 3).T).all()
246     assert (test_wrapper.evaluate_expression('(rot(45)^4)^T') == la.matrix_power(create_rotation_matrix(45),
247            ↪ 4).T).all()
248     assert (test_wrapper.evaluate_expression('(rot(45)^5)^T') == la.matrix_power(create_rotation_matrix(45),
249            ↪ 5).T).all()
250
251     assert (test_wrapper.evaluate_expression('D^3(A+6.2F-0.397G^TE)^{-2+A}') ==
252            la.matrix_power(test_wrapper['D'], 3) @ la.matrix_power(
253            test_wrapper['A'] + 6.2 * test_wrapper['F'] - 0.397 * test_wrapper['G'].T @ test_wrapper['E'],
254            -2
255            ) + test_wrapper['A']).all()
256
257     assert (test_wrapper.evaluate_expression('-1.2F^{3}4.9D^T(A^2(B+3E^TF)^{-1})^2') ==
258            -1.2 * la.matrix_power(test_wrapper['F'], 3) @ (4.9 * test_wrapper['D'].T) @
259            la.matrix_power(
260            la.matrix_power(test_wrapper['A'], 2) @ la.matrix_power(
261            test_wrapper['B'] + 3 * test_wrapper['E'].T @ test_wrapper['F'],
262            -1
263            ),
264            2
265            )).all()
266
267
268 def test_anonymous_matrices(test_wrapper: MatrixWrapper) -> None:
269     """Test that anonymous matrices get evaluated correctly."""
270     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
271            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
272            test_wrapper['G'] is not None
273
274     assert (test_wrapper.evaluate_expression('[1 2; -3 -1]') == np.array([[1, 2], [-3, -1]])).all()
275     assert (test_wrapper.evaluate_expression('[1 2; -3 -1][-5 6; 8.3 2]') ==
276            np.array([[1, 2], [-3, -1]]) @ np.array([[ -5, 6], [8.3, 2]])).all()
277     assert (test_wrapper.evaluate_expression('[1 2; -3 -1]^~1') == la.inv(np.array([[1, 2], [-3, -1]]))).all()
278     assert (test_wrapper.evaluate_expression('3A[1 2; -3 -1]^2-15[-5 6; 8.3 2]^TB') ==
279            3 * test_wrapper['A'] @ la.matrix_power(np.array([[1, 2], [-3, -1]]), 2)
280            - 15 * np.array([[ -5, 8.3], [6, 2]]) @ test_wrapper['B']).all()

```

```

277
278
279 def test_value_errors(test_wrapper: MatrixWrapper) -> None:
280     """Test that evaluate_expression() raises a ValueError for any malformed input."""
281     invalid_expressions = ['', '+', '-', 'This is not a valid expression', '3+4',
282                             'A+2', 'A^', '^2', 'A^-', 'At', 'A^t', '3^2']
283
284     for expression in invalid_expressions:
285         with pytest.raises(ValueError):
286             test_wrapper.evaluate_expression(expression)
287
288
289 def test_linalgerror() -> None:
290     """Test that certain expressions raise np.linalg.LinAlgError."""
291     matrix_a: MatrixType = np.array([
292         [0, 0],
293         [0, 0]
294     ])
295
296     matrix_b: MatrixType = np.array([
297         [1, 2],
298         [1, 2]
299     ])
300
301     wrapper = MatrixWrapper()
302     wrapper['A'] = matrix_a
303     wrapper['B'] = matrix_b
304
305     assert (wrapper.evaluate_expression('A') == matrix_a).all()
306     assert (wrapper.evaluate_expression('B') == matrix_b).all()
307
308     with pytest.raises(np.linalg.LinAlgError):
309         wrapper.evaluate_expression('A^-1')
310
311     with pytest.raises(np.linalg.LinAlgError):
312         wrapper.evaluate_expression('B^-1')
313
314     assert (wrapper['A'] == matrix_a).all()
315     assert (wrapper['B'] == matrix_b).all()

```

## B.8 backend/matrices/matrix\_wrapper/test\_setting\_and\_getting.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """Test the MatrixWrapper __setitem__() and __getitem__() methods."""
8
9  from typing import Any, Dict, List
10
11  import numpy as np
12  import pytest
13  from numpy import linalg as la
14
15  from lintrans.matrices import MatrixWrapper
16  from lintrans.typing import MatrixType
17
18  valid_matrix_names = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
19  invalid_matrix_names = ['bad name', '123456', 'Th15 Is an 1nV@l1D n@m3', 'abc', 'a']
20
21  test_matrix: MatrixType = np.array([[1, 2], [4, 3]])
22
23
24  def test_basic_get_matrix(new_wrapper: MatrixWrapper) -> None:
25     """Test MatrixWrapper().__getitem__()."""
26     for name in valid_matrix_names:
27         assert new_wrapper[name] is None
28

