

# lintrans

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# 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[19], 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’[20] 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 dragable 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.

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

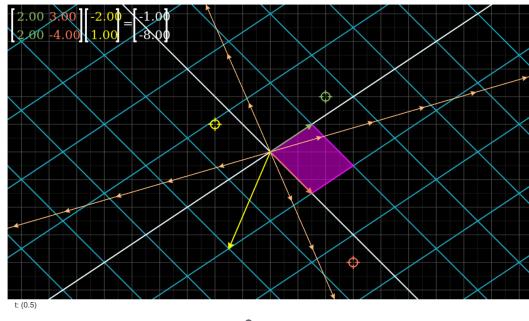


Figure 1.3.2: 'Linear Transformation Visualizer' halfway through an animation

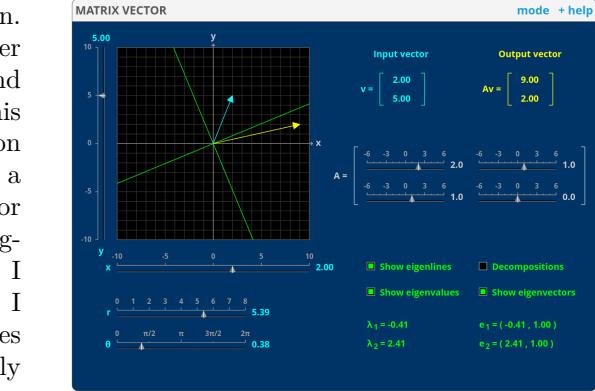


Figure 1.3.1: The MIT 'Matrix Vector' Mathlet

Another web app that I found was one simply called 'Linear Transformation Visualizer' by Shad Sharma[50]. 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 overcomplicated. 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.

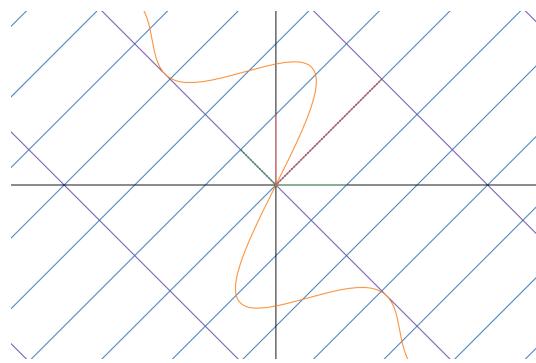


Figure 1.3.3: The Desmos app halfway through an animation, rendering  $f(x) = \frac{\sin^2 x}{x}$  in orange

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

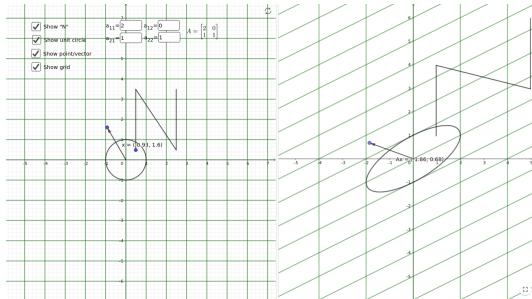


Figure 1.3.4: The GeoGebra applet rendering its default matrix

The last solution that I want to talk about is a GeoGebra applet simply titled 'Visualizing Linear Transformations'[22]. 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[38]

<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[40]

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.

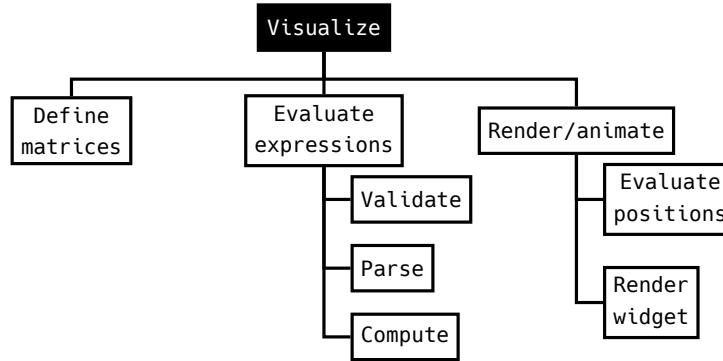
Transforming polygons is the lowest priority item on this list and will likely be implemented last, but it would definitely benefit learning. I wouldn't consider it necessary for success, but it would be very good to include, and it's certainly a feature that I want to have.

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.

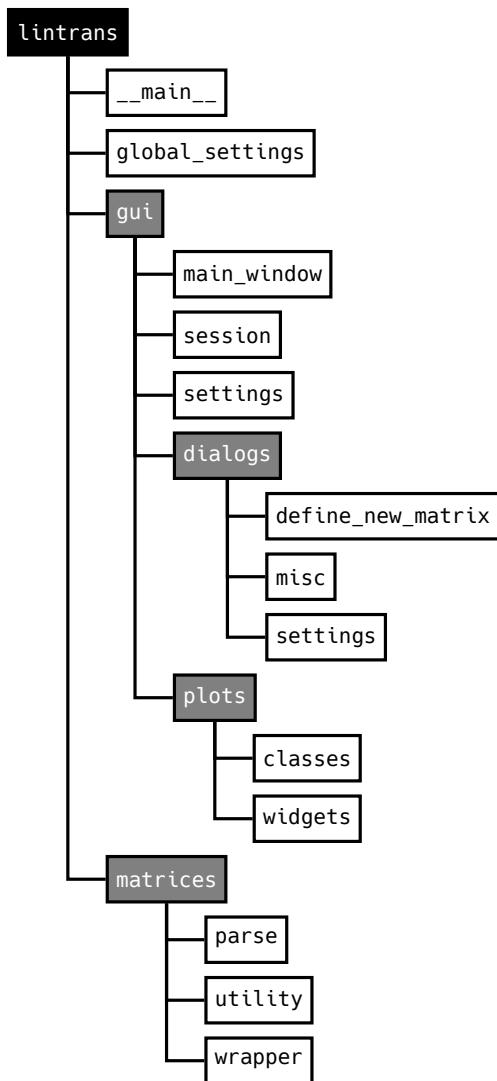
Evaluating expressions is another key part of the app and can be further broken down into validating, parsing, and computing the value. Validating an expression simply consists of checking that it adheres to a set of syntax rules for matrix expressions, and that it only contains matrices which have already 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 `DefineDialog` 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 and a lot of them will be related to drawing transformations on the canvas itself, but 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. The real implementations may be different from these initial plans.

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

```

1 import numpy as np // Python import
2
3 // Create a matrix representing a rotation (anticlockwise) by the given angle
4 function create_rotation_matrix(angle: float, degrees: bool = True) -> MatrixType
5     if (degrees) then
6         rad = np.deg2rad(angle MOD 360)
7     else
8         rad = angle MOD (2 * np.pi)
9     endif
10
11    return np.array([
12        [np.cos(rad), -1 * np.sin(rad)],
13        [np.sin(rad), np.cos(rad)]
14    ])
15 endfunction

```

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     // This is a hashmap from string to matrices, but the matrices might be null
9     private matrices: Dict[string, Optional[MatrixType]]
10
11    public procedure new()
12        matrices = {
13            "A": null, "B": null, "C": null, "D": null,
14            "E": null, "F": null, "G": null, "H": null,
15            "I": np.eye(2), // I is always defined as the identity matrix
16            "J": null, "K": null, "L": null, "M": null,
17            "N": null, "O": null, "P": null, "Q": null,
18            "R": null, "S": null, "T": null, "U": null,
19            "V": null, "W": null, "X": null, "Y": null,
20            "Z": null
21        }
22    endprocedure
23
24    // This is a Python "magic method", which enable syntax like `wrapper['A']` to get the matrix A
25    public function getitem(name: string) -> Optional[MatrixType]
26        // If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)``, with
27        // a given angle in degrees, then we return a new matrix representing a rotation by that angle
28
29        // Return a new rotation matrix
30        match = re.match(r"^\w+((\.\w+)*\.\w+)$", name)
31        if (match != null)
32            return create_rotation_matrix(float(match.group(1)))
33        endif
34
35        if (!matrices.contains(name))
36            raise NameError(f"Unrecognised matrix name '{name}'")
37        endif
38
39        return matrices[name]
40    endfunction
41
42    // Again, this is Python magic. This one allows assignments like `wrapper['A'] = my_matrix`
43    public procedure setitem(name: string, new_matrix: Optional[MatrixType])
44        // If new_matrix is null, then that effectively unsets the matrix name.
45
46        if (name == "I" OR !matrices.contains(name))
47            raise NameError("Matrix name is illegal")
48        endif
49
50        if (new_matrix == null)
51            matrices[name] = null
52            return
53        endif
54
55        if (!is_matrix_type(new_matrix))
56            raise TypeError("Matrix must be a 2x2 NumPy array")
57        endif
58
59        // All matrices must have float entries
60        a = float(new_matrix[0][0])
61        b = float(new_matrix[0][1])
62        c = float(new_matrix[1][0])
63        d = float(new_matrix[1][1])
64
65        matrices[name] = np.array([[a, b], [c, d]])
66    endprocedure
67 endclass

```

The `lintrans.gui.plots.classes` module will contain the following utility functions:

```

1 from PyQt5.QtGui import QPainter
2 from PyQt5.QtWidgets import QWidget
3
4 const DEFAULT_GRID_SPACING: int = 85
5
6 // This class will act as a baseclass for the viewport and visual defintion dialog.

```

```

7 // They will both use different subclasses of this class to visualize things on a grid.
8 // Canvas coordinates are the coordinates that Qt5 uses internally. These are standard
9 // computer graphics coordinates, with (0, 0) in the top left, positive x to the right,
10 // and positive y going down.
11 class BackgroundPlot extends QWidget
12     private grid_spacing: int
13
14     public procedure new()
15         super.new()
16
17         grid_spacing = DEFAULT_GRID_SPACING
18     endprocedure
19
20     // Return the canvas coordinates of the grid origin (centre)
21     private function canvas_origin() -> (int, int):
22         // width() and height() come from QWidget. They get the total width or height of the widget
23         return (width() DIV 2, height() DIV 2)
24     endfunction
25
26     // Convert an x coordinate from grid coords to canvas coords so it can be drawn
27     private function canvas_x(self, x: float) -> int
28         return int(canvas_origin()[0] + x * grid_spacing)
29     endfunction
30
31     // Convert an x coordinate from grid coords to canvas coords so it can be drawn
32     private function canvas_y(self, y: float) -> int
33         return int(canvas_origin()[1] - y * grid_spacing)
34     endfunction
35
36     // Convert a coordinate from grid coords to canvas coords
37     private function canvas_coords(x: float, y: float) -> (int, int)
38         return (canvas_x(x), canvas_y(y))
39     endfunction
40
41     // Find the grid coordinates of the top right corner. We use the top right because
42     // both coordinates will be positive
43     private function grid_corner() -> (float, float)
44         // Again, width() and height() come from QWidget
45         return (width() / (2 * grid_spacing), height() / (2 * grid_spacing))
46     endfunction
47
48     // Convert a coordinate from canvas coords to grid coords
49     private function grid_coords(x: int, y: int) -> (float, float)
50         return (
51             (x - canvas_origin[0]) / grid_spacing,
52             (-y + canvas_origin[1]) / grid_spacing
53         )
54     endfunction
55
56     // Draw the background grid. This method is meant to be used by subclasses when
57     // they paint their whole scene
58     private function draw_background(painter: QPainter)
59         // Draw equally spaced vertical lines, starting in the middle and going out
60         // We loop up to half the width because we draw one line on each side of the axis per iteration
61         for (int x = width() DIV 2 + grid_spacing; x < width(); x += grid_spacing)
62             painter.drawLine((x, 0), (x, height()))
63             painter.drawLine((width() - x, 0), (width() - x, height()))
64         next x
65
66         // Now do the same for horizontal lines
67         for (int y = height() DIV 2 + grid_spacing; y < height(); y += grid_spacing)
68             painter.drawLine((0, y), (width(), y))
69             painter.drawLine((0, height() - y), (width(), height() - y))
70         next y
71
72         // Now draw the axes
73         painter.drawLine((width() DIV 2, 0), (width() DIV 2, height()))
74         painter.drawLine((0, height() DIV 2), (width(), height() DIV 2))
75     endfunction
76 endclass

```

These modules handle the creation, storage, and use of matrices. Their implementations are deliber-

ately 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):

```

1  expression      ::= [ "-" ] matrices { ( "+" | "-" ) matrices };
2  matrices       ::= matrix { matrix };
3  matrix         ::= [ real_number ] matrix_identifier [ index ] | "(" expression ")";
4  matrix_identifier ::= "A" .. "Z" | "rot(" [ "-" ] real_number ")";
5  index          ::= "^{" index_content "}" | "^" index_content;
6  index_content  ::= [ "-" ] integer_not_zero | "T";
7
8  digit_no_zero ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
9  digit          ::= "0" | digit_no_zero;
10 digits         ::= digit | digits digit;
11 integer_not_zero ::= digit_no_zero [ digits ];
12 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 deutanopia[55], 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 deutanopia 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[26] 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.

---

<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

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 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

<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()`

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.

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

There is a Python library called `pytest`, which can be used to run unit tests[23]. Unit tests are automatic tests that I can run whenever I like[56]. I can also set these up to be run automatically by using GitHub Actions[15]. Doing this will make it easy to test my code, because I can write separate testing code which makes sure that all my backend functions work as intended. This testing code is easy to run, and can be run automatically after every change, so I know that my changes won't break previous behaviour. All the unit testing code is in appendix B.

Additionally, `pytest` supports doctests[24], which are unit tests written in the source code documentation[37]. These tests are typically small, simple examples used to demonstrate how to use a function to an end user of the API (in this case, me). It is important to test these examples to verify that the API is always correctly documented. I will use a few doctests for important functions, but I will mainly focus on unit tests.

In unit tests, 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, such as `is_valid_float()`, which is needed to verify input when defining a matrix visually. I will not be testing the GUI in unit tests, since this is almost impossible to do automatically. Instead, I will have to regularly test the GUI manually; 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.

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} 4.5\rot(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.

## 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[36] 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         """
32         return self._matrices[name]
33
34     def __setitem__(self, name: str, new_matrix: MatrixType) -> None:
35         """Set the value of matrix `name` with the new_matrix.
36
37         Raises:
38             ValueError:
39                 If `name` isn't a valid matrix name
40
41         """
42         name = name.upper()
43
44         if name == 'I' or name not in self._matrices:
45             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 = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
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 InV@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 InV@l1D n@m3'] = test_matrix
53     wrapper['abc'] = test_matrix

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 5 items

tests/test_matrix_wrapper.py::test_get_matrix PASSED [ 20%]
tests/test_matrix_wrapper.py::test_get_name_error PASSED [ 40%]
tests/test_matrix_wrapper.py::test_set_matrix PASSED [ 60%]
tests/test_matrix_wrapper.py::test_set_identity_error PASSED [ 80%]
tests/test_matrix_wrapper.py::test_set_name_error PASSED [100%]

===== 5 passed in 0.27s =====

```

Figure 3.1.1: Running `pytest` with the new tests

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  $\mathbf{I}$  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 `NameError` 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
41          # Return a new rotation matrix
42          match = re.match(r'rot\((\d+)\)', name)
43          if match is not None:
44              return create_rotation_matrix(float(match.group(1)))
45
46          # Return the transpose of this matrix
47          match = re.match(r'([A-Z])t', name)
48          if match is not None:
49              matrix = self[match.group(1)]
50
51          if matrix is not None:
52              return matrix.T
53          else:
54              return None
55
56          if name not in self._matrices:
57              raise NameError(f'Unrecognised matrix name "{name}"')
58
59      return self._matrices[name]
```

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
165      rad = np.deg2rad(angle)
166      return np.array([
167          [np.cos(rad), -1 * np.sin(rad)],
168          [np.sin(rad), np.cos(rad)]
169      ])
```

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:
...
33      def parse_expression(self, expression: str) -> MatrixType:
34          """Parse a given expression and return the matrix for that expression.
35
36          Expressions are written with standard LaTeX notation for exponents. All whitespace is ignored.
37
38          Here is documentation on syntax:
39          A single matrix is written as 'A'.
40          Matrix A multiplied by matrix B is written as 'AB'
41          Matrix A plus matrix B is written as 'A+B'
42          Matrix A minus matrix B is written as 'A-B'
43          Matrix A squared is written as 'A^2'
44          Matrix A to the power of 10 is written as 'A^10' or 'A^{10}'
45          The inverse of matrix A is written as 'A^-1' or 'A^{-1}'
46          The transpose of matrix A is written as 'A^T' or 'At'
47
48          :param str expression: The expression to be parsed
49          :returns MatrixType: The matrix result of the expression
50
51          :raises ValueError: If the expression is invalid, such as an empty string
52          """
53
54      if expression == '':
55          raise ValueError('The expression cannot be an empty string')
56
57      match = re.search(r'^-+A-Z\{\}rot()\d.', expression)
58      if match is not None:
59          raise ValueError(f'Invalid character "{match.group(0)}"')
60
61      # Remove all whitespace in the expression
62      expression = re.sub(r'\s', '', expression)
63
64      # Wrap all exponents and transposition powers with {}
65      expression = re.sub(r'(?<=^)(-?\d+|T)(?=[^])|$)', r'{\g<0>}', expression)
66
67      # Replace all subtractions with additions, multiplied by -1
68      expression = re.sub(r'(?<=.)-(?=[A-Z])', '+-1', expression)
69
70      # Replace a possible leading minus sign with -1
71      expression = re.sub(r'^-(?=[A-Z])', '-1', expression)
72
73      # Change all transposition exponents into lowercase
74      expression = expression.replace('^{T}', 't')
75
76      # Split the expression into groups to be multiplied, and then we add those groups at the end
77      # We also have to filter out the empty strings to reduce errors
78      multiplication_groups = [x for x in expression.split('+') if x != '']
79
80      # Start with the 0 matrix and add each group on
81      matrix_sum: MatrixType = np.array([[0., 0.], [0., 0.]])
82
83      for group in multiplication_groups:
84          # Generate a list of tuples, each representing a matrix
85          # These tuples are (the multiplier, the matrix (with optional
86          # 't' at the end to indicate a transpose), the exponent)
87          string_matrices: list[tuple[str, str, str]] =
88
89              # The generate tuple is (multiplier, matrix, full exponent, stripped exponent)
90              # The full exponent contains {}, so we ignore it
91              # The multiplier and exponent might be '', so we have to set them to '1'
92              string_matrices = [(t[0] if t[0] != '' else '1', t[1], t[3] if t[3] != '' else '1')
93                                for t in re.findall(r'(-?\d*\.\d*)([A-Z]t?|rot(\d+))(^\{(-?\d+|T)\})?', group)]
94
95              # This list is a list of tuple, where each tuple is (a float multiplier,
96              # the matrix (gotten from the wrapper's __getitem__()), the integer power)
97              matrices: list[tuple[float, MatrixType, int]] =
98                  matrices = [(float(t[0]), self[t[1]], int(t[2])) for t in string_matrices]
99
100             # Process the matrices and make actual MatrixType objects
101             processed_matrices: list[MatrixType] = [t[0] * np.linalg.matrix_power(t[1], t[2]) for t in matrices]
102
103             # Add this matrix product to the sum total
104             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 to 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()

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 12 items

tests/test_matrix_wrapper_parse_expression.py::test_simple_matrix_addition PASSED [ 8%]
tests/test_matrix_wrapper_parse_expression.py::test_simple_two_matrix_multiplication PASSED [ 16%]
tests/test_matrix_wrapper_parse_expression.py::test_identity_multiplication PASSED [ 25%]
tests/test_matrix_wrapper_parse_expression.py::test_simple_three_matrix_multiplication PASSED [ 33%]
tests/test_matrix_wrapper_parse_expression.py::test_matrix_inverses PASSED [ 41%]
tests/test_matrix_wrapper_parse_expression.py::test_matrix_powers PASSED [ 50%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_get_matrix PASSED [ 58%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_get_name_error PASSED [ 66%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_set_matrix PASSED [ 75%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_set_identity_error PASSED [ 83%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_set_name_error PASSED [ 91%]
tests/test_matrix_wrapper_setitem_and_getitem.py::test_set_type_error PASSED [100%]

===== 12 passed in 0.35s =====