```



```

29     assert (new_wrapper['I'] == np.array([[1, 0], [0, 1]])).all()
30
31
32 def test_get_name_error(new_wrapper: MatrixWrapper) -> None:
33     """Test that MatrixWrapper().__getitem__() raises a NameError if called with an invalid name."""
34     for name in invalid_matrix_names:
35         with pytest.raises(NameError):
36             _ = new_wrapper[name]
37
38
39 def test_basic_set_matrix(new_wrapper: MatrixWrapper) -> None:
40     """Test MatrixWrapper().__setitem__()"""
41     for name in valid_matrix_names:
42         new_wrapper[name] = test_matrix
43         assert (new_wrapper[name] == test_matrix).all()
44
45         new_wrapper[name] = None
46         assert new_wrapper[name] is None
47
48
49 def test_set_expression(test_wrapper: MatrixWrapper) -> None:
50     """Test that MatrixWrapper.__setitem__() can accept a valid expression."""
51     test_wrapper['N'] = 'A^2'
52     test_wrapper['O'] = 'BA+2C'
53     test_wrapper['P'] = 'E^T'
54     test_wrapper['Q'] = 'C^-1B'
55     test_wrapper['R'] = 'A^{2}3B'
56     test_wrapper['S'] = 'N^-1'
57     test_wrapper['T'] = 'PQP^-1'
58
59     with pytest.raises(TypeError):
60         test_wrapper['U'] = 'A+1'
61
62     with pytest.raises(TypeError):
63         test_wrapper['V'] = 'K'
64
65     with pytest.raises(TypeError):
66         test_wrapper['W'] = 'L^2'
67
68     with pytest.raises(TypeError):
69         test_wrapper['X'] = 'M^-1'
70
71     with pytest.raises(TypeError):
72         test_wrapper['Y'] = 'A^2B+C^'
73
74
75 def test_simple_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
76     """Test that expression-defined matrices are evaluated dynamically."""
77     test_wrapper['N'] = 'A^2'
78     test_wrapper['O'] = '4B'
79     test_wrapper['P'] = 'A+C'
80
81     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
82     assert (test_wrapper['O'] == test_wrapper.evaluate_expression('4B')).all()
83     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
84
85     assert (test_wrapper.evaluate_expression('N^2 + 3O') ==
86             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
87             3 * test_wrapper.evaluate_expression('4B')
88             ).all()
89     assert (test_wrapper.evaluate_expression('P^-1 - 3N^2') ==
90             la.inv(test_wrapper.evaluate_expression('A+C')) -
91             (3 * test_wrapper.evaluate_expression('A^2')) @
92             la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
93             ).all()
94
95     test_wrapper['A'] = np.array([
96         [19, -21.5],
97         [84, 96.572]
98     ])
99     test_wrapper['B'] = np.array([
100         [-0.993, 2.52],
101         [1e10, 0]

```

```

102     ])
103     test_wrapper['C'] = np.array([
104         [0, 19512],
105         [1.414, 19]
106     ])
107
108     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
109     assert (test_wrapper['O'] == test_wrapper.evaluate_expression('4B')).all()
110     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
111
112     assert (test_wrapper.evaluate_expression('N^2 + 30') ==
113             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
114             3 * test_wrapper.evaluate_expression('4B')
115             ).all()
116     assert (test_wrapper.evaluate_expression('P^-1 - 3N0^2') ==
117             la.inv(test_wrapper.evaluate_expression('A+C')) -
118             (3 * test_wrapper.evaluate_expression('A^2')) @
119             la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
120             ).all()
121
122
123     def test_recursive_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
124         """Test that dynamic evaluation works recursively."""
125         test_wrapper['N'] = 'A^2'
126         test_wrapper['O'] = '4B'
127         test_wrapper['P'] = 'A+C'
128
129         test_wrapper['Q'] = 'N^-1'
130         test_wrapper['R'] = 'P-40'
131         test_wrapper['S'] = 'NOP'
132
133         assert test_wrapper['Q'] == pytest.approx(test_wrapper.evaluate_expression('A^-2'))
134         assert test_wrapper['R'] == pytest.approx(test_wrapper.evaluate_expression('A + C - 16B'))
135         assert test_wrapper['S'] == pytest.approx(test_wrapper.evaluate_expression('A^{2}4BA + A^{2}4BC'))
136
137
138     def test_self_referential_expressions(test_wrapper: MatrixWrapper) -> None:
139         """Test that self-referential expressions raise an error."""
140         expressions: Dict[str, str] = {
141             'A': 'A^2',
142             'B': 'A(C^-1A^T)+rot(45)B',
143             'C': '2Brot(1482.536)(A^-1D^{2}4CE)^3F'
144         }
145
146         for name, expression in expressions.items():
147             with pytest.raises(ValueError):
148                 test_wrapper[name] = expression
149
150         test_wrapper['B'] = '3A^2'
151         test_wrapper['C'] = 'ABBA'
152         with pytest.raises(ValueError):
153             test_wrapper['A'] = 'C^-1'
154
155         test_wrapper['E'] = 'rot(45)B^-1+C^T'
156         test_wrapper['F'] = 'EBDBIC'
157         test_wrapper['D'] = 'E'
158         with pytest.raises(ValueError):
159             test_wrapper['D'] = 'F'
160
161
162     def test_get_matrix_dependencies(test_wrapper: MatrixWrapper) -> None:
163         """Test MatrixWrapper's get_matrix_dependencies() and get_expression_dependencies() methods."""
164         test_wrapper['N'] = 'A^2'
165         test_wrapper['O'] = '4B'
166         test_wrapper['P'] = 'A+C'
167         test_wrapper['Q'] = 'N^-1'
168         test_wrapper['R'] = 'P-40'
169         test_wrapper['S'] = 'NOP'
170
171         assert test_wrapper.get_matrix_dependencies('A') == set()
172         assert test_wrapper.get_matrix_dependencies('B') == set()
173         assert test_wrapper.get_matrix_dependencies('C') == set()
174         assert test_wrapper.get_matrix_dependencies('D') == set()