```

Figure 3.1.2: Running `pytest` with the new tests

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.

```

# 39b918651f60bc72bc19d2018075b24a6fc3af1
# 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
55     match = valid_expression_pattern.match(expression)
56     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
13 class MatrixWrapper:
14 ...
15
16     def is_valid_expression(self, expression: str) -> bool:
17         """Check if the given expression is valid, using the context of the wrapper.
18
19         This method calls _parse.validate_matrix_expression(), but also ensures
20         that all the matrices in the expression are defined in the wrapper.
21
22         :param str expression: The expression to validate
23         :returns bool: Whether the expression is valid according to the schema
24 """
25
26         # Get rid of the transposes to check all capital letters
27         expression = re.sub(r'\^T', 't', expression)
28         expression = re.sub(r'\^{T}', 't', expression)
29
30         # Make sure all the referenced matrices are defined
31         for matrix in {x for x in expression if re.match('[A-Z]', x)}:
32             if self[matrix] is None:
33                 return False
34
35         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}', 'A^{12}', 'A^T', 'A^{5}', 'A^{T}', '4.3A^7', '9.2A^{18}', 'rot(45)', 'rot(12.5)', '3rot(90)', 'rot(135)^3', 'rot(51)^T', 'rot(-34)^{-1}', 'A+B', 'A+2B', '4.3A+9B', 'A^2+B^T', '3A^7+0.8B^{16}', 'A-B', '3A-4B', '3.2A^3-16.79B^T', '4.752A^{17}-3.32B^{36}', 'A--1B', '-A', '--1A', '3A4B', 'A^TB', 'A^{T}B', '4A^6B^3', '2A^{3}4B^5', '4rot(90)^3', 'rot(45)rot(13)', 'Arot(90)', 'AB^2', 'A^2B^2', '8.36A^T3.4B^12', '3.5A^{4}5.6rot(19.2)^T-B^{-1}4.1C^5', ]
8
9
10
11
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22
23
24
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35
36

invalid_inputs: list[str] = [
    '', 'rot()', 'A^', 'A^{1.2}', 'A^{3.4}', '1,2A', 'ro(12)', '5', '12^2', '^T', '{12}', 'A^{13}', 'A^3', 'A^A', '^2', 'A--B', '--A'
    'This is 100% a valid matrix expression, I swear'
]

@pytest.mark.parametrize('inputs,output', [(valid_inputs, True), (invalid_inputs, False)])
def test_validate_matrix_expression(inputs: list[str], output: bool) -> None:
    """Test the validate_matrix_expression() function."""
    for inp in inputs:
        assert validate_matrix_expression(inp) == output

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 18 items

tests/_parse/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 5%]
tests/_parse/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 11%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED [ 16%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 22%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 27%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 33%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 38%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 44%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 50%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 55%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 61%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 66%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_matrix PASSED [ 72%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 77%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_matrix PASSED [ 83%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 88%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 94%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [100%]

===== 18 passed in 0.31s =====

```

Figure 3.1.3: Running pytest with the new tests

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.

While I was adding tests, I added new doctests for the `MatrixWrapper` class and `create_rotation_matrix()` function.

```
# 6db1a1a1b3deaa30b1a8d23bb66ff738a3f212d2
# src/lintrans/matrices/wrapper.py

21 class MatrixWrapper:
22     """A simple wrapper class to hold all possible matrices and allow access to them.
23
24     The contained matrices can be accessed with square bracket notation.
25
26     :Example:
27
28     >>> wrapper = MatrixWrapper()
29     >>> wrapper['I']
30     array([[1., 0.],
31            [0., 1.]])
32     >>> wrapper['M'] # Returns None
33     >>> wrapper['M'] = np.array([[1, 2], [3, 4]])
34     >>> wrapper['M']
35     array([[1., 2.],
36            [3., 4.]])
37
38     Methods:
39     is_valid_expression(expression: str) -> bool:
40         Check if the given expression is valid, using the context of the wrapper.
41
42     evaluate_expression(expression: str) -> MatrixType:
43         Evaluate a given expression and return the matrix for that expression.
44     """

# e79664861434059eb2b27a38310a140e00c6432b
# src/lintrans/matrices/wrapper.py

227 def create_rotation_matrix(angle: float, degrees: bool = True) -> MatrixType:
228     """Create a matrix representing a rotation by the given angle (anticlockwise).
229
230     :Example:
231
232     >>> create_rotation_matrix(30)
233     array([[ 0.8660254, -0.5       ],
234            [ 0.5       ,  0.8660254]])
235     >>> create_rotation_matrix(45)
236     array([[ 0.70710678, -0.70710678],
237            [ 0.70710678,  0.70710678]])
238     >>> create_rotation_matrix(np.pi / 3, degrees=False)
239     array([[ 0.5       , -0.8660254],
240            [ 0.8660254,  0.5       ]])
241
242     :param float angle: The angle to rotate anticlockwise by
243     :param bool degrees: Whether to interpret the angle as degrees (True) or radians (False)
244     :returns MatrixType: The resultant rotation matrix
245     """

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *=]
$ pytest --doctest-modules src/ -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml
collected 2 items

src/lintrans/matrices/wrapper.py::lintrans.matrices.wrapper.MatrixWrapper PASSED [ 50%]
src/lintrans/matrices/wrapper.py::lintrans.matrices.wrapper.create_rotation_matrix PASSED [100%]

===== 2 passed in 0.28s =====
```

Figure 3.1.4: Running `pytest` with the new doctests

### 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

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 19 items

tests/_parse/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED
[ 5%]
tests/_parse/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED
[ 10%]
tests/_parse/test_parse_and_validate_expression.py::test_parse_matrix_expression SKIPPED (parse_matrix_expression() not implemented)
[ 15%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED
[ 21%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED
[ 26%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED
[ 31%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED
[ 36%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED
[ 42%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED
[ 47%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED
[ 52%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED
[ 57%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED
[ 63%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED
[ 68%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_matrix PASSED
[ 73%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED
[ 78%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_matrix PASSED
[ 84%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED
[ 89%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED
[ 94%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED
[100%]

===== 18 passed, 1 skipped in 0.33s =====
```

Figure 3.1.5: Running `pytest` with the new tests

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";
```

```

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'-(?=([A-Z])|\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:

```

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

```

22 `class MatrixWrapper:`

```

...
147     def evaluate_expression(self, expression: str) -> MatrixType:
148         """Evaluate a given expression and return the matrix for that expression.
149
150         Expressions are written with standard LaTeX notation for exponents. All whitespace is ignored.
151
152         Here is documentation on syntax:
153             A single matrix is written as a capital letter like 'A', or as 'rot(x)', where x is some angle in
154             degrees.
155                 Matrix A multiplied by matrix B is written as 'AB'
156                 Matrix A plus matrix B is written as 'A+B'
157                 Matrix A minus matrix B is written as 'A-B'
158                 Matrix A squared is written as 'A^2'
159                 Matrix A to the power of 10 is written as 'A^10' or 'A^{10}'
160                 The inverse of matrix A is written as 'A^-1' or 'A^{-1}'
161                 The transpose of matrix A is written as 'A^T' or 'At'
162                 Any matrix may be multiplied by a real constant, like '3A', or '1.2B'
163
164         :param str expression: The expression to be parsed
165         :returns MatrixType: The matrix result of the expression
166
167         :raises ValueError: If the expression is invalid
168         """
169
170     if not self.is_valid_expression(expression):
171         raise ValueError('The expression is invalid')
172
173     parsed_result = _parse.parse_matrix_expression(expression)
174     final_groups: list[list[MatrixType]] = []
175
176     for group in parsed_result:
177         f_group: list[MatrixType] = []
178
179         for matrix in group:
180             if matrix[2] == 'T':
181                 m = self[matrix[1]]
182                 assert m is not None
183                 matrix_value = m.T
184             else:
185                 matrix_value = np.linalg.matrix_power(self[matrix[1]],
186                                                     1 if (index := matrix[2]) == '' else int(index))
187
188             matrix_value *= 1 if (multiplier := matrix[0]) == '' else float(multiplier)
189             f_group.append(matrix_value)
190
191     final_groups.append(f_group)
192
193     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 display 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 new 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.setLayout(self.vlay_misc_buttons)
123    self.vlay_right.setLayout(self.vlay_define_new_matrix)
124    self.vlay_right.setLayout(self.vlay_render)
125
126    self.hlay_all = QHBoxLayout()
127    self.hlay_all.setSpacing(15)
128    self.hlay_all.setLayout(self.vlay_left)
129    self.hlay_all.setLayout(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()

```

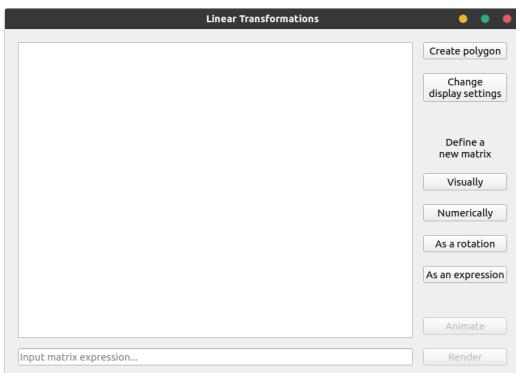


Figure 3.2.1: The first version of the GUI

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 = 'ABCDEFGHIJKLMNPQRSTUVWXYZ'
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
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
44     QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
45
46     self.button_cancel = QtWidgets.QPushButton(self)
47     self.button_cancel.setText('Cancel')
48     self.button_cancel.clicked.connect(self.close)
49     self.button_cancel.setToolTip('Cancel this definition<br><b>(Ctrl + Q)</b>')
50
51     QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Q'), self).activated.connect(self.button_cancel.click)
52
53     self.element_tl = QtWidgets.QLineEdit(self)
54     self.element_tl.textChanged.connect(self.update_confirm_button)
55
56     self.element_tr = QtWidgets.QLineEdit(self)
57     self.element_tr.textChanged.connect(self.update_confirm_button)
58
59     self.element_bl = QtWidgets.QLineEdit(self)
60     self.element_bl.textChanged.connect(self.update_confirm_button)
61
62     self.element_br = QtWidgets.QLineEdit(self)
63     self.element_br.textChanged.connect(self.update_confirm_button)
64
65     self.matrix_elements = (self.element_tl, self.element_tr, self.element_bl, self.element_br)
66
67     self.letter_combo_box = QtWidgets.QComboBox(self)
68
69     # Everything except I, because that's the identity
70     for letter in ALPHABET_NO_I:
71         self.letter_combo_box.addItem(letter)
72
73     self.letter_combo_box.activated.connect(self.load_matrix)
74
75     # === Arrange the widgets
76
77     self.setContentsMargins(10, 10, 10, 10)
78
79     self.grid_matrix = QGridLayout()
80     self.grid_matrix.setSpacing(20)
81     self.grid_matrix.addWidget(self.element_tl, 0, 0)
82     self.grid_matrix.addWidget(self.element_tr, 0, 1)
83     self.grid_matrix.addWidget(self.element_bl, 1, 0)
84     self.grid_matrix.addWidget(self.element_br, 1, 1)
85
86     self.hlay_buttons = QHBoxLayout()
87     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()

```

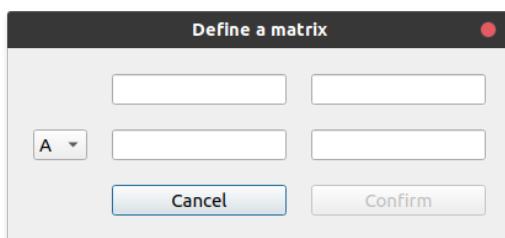


Figure 3.2.2: The first version of the numerical definition dialog

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):
...
15      def __init__(self):
...
16          self.button_define_numerically.clicked.connect(
17              lambda: DefineNumericallyDialog(self.matrix_wrapper, self).exec()
18      )
```

### 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)
```

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):
...
31         # === Arrange the widgets
32
33         self.setContentsMargins(10, 10, 10, 10)
34
35         self.horizontal_spacer = QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum)
36
37         self.hlay_buttons = QHBoxLayout()
38         self.hlay_buttons.setSpacing(20)
39         self.hlay_buttons.addItem(self.horizontal_spacer)
40         self.hlay_buttons.addWidget(self.button_cancel)
41         self.hlay_buttons.addWidget(self.button_confirm)
42
43     @property
44     def selected_letter(self) -> str:
45         """The letter currently selected in the combo box."""
46         return self.letter_combo_box.currentText()
47
48     @abc.abstractmethod
49     def update_confirm_button(self) -> None:
50         """Enable the confirm button if it should be enabled."""
51
52     ...
53
54     @abc.abstractmethod
55     def confirm_matrix(self) -> None:
56         """Confirm the inputted matrix and assign it.
57
58         This should mutate self.matrix_wrapper and then call self.accept().
59         """
60
61     ...
62
63     ...
64
65     ...
66
67     ...
68
69     ...
70
71     ...
72
73     ...
74
75     ...
76
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199
200
201
202
203
204
205
206
```

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.

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
18 class LintransMainWindow(QMainWindow):
...
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

```



Figure 3.2.3: The first version of the rotation definition dialog

```

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
207         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(DefineDialog):
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’[35], 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[31].

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 .. warning:: This class should never be directly instantiated, only subclassed.
18
19 .. note::
20     I would make this class have ``metaclass=abc.ABCMeta``, but I can't because it subclasses ``QWidget``,
21     and a every superclass of a class must have the same metaclass, and ``QWidget`` is not an abstract class.
22 """
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(TtransformationPlotWidget):
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)
```

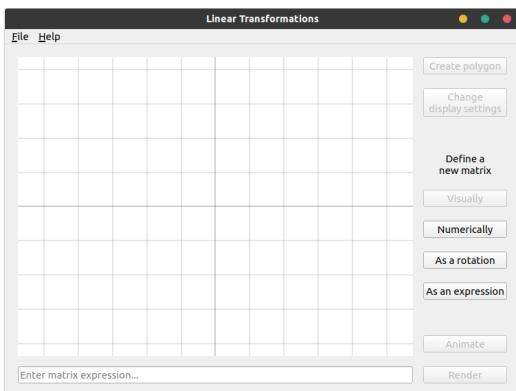


Figure 3.3.1: The GUI with background axes

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 `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()`.

```

# 37e7c208a33d7cbcc8e0bb6c94cd889e2918c605
# src/lintrans/gui/plots/plot_widget.py

92
93     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.

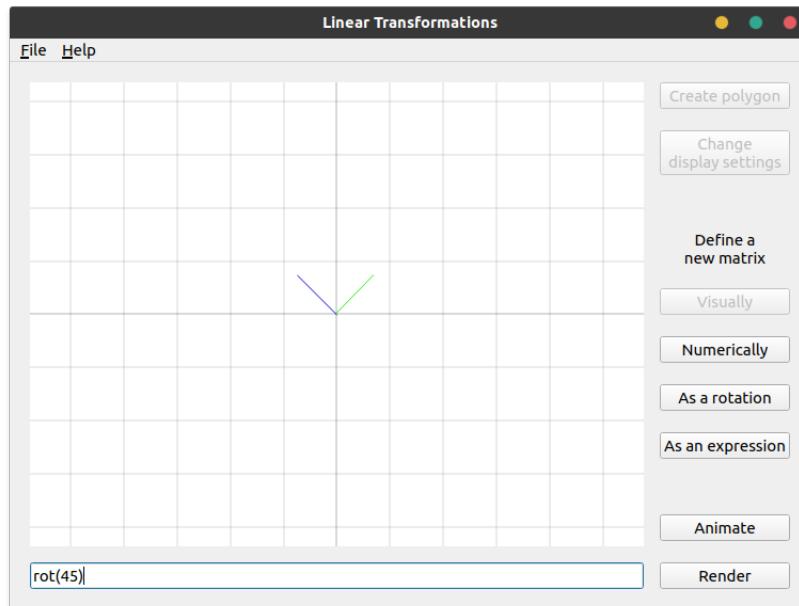
```

# 37e7c208a33d7cbcc8e0bb6c94cd889e2918c605
# src/lintrans/gui/main_window.py

19
20     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 3.3.2: 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]) ->
127         None:
128             """Draw a set of grid lines parallel to ``vector`` intersecting ``point``."""
129             max_x, max_y = self.grid_corner()
130             vector_x, vector_y = vector
131             point_x, point_y = point
132
133             if vector_x == 0:
134                 painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
135
136             for i in range(int(max_x / point_x)):
137                 painter.drawLine(
138                     self.trans_x((i + 1) * point_x),
139                     0,
                     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):
...
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 3.3.2.

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.

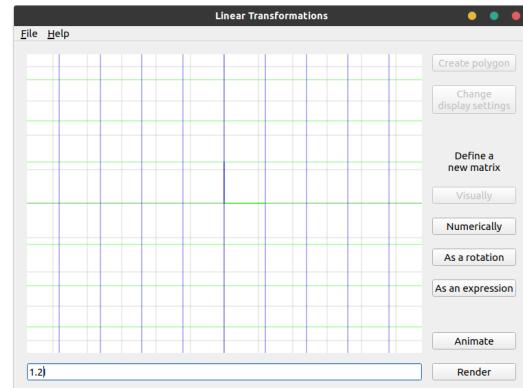


Figure 3.3.3: Parallel lines being drawn for matrix  $1.2\mathbf{I}$

```

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

```

```
96 class ViewTransformationWidget(TtransformationPlotWidget):
...
126     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
127         None:
128             """Draw a set of grid lines parallel to ``vector`` intersecting ``point``."""
129             max_x, max_y = self.grid_corner()
130             vector_x, vector_y = vector
131             point_x, point_y = point
132
133             print(max_x, max_y, vector_x, vector_y, point_x, point_y)
134
135             # We want to use  $y = mx + c$  but  $m = y / x$  and if either of those are 0, then this
136             # equation is harder to work with, so we deal with these edge cases first
137             if abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
138                 # If both components of the vector are practically 0, then we can't render any grid lines
139                 return
140
141             elif abs(vector_x) < 1e-12:
142                 painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
143
144                 for i in range(abs(int(max_x / point_x))):
145                     painter.drawLine(
146                         self.trans_x((i + 1) * point_x),
147                         0,
148                         self.trans_x((i + 1) * point_x),
149                         self.height()
150                     )
151                     painter.drawLine(
152                         self.trans_x(-1 * (i + 1) * point_x),
153                         0,
154                         self.trans_x(-1 * (i + 1) * point_x),
155                         self.height()
156                     )
157
158             elif abs(vector_y) < 1e-12:
159                 painter.drawLine(0, self.trans_y(0), self.width(), self.trans_y(0))
160
161                 for i in range(abs(int(max_y / point_y))):
162                     painter.drawLine(
163                         0,
164                         self.trans_y((i + 1) * point_y),
165                         self.width(),
166                         self.trans_y((i + 1) * point_y)
167                     )
168                     painter.drawLine(
169                         0,
170                         self.trans_y(-1 * (i + 1) * point_y),
171                         self.width(),
172                         self.trans_y(-1 * (i + 1) * point_y)
173                     )
174
175             else: # If the line is not horizontal or vertical, then we can use  $y = mx + c$ 
176                 m = vector_y / vector_x
177                 c = point_y - m * point_x
178
179                 # For c = 0
180                 painter.drawLine(
181                     *self.trans_coords(
182                         -1 * max_x,
183                         m * -1 * max_x
184                     ),
185                     *self.trans_coords(
186                         max_x,
187                         m * max_x
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.

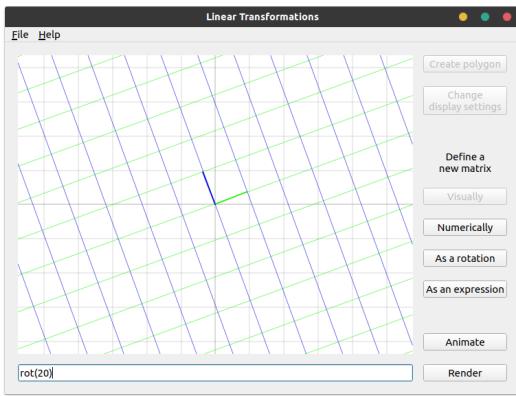


Figure 3.3.4: An example of a 20° rotation

### 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/mainwindow.py
```

```
20 class LintransMainWindow(QMainWindow):
```