```

```

175     assert test_wrapper.get_matrix_dependencies('E') == set()
176     assert test_wrapper.get_matrix_dependencies('F') == set()
177     assert test_wrapper.get_matrix_dependencies('G') == set()
178
179     assert test_wrapper.get_matrix_dependencies('N') == {'A'}
180     assert test_wrapper.get_matrix_dependencies('O') == {'B'}
181     assert test_wrapper.get_matrix_dependencies('P') == {'A', 'C'}
182     assert test_wrapper.get_matrix_dependencies('Q') == {'A', 'N'}
183     assert test_wrapper.get_matrix_dependencies('R') == {'A', 'B', 'C', 'O', 'P'}
184     assert test_wrapper.get_matrix_dependencies('S') == {'A', 'B', 'C', 'N', 'O', 'P'}
185
186     assert test_wrapper.get_expression_dependencies('ABC') == set()
187     assert test_wrapper.get_expression_dependencies('NOB') == {'A', 'B'}
188     assert test_wrapper.get_expression_dependencies('N^20^Trot(90)B^-1') == {'A', 'B'}
189     assert test_wrapper.get_expression_dependencies('NOP') == {'A', 'B', 'C'}
190     assert test_wrapper.get_expression_dependencies('NOPQ') == {'A', 'B', 'C', 'N'}
191     assert test_wrapper.get_expression_dependencies('NOPQR') == {'A', 'B', 'C', 'N', 'O', 'P'}
192     assert test_wrapper.get_expression_dependencies('NOPQRS') == {'A', 'B', 'C', 'N', 'O', 'P'}
193
194
195 def test_set_identity_error(new_wrapper: MatrixWrapper) -> None:
196     """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to the identity matrix."""
197     with pytest.raises(NameError):
198         new_wrapper['I'] = test_matrix
199
200
201 def test_set_name_error(new_wrapper: MatrixWrapper) -> None:
202     """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to an invalid name."""
203     for name in invalid_matrix_names:
204         with pytest.raises(NameError):
205             new_wrapper[name] = test_matrix
206
207
208 def test_set_type_error(new_wrapper: MatrixWrapper) -> None:
209     """Test that MatrixWrapper().__setitem__() raises a TypeError when trying to set a non-matrix."""
210     invalid_values: List[Any] = [
211         12,
212         [1, 2, 3, 4, 5],
213         [[1, 2], [3, 4]],
214         True,
215         24.3222,
216         'This is totally a matrix, I swear',
217         MatrixWrapper,
218         MatrixWrapper(),
219         np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]]),
220         np.eye(100)
221     ]
222
223     for value in invalid_values:
224         with pytest.raises(TypeError):
225             new_wrapper['M'] = value
226
227
228 def test_get_expression(test_wrapper: MatrixWrapper) -> None:
229     """Test the get_expression method of the MatrixWrapper class."""
230     test_wrapper['N'] = 'A^2'
231     test_wrapper['O'] = '4B'
232     test_wrapper['P'] = 'A+C'
233
234     test_wrapper['Q'] = 'N^-1'
235     test_wrapper['R'] = 'P-4O'
236     test_wrapper['S'] = 'NOP'
237
238     assert test_wrapper.get_expression('A') is None
239     assert test_wrapper.get_expression('B') is None
240     assert test_wrapper.get_expression('C') is None
241     assert test_wrapper.get_expression('D') is None
242     assert test_wrapper.get_expression('E') is None
243     assert test_wrapper.get_expression('F') is None
244     assert test_wrapper.get_expression('G') is None
245
246     assert test_wrapper.get_expression('N') == 'A^2'
247     assert test_wrapper.get_expression('O') == '4B'

```

```
248     assert test_wrapper.get_expression( 'P' ) == 'A+C'
249
250     assert test_wrapper.get_expression( 'Q' ) == 'N^-1'
251     assert test_wrapper.get_expression( 'R' ) == 'P-40'
252     assert test_wrapper.get_expression( 'S' ) == 'NOP'
```