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

```

...
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.

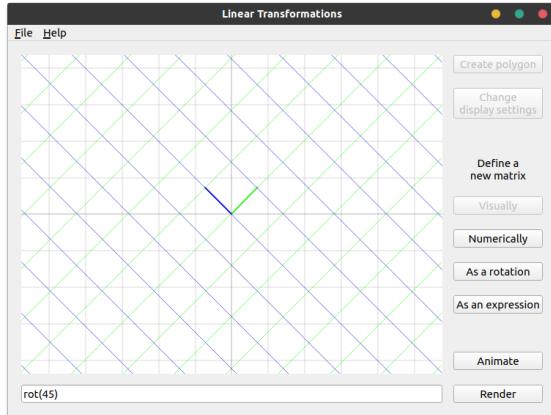


Figure 3.3.5: What we would expect halfway through a 90° rotation

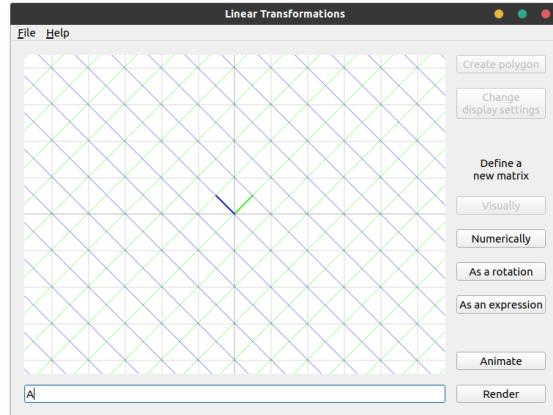


Figure 3.3.6: What we actually get halfway through a 90° rotation

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[27] 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  $d = \sqrt{\left| \frac{\det(\mathbf{T})}{\det(\mathbf{B})} \right|}$ . 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.lineEdit_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):
...
150     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
151         None:
...
203     else: # If the line is not horizontal or vertical, then we can use y = mx + c
204         m = vector_y / vector_x
205         c = point_y - m * point_x
206
207         # For c = 0
208         painter.drawLine(
209             *self.trans_coords(
210                 -1 * max_x,
211                 m * -1 * max_x
212             ),
213             *self.trans_coords(
214                 max_x,
215                 m * max_x
216             )
217         )
218
219         # We keep looping and increasing the multiple of c until we stop drawing lines on the canvas
220         multiple_of_c = 1
221         while self.draw_pair_of_oblique_lines(painter, m, multiple_of_c * c):
222             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):
...
224     def draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
225         """Draw a pair of oblique lines, using the equation y = mx + c.
226
227         This method just calls :meth:`draw_oblique_line` with ``c`` and ``-c``, and returns True if either call returned True.
228
229         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
230         :param float m: The gradient of the lines to draw
231         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
232         :returns bool: Whether we were able to draw any lines on the canvas
233
234         """
235
236         return any([
237             self.draw_oblique_line(painter, m, c),
238             self.draw_oblique_line(painter, m, -c)
239         ])
```

```
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         mxi = 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, mxi) if -max_y < mxi < 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.

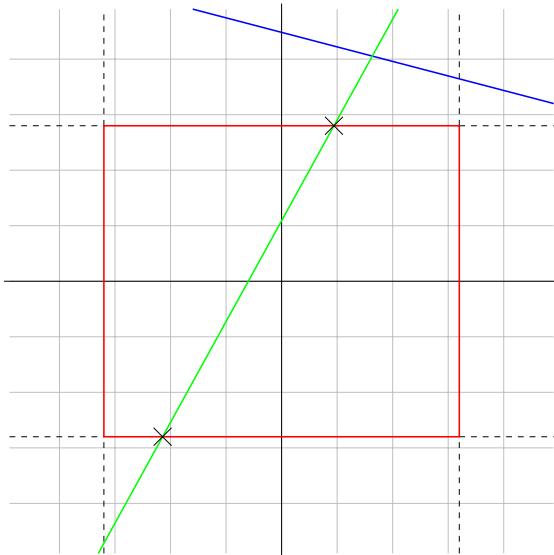


Figure 3.4.1: Two example lines and the viewport box

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`, `mmyi`, `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

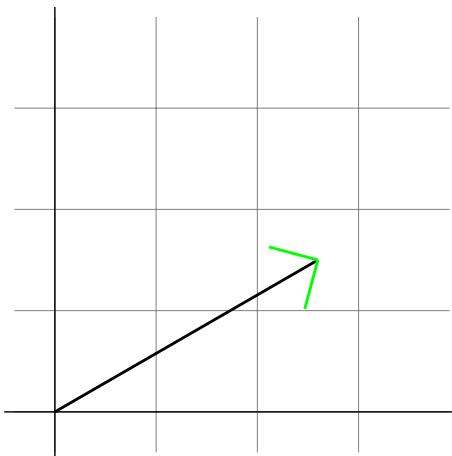


Figure 3.4.3: An example of a vector with the arrowheads highlighted in green

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 [csharphelper.com](http://csharphelper.com)[53], which I adapted for Python.

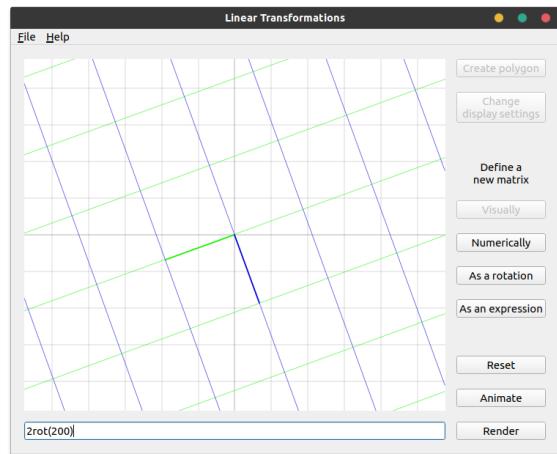
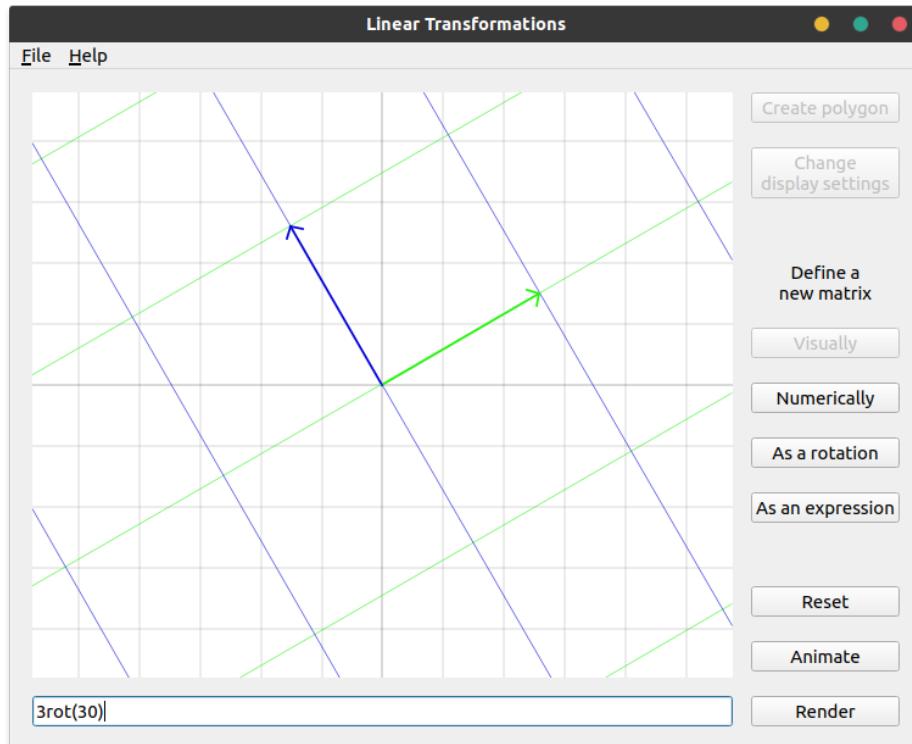


Figure 3.4.2: A demonstration of the new oblique lines system.

```
# 5373b1ad8040f6726147ccce523c0570251cf67
# src/lintrans/gui/plots/widgets.py

12 class VisualizeTransformationWidget(VectorGridPlot):
...
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
60         # This algorithm was adapted from a C# algorithm found at
61         # http://csharphelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
62
63         # Get the x and y coords of the point, and then normalize them
64         # We have to normalize them, or else the size of the arrowhead will
65         # scale with the distance of the point from the origin
66         x, y = point
67         nx = x / np.sqrt(x * x + y * y)
68         ny = y / np.sqrt(x * x + y * y)
69
70         # We choose a length and do some magic to find the steps in the x and y directions
71         length = 0.15
72         dx = length * (-nx - ny)
73         dy = length * (nx - ny)
74
75         # Then we just plot those lines
76         painter.drawLine(*self.trans_coords(x, y), *self.trans_coords(x + dx, y + dy))
77         painter.drawLine(*self.trans_coords(x, y), *self.trans_coords(x - dy, y + dx))
78
79     def draw_vector_arrowheads(self, painter: QPainter) -> None:
80         """Draw arrowheads at the tips of the basis vectors.
81
82         :param QPainter painter: The ``QPainter`` object to use to draw the arrowheads with
83         """
84
85         painter.setPen(QPen(self.colour_i, self.width_vector_line))
86         self.draw_arrowhead_away_from_origin(painter, self.point_i)
87         painter.setPen(QPen(self.colour_j, self.width_vector_line))
88         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 3.4.4: 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
13  class BackgroundPlot(QWidget):
14
15      ...
16
17      default_grid_spacing: int = 50
18
19      def __init__(self, *args, **kwargs):
20          """Create the widget and setup backend stuff for rendering.
21
22          .. note:: ``*args`` and ``**kwargs`` are passed the superclass constructor (``QWidget``).
23          """
24
25          super().__init__(*args, **kwargs)
26
27          self.setAutoFillBackground(True)
28
29          # Set the background to white
30          palette = self.palette()
31          palette.setColor(self.backgroundRole(), Qt.white)
32          self.setPalette(palette)
33
34          # Set the grid colour to grey and the axes colour to black
35          self.colour_background_grid = QColor(128, 128, 128)
36          self.colour_background_axes = QColor(0, 0, 0)
37
38          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[42], I learned how to handle this event.

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

12
...
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.

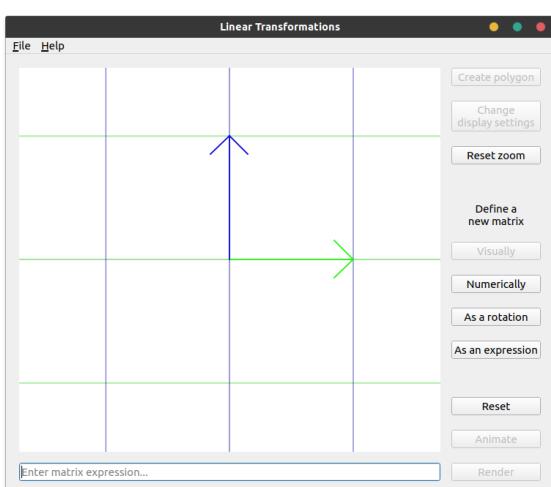


Figure 3.4.5: The GUI zoomed in a bit

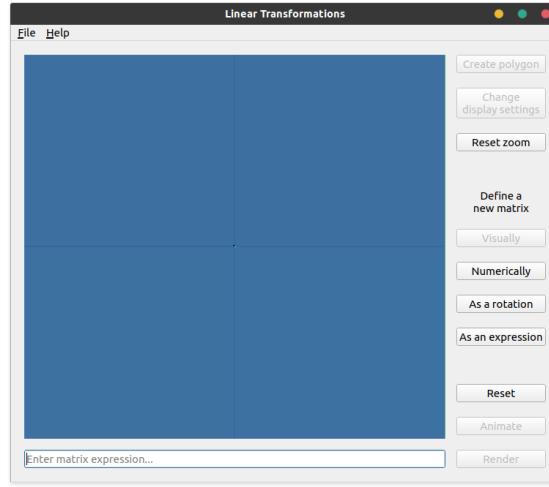


Figure 3.4.6: The GUI zoomed out as far as possible

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 3.4.5.

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.

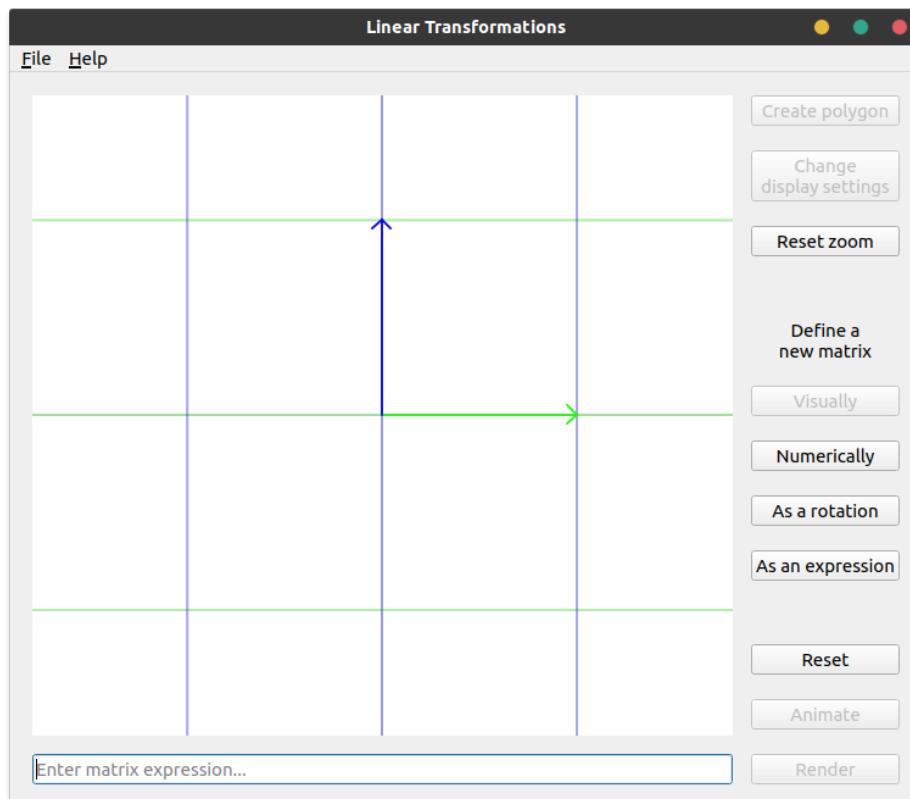


Figure 3.4.7: The arrowheads adjusted for zoom level

#### 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[21] 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[54], 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[45, 47] 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):
...
164     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
→      None:
...
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/mainwindow.py

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

```

274     for i in range(0, steps + 1):
...
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):
...
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()`.

```

# 4682a7b225747cf77aca0fe3abcdd1397b7c5dd
# 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
416         coords: list[tuple[int, int]] = [self.plot.trans_coords(*vector) for vector in matrix.T]
417
418         for x, y in coords:
419             if not (-2147483648 <= x <= 2147483647 and -2147483648 <= y <= 2147483647):
420                 return True
421
422     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
144         super().__init__(matrix_wrapper, *args, **kwargs)
145
146         self.setMinimumSize(500, 450)
147
148         # === Create the widgets
149
150         self.combo_box_letter.activated.connect(self.show_matrix)
151
152         self.plot = DefineVisuallyWidget(self)
153
154         # === Arrange the widgets
155
156         self.hlay_definition.addWidget(self.plot)
157         self.hlay_definition.setStretchFactor(self.plot, 1)
158
159         self.vlay_all = QVBoxLayout()
160         self.vlay_all.setSpacing(20)
161         self.vlay_all.addLayout(self.hlay_definition)
162         self.vlay_all.addLayout(self.hlay_buttons)
163
164         self.setLayout(self.vlay_all)
165
166         # We load the default matrix A into the plot
167         self.show_matrix(0)
168
169         # We also enable the confirm button, because any visually defined matrix is valid
170         self.button_confirm.setEnabled(True)
171
172     def update_confirm_button(self) -> None:
173         """Enable the confirm button.
174
175         .. note::
176             The confirm button is always enabled in this dialog and this method is never actually used,
177             so it's got an empty body. It's only here because we need to implement the abstract method.
178         """

```

```

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[44], I renamed 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
94         # We get the maximum grid coords and convert them into canvas coords
95         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):
...
174     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
196         if rank == 1:
200             if abs(vector_x) < 1e-12:
204                 painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
208                 elif abs(vector_y) < 1e-12:
212                     painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
216                 else:
220                     self.draw_oblique_line(painter, vector_y / vector_x, 0)
224
228         # If the rank is 0, then we don't draw any lines
232     else:
236         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:

```

# 4017b84fbce67d8e041bc9ce84cefcb0b6e65e1f
# src/lintrans/gui/main_window.py

25 class LintransMainWindow(QMainWindow):
...
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 its determinant
281         try:

```

```
282     matrix_target = self.matrix_wrapper.evaluate_expression(self.linedit_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(np.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(np.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.

```

# 60584d2559cacbf23479a1beb986a800a32331
# src/lintrans/gui/main_window.py

25
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()
40
41         # If there's commas in the expression, then we want to animate each part at a time
42         if ',' in text:
43             current_matrix = matrix_start
44
45             # For each expression in the list, right multiply it by the current matrix,
46             # and animate from the current matrix to that new matrix
47             for expr in text.split(',')[:-1]:
48                 new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
49
50                 self.animate_between_matrices(current_matrix, new_matrix)
51                 current_matrix = new_matrix
52
53             # Here we just redraw and allow for other events to be handled while we pause
54             self.plot.update()
55             QApplication.processEvents()
56             QThread.msleep(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:

```

# 4017b84fbce67d8e041bc9ce84cefcb0b6e65e1f
# 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)

# 60584d2559cacbf23479a1bebbb986a800a32331
# 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/mainwindow.py

26  class LintransMainWindow(QMainWindow):
...
286     def animate_expression(self) -> None:
287         """Animate from the current matrix to the matrix in the expression box."""
288         self.button_render.setEnabled(False)
289         self.button_animate.setEnabled(False)
290
291         matrix_start: MatrixType = np.array([
292             [self.plot.point_i[0], self.plot.point_j[0]],
293             [self.plot.point_i[1], self.plot.point_j[1]]
294         ])
295
296         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.msleep(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) ->
334         None:
335             """Animate from the start matrix to the target matrix."""
336             det_target = linalg.det(matrix_target)
337             det_start = linalg.det(matrix_start)
338
339             for i in range(0, steps + 1):
340                 # This proportion is how far we are through the loop
341                 proportion = i / steps
342
343                 # matrix_a is the start matrix plus some part of the target, scaled by the proportion
344                 # If we just used matrix_a, then things would animate, but the determinants would be weird
345                 matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
346
347                 if self.display_settings.animate_determinant and det_target != 0:
348                     # 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(np.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(np.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
28 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

```

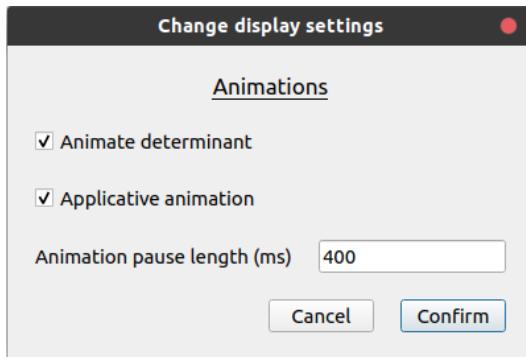


Figure 3.5.1: The display settings dialog

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. See §3.9.1.

### 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.

```

# fa4a65540749e84b750dde8abfd36a86c224b47
# src/lintrans/gui/main_window.py

27
285     class LintransMainWindow(QMainWindow):
...
294     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.msleep(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
    """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:
        """Draw the parallelogram of the determinant of the matrix."""
        path = QPainterPath()
        path.moveTo(*self.canvas_origin)
        path.lineTo(*self.canvas_coords(*self.point_i))
        path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
        path.lineTo(*self.canvas_coords(*self.point_j))

        brush = QBrush(QColor(16, 235, 253, alpha=128), Qt.SolidPattern)
        painter.fillPath(path, brush)

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

13   class VisualizeTransformationWidget(VectorGridPlot):
...
42     def paintEvent(self, event: QPaintEvent) -> None:
        """Handle a ``QPaintEvent`` by drawing the background grid and the transformed grid.

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.
        """
        painter = QPainter()
        painter.begin(self)

51       painter.setRenderHint(QPainter.Antialiasing)
52       painter.setBrush(Qt.NoBrush)

54       self.draw_background(painter)
55       self.draw_transformed_grid(painter)
56       self.draw_vector_arrowheads(painter)

58       if self.display_settings.draw_determinant_parallelogram:
59           self.draw_determinant_parallelogram(painter)

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_parallellogram(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.

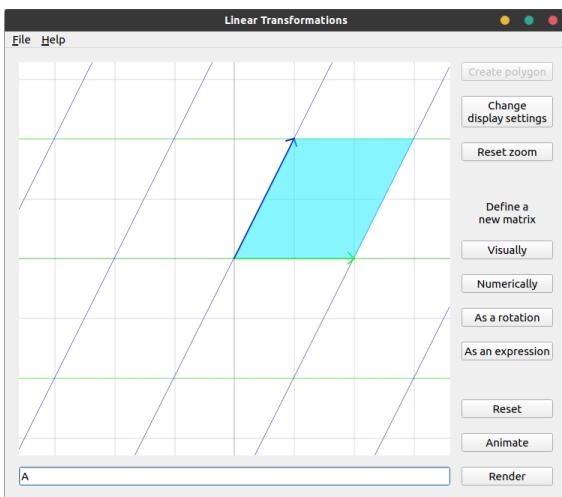


Figure 3.5.2: The blue parallelogram

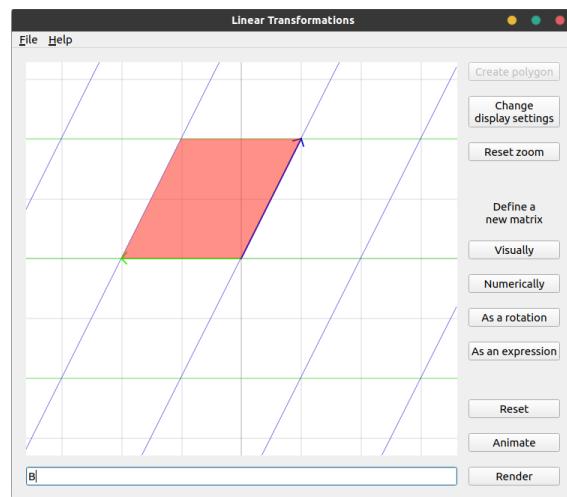


Figure 3.5.3: The red parallelogram

### 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()`.

```

# e344e50eccfd87c0834cfbd459f0dd1d555fc6
# 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 inside the parallelogram.
37
38       The text only gets drawn if :attr:`draw_determinant_parallellogram` is also True.
39       """

```

```

# e344e50eccfd87c0834cfbd459f0dd1d555fc6
# src/lintrans/gui/dialogs/settings.py

```

```

63  class DisplaySettingsDialog(SettingsDialog):
...
66      def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
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     )

# e344e50eccfd87c0834cfbd459f0dd1d555fc6
# src/lintrans/gui/plots/classes.py

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

```

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.

```

# e344e50eccfd87c0834cfbd459f0dd1d555fc6
# src/lintrans/gui/plots/widgets.py

13  class VisualizeTransformationWidget(VectorGridPlot):
...
42      def paintEvent(self, event: QPaintEvent) -> None:
...
58          if self.display_settings.draw_determinant_parallelgram:
              self.draw_determinant_parallelgram(painter)
...
61          if self.display_settings.draw_determinant_text:
              self.draw_determinant_text(painter)

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

63  class DisplaySettingsDialog(SettingsDialog):
...
66      def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
107         self.checkbox_draw_determinant_parallelgram.clicked.connect(self.update_gui)
...
173     def update_gui(self) -> None:
        """Update the GUI according to other widgets in the GUI.
        For example, this method updates which checkboxes are enabled based on the values of other checkboxes.
        """
        self.checkbox_draw_determinant_text.setEnabled(self.checkbox_draw_determinant_parallelgram.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  $\mathbf{A}$  which is the start matrix plus some proportion of the difference between the target and start matrices. It then defines matrix  $\mathbf{B}$  to be the matrix  $\mathbf{A}$  normalised to have a determinant of 1. We then divide by  $\det(\mathbf{B})$  to get matrix  $\mathbf{C}$ , which we then render.

This works very well for most matrices, but if we're animating from  $\mathbf{I}$  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  $\mathbf{I}$  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     else:
390         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]) ->
192         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.

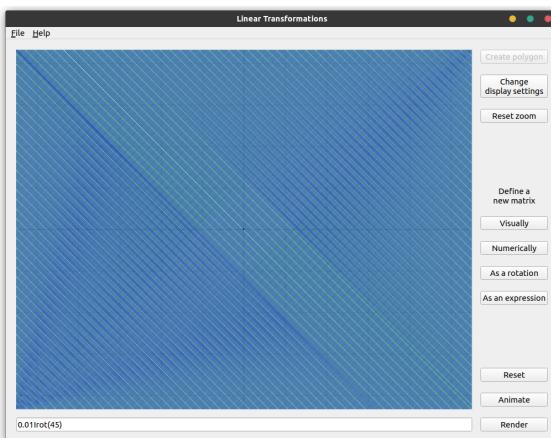


Figure 3.6.1: The old version with too many parallel lines.

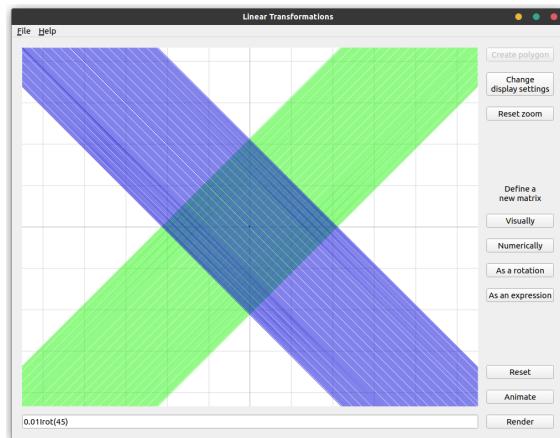


Figure 3.6.2: The fixed version with a maximum number of parallel lines.

### 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
28 class LintransMainWindow(QMainWindow):
29 ...
30
31     def assign_matrix_wrapper(self, matrix_wrapper: MatrixWrapper) -> None:
32         """Assign a new value to ``self.matrix_wrapper`` and give the expression box focus.
33
34         :param matrix_wrapper: The new value of the matrix wrapper to assign
35         :type matrix_wrapper: MatrixWrapper
36         """
37
38         self.matrix_wrapper = matrix_wrapper
39         self.lineEdit_expression_box.setFocus()
40         self.update_render_buttons()
41
42     def assign_display_settings(self, display_settings: DisplaySettings) -> None:
43         """Assign a new value to ``self.plot.display_settings`` and give the expression box focus."""
44
45         self.plot.display_settings = display_settings
46         self.plot.update()
47

```

```
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/mainwindow.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/mainwindow.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:
        """Reset the visualized transformation back to the identity."""
        self.plot.visualize_matrix_transformation(self.matrix_wrapper['I'])
        self.animating = False
        self.animating_sequence = False
        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:
            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.msleep(self.plot.display_settings.animation_pause_length)
328
329         self.animating_sequence = False
...
360     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
361         None:
...
365         self.animating = True
366
367         for i in range(0, steps + 1):
368             if not self.animating:
369                 break
370
...
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[41]. 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/mainwindow.py

28     class LintransMainWindow(QMainWindow):
...
34         def __init__(self):
...
125             self.lineEdit_expression_box.setValidator(MatrixExpressionValidator(self))

# 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):
...
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())
...
299 class DefineAsARotationDialog(DefineDialog):
...
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())
...
358 class DefineAsAnExpressionDialog(DefineDialog):
...
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

63 class DisplaySettingsDialog(SettingsDialog):
64     """The dialog to allow the user to edit the display settings."""
65
66     def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
67         """Create the widgets and layout of the dialog.
68
69         :param DisplaySettings display_settings: The :class:`lintrans.gui.settings.DisplaySettings` object to mutate
70         """
71         super().__init__(*args, **kwargs)
72
73         self.display_settings = display_settings
74         self.setWindowTitle('Change display settings')
75
76         self.dict_checkboxes: dict[str, QCheckBox] = dict()
77
78         # === Create the widgets
79
80         # Animations
81
82         self.checkbox_smoothen_determinant = QCheckBox(self)
83         self.checkbox_smoothen_determinant.setText('&Smoothen determinant')
84         self.checkbox_smoothen_determinant.setToolTip(
85             'Smoothly animate the determinant transition during animation (if possible)'
86         )
87         self.dict_checkboxes['s'] = self.checkbox_smoothen_determinant
88
89         self.checkbox_applicative_animation = QCheckBox(self)
90         self.checkbox_applicative_animation.setText('&Applicative animation')
91         self.checkbox_applicative_animation.setToolTip(
92             'Animate the new transformation applied to the current one,\n'
93             'rather than just that transformation on its own'
94         )
95         self.dict_checkboxes['a'] = self.checkbox_applicative_animation
96
97         self.label_animation_pause_length = QtWidgets.QLabel(self)
98         self.label_animation_pause_length.setText('Animation pause length (ms)')
99         self.label_animation_pause_length.setToolTip(
100            'How many milliseconds to pause for in comma-separated animations'
101        )
102
103         self.lineEdit_animation_pause_length = QtWidgets.QLineEdit(self)
104         self.lineEdit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
105
106         # Matrix info
107
108         self.checkbox_draw_determinant_parallellogram = QCheckBox(self)
109         self.checkbox_draw_determinant_parallellogram.setText('Draw &determinant parallelogram')
110         self.checkbox_draw_determinant_parallellogram.setToolTip(
111             'Shade the parallelogram representing the determinant of the matrix'
112         )
113         self.checkbox_draw_determinant_parallellogram.clicked.connect(self.update_gui)
114         self.dict_checkboxes['d'] = self.checkbox_draw_determinant_parallellogram
115
116         self.checkbox_draw_determinant_text = QCheckBox(self)
117         self.checkbox_draw_determinant_text.setText('Draw determinant &text')
118         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_smoothen_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_parallelgram)
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()
...
188 def keyPressEvent(self, event: QKeyEvent) -> None:
189     """Handle a ``QKeyEvent`` by manually activating toggling checkboxes.
190
191     Qt handles these shortcuts automatically and allows the user to do ``Alt + Key``
192     to activate a simple shortcut defined with ``&``. However, I like to be able to
193     just hit ``Key`` and have the shortcut activate.
194     """
195     letter = event.text().lower()
196     key = event.key()
197
198     if letter in self.dict_checkboxes:
199         self.dict_checkboxes[letter].animateClick()
200
201     # Return or keypad enter
202     elif key == 0x01000004 or key == 0x01000005:
203         self.button_confirm.click()
204
205     # Escape
206     elif key == 0x01000000:
207         self.button_cancel.click()
208
209     else:
210         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):
...
419     def draw_determinant_text(self, painter: QPainter) -> None:
        """Write the string value of the determinant in the middle of the parallelogram."""
        painter.setPen(QPen(QColor(0, 0, 0), self.width_vector_line))
        painter.drawText(
            *self.canvas_coords(
                (self.point_i[0] + self.point_j[0]) / 2,
                (self.point_i[1] + self.point_j[1]) / 2
            ),
            f'{self.det:.2f}'
        )

```

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):
...
419     def draw_determinant_text(self, painter: QPainter) -> None:
        """Write the string value of the determinant in the middle of the parallelogram."""
        painter.setPen(QPen(QColor(0, 0, 0), self.width_vector_line))

423         # We're building a QRect that encloses the determinant parallelogram
424         # Then we can center the text in this QRect
425         coords: list[tuple[float, float]] = [
426             (0, 0),
427             self.point_i,
428             self.point_j,
429             (
430                 self.point_i[0] + self.point_j[0],
431                 self.point_i[1] + self.point_j[1]
432             )
433         ]
434
435         xs = [t[0] for t in coords]
436         ys = [t[1] for t in coords]
437
438         top_left = QPoint(*self.canvas_coords(min(xs), max(ys)))
439         bottom_right = QPoint(*self.canvas_coords(max(xs), min(ys)))
440
441         rect = QRectF(top_left, bottom_right)
442
443         painter.drawText(
444             rect,
445             Qt.AlignHCenter | Qt.AlignVCenter,
446             f'{self.det:.2f}'
447         )

```

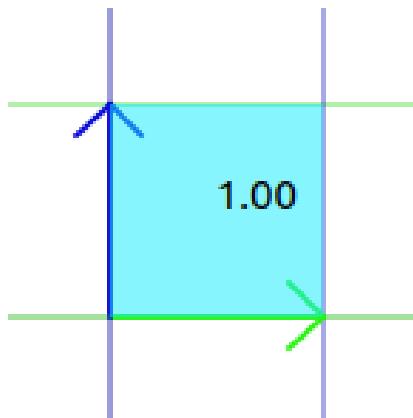


Figure 3.6.3: Text not centered.

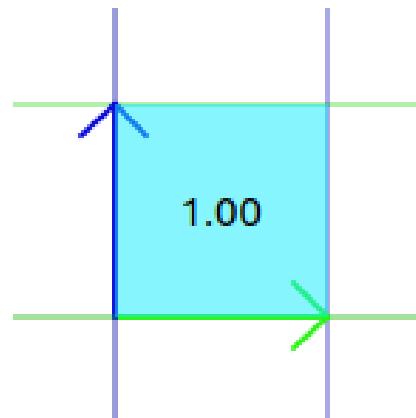


Figure 3.6.4: Text centered.

### 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
123     if name not in self._matrices:
124         raise NameError('Matrix name must be a single capital letter')
125
126     if name == 'I':
127         raise NameError('Matrix name cannot be "I"')
128
129     if new_matrix is None:
130         self._matrices[name] = None
131         return
132
133     if not is_matrix_type(new_matrix):
134         raise TypeError('Matrix must be a 2x2 NumPy array')
135
136     # All matrices must have float entries
137     a = float(new_matrix[0][0])
138     b = float(new_matrix[0][1])
139     c = float(new_matrix[1][0])
140     d = float(new_matrix[1][1])
141
142     self._matrices[name] = np.array([[a, b], [c, d]])
143
144 def is_valid_expression(self, expression: str) -> bool:
145     """Check if the given expression is valid, using the context of the wrapper.
146
147     This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
148     ensures that all the matrices in the expression are defined in the wrapper.
149
150     :param str expression: The expression to validate
151     :returns: Whether the expression is valid in this wrapper
152     :rtype: bool
153     """
154
155     # Get rid of the transposes to check all capital letters
156     new_expression = expression.replace('^T', '').replace('^{T}', '')
157
158     # Make sure all the referenced matrices are defined
159     for matrix in {x for x in new_expression if re.match('[A-Z]', x)}:
160         if self[matrix] is None:
161             return False
162
163     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:
...
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         }
50
51 ...
52
53 def __getitem__(self, name: str) -> Optional[MatrixType]:
54     """Get the matrix with the given name.
55
56     If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)``, with
57     a given angle in degrees, then we return a new matrix representing a rotation by that angle.
58
59     :param str name: The name of the matrix to get
60     :returns: The value of the matrix (may be None)
61     :rtype: Optional[MatrixType]
62
63     :raises NameError: If there is no matrix with the given name
64     """
65
66     # Return a new rotation matrix
67     if (match := re.match(r'rot\((-?\d*\.\d*)\)', name)) is not None:
68         return create_rotation_matrix(float(match.group(1)))
69
70     if name not in self._matrices:
71         raise NameError(f'Unrecognised matrix name "{name}"')
72
73     # We copy the matrix before we return it so the user can't accidentally mutate the matrix
74     matrix = copy(self._matrices[name])
75
76     if isinstance(matrix, str):
77         return self.evaluate_expression(matrix)
78
79     return matrix
80
81 def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:
82     """Set the value of matrix ``name`` with the new_matrix.
83
84     :param str name: The name of the matrix to set the value of
85     :param Optional[Union[MatrixType, str]] new_matrix: The value of the new matrix (may be None)
86
87     :raises NameError: If the name isn't a legal matrix name
88     :raises TypeError: If the matrix isn't a valid 2x2 NumPy array
89     """
90
91     if not (name in self._matrices and name != 'I'):
92         raise NameError('Matrix name is illegal')
93
94     if new_matrix is None:
95         self._matrices[name] = None
96         return
97
98     if isinstance(new_matrix, str):
99         if self.is_valid_expression(new_matrix):
100            self._matrices[name] = new_matrix
101            return
102
103     if not is_matrix_type(new_matrix):
104         raise TypeError('Matrix must be a 2x2 NumPy array')
105
106     # All matrices must have float entries
107     a = float(new_matrix[0][0])
108     b = float(new_matrix[0][1])
109     c = float(new_matrix[1][0])
110     d = float(new_matrix[1][1])
111
112     self._matrices[name] = np.array([[a, b], [c, d]])
113
114 def get_expression(self, name: str) -> Optional[str]:
115     """If the named matrix is defined as an expression, return that expression, else return None.
116
117     :param str name: The name of the matrix to get
118
119     :returns: The value of the matrix (may be None)
120     :rtype: Optional[str]
121
122     :raises NameError: If there is no matrix with the given name
123     """
124
125     if name not in self._matrices:
126         raise NameError(f'Unrecognised matrix name "{name}"')
127
128     # We copy the matrix before we return it so the user can't accidentally mutate the matrix
129     matrix = copy(self._matrices[name])
130
131     if isinstance(matrix, str):
132         return self.evaluate_expression(matrix)
133
134     return matrix
```

```

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
182     # Get rid of the transposes to check all capital letters
183     new_expression = expression.replace('^T', '').replace('{T}', '')
184
185     # Make sure all the referenced matrices are defined
186     for matrix in {x for x in new_expression if re.match('[A-Z]', x)}:
187         if self[matrix] is None:
188             return False
189
190         if (expr := self.get_expression(matrix)) is not None:
191             if not self.is_valid_expression(expr):
192                 return False
193
194     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'
```

```
(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 6%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 10%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 13%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 17%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 20%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 24%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 27%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 31%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 34%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 37%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 41%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 44%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 48%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 51%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 55%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 58%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 62%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 65%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 68%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 72%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 75%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 79%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 82%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 86%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 89%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 93%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 96%]
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 29 items

===== 29 passed in 0.36s =====
```

Figure 3.6.5: Running pytest with the new tests

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):
...
388     def confirm_matrix(self) -> None:
389         """Evaluate the matrix expression and assign its value to the name in the combo box."""
390         self.matrix_wrapper[self.selected_letter] = self.lineedit_expression_box.text()
391         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 DefineDialog(QDialog):
...
69     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
...
78         self.comboobox_letter = QtWidgets.QComboBox(self)
99
100        for letter in ALPHABET_NO_I:
101            self.comboobox_letter.addItem(letter)
102
103        self.comboobox_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(DefineDialog):
...
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(DefineDialog):
...
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:
...
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.

---

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

## 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[28].

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):
...
151     def __init__(self, *args, **kwargs):
...
163         self.colour_eigen = QColor('#ffff900')
...
171     def draw_eigenvectors(self, painter: QPainter) -> None:
172         """Draw the eigenvectors of the displayed matrix transformation."""
173         painter.setPen(QPen(self.colour_eigen, self.width_vector_line))
174
175         values, vectors = np.linalg.eig(self.matrix)
176         vectors = vectors.T
177
178         for value, vector in zip(values, vectors):
179             x = value * vector[0]
180             y = value * vector[1]
181
182             if x.imag != 0 or y.imag != 0:
183                 continue
184
185             painter.drawLine(*self.canvas_origin, *self.canvas_coords(x, y))
186             self.draw_arrowhead_away_from_origin(painter, (x, y))

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

13 class VisualizeTransformationWidget(VectorGridPlot):
...
42     def paintEvent(self, event: QPaintEvent) -> None:
...
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[13]

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.

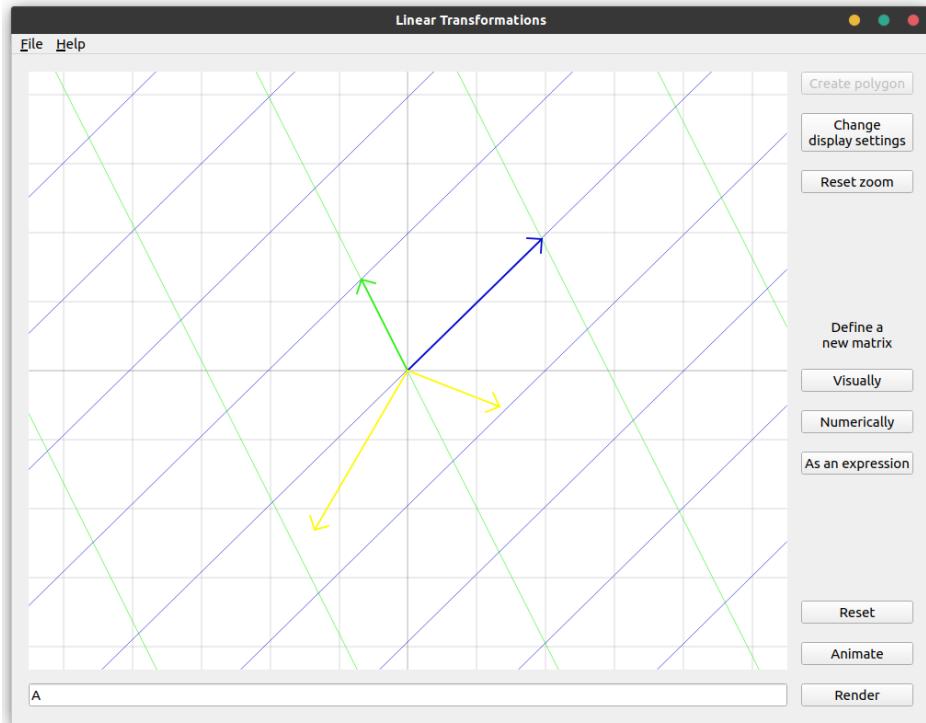


Figure 3.7.1: The eigenvectors being displayed for an arbitrary matrix

### 3.7.2 Adding display settings for eigenvectors

Once I'd got the eigenvectors working and being drawn, I wanted to be able to turn them on and off from the display settings. This was a simple case of just adding it to the `DisplaySettings` dataclass, adding the checkbox to the dialog, and only drawing the eigenvectors if this display setting is true.

```
# 3ebb5997a7a887e751b5f4f717aa5161ed013e62
# src/lintrans/gui/settings.py

9  class DisplaySettings:
...
41      draw_eigenvectors: bool = False
42      """This controls whether we should draw the eigenvectors of the transformation."""

# 3ebb5997a7a887e751b5f4f717aa5161ed013e62
# src/lintrans/gui/dialogs/settings.py

63  class DisplaySettingsDialog(SettingsDialog):
...
66      def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
123      self.checkbox_draw_eigenvectors = QCheckBox(self)
124      self.checkbox_draw_eigenvectors.setText('Draw &eigenvectors')
125      self.checkbox_draw_eigenvectors.setToolTip('Draw the eigenvectors of the transformations')
126      self.dict_checkboxes['e'] = self.checkbox_draw_eigenvectors
```

```
# 3ebb5997a7a887e751b5f4f717aa5161ed013e62
# src/lintrans/gui/plots/widgets.py
```

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

### 3.7.3 Refactoring drawing vectors

Since I've now got several drawing methods that involve drawing vectors, I thought I should factor out this functionality into a separate utility method which I could call from all these places.

```
# 754eba0318a682b068a8a5d5ca451decbaa204ce
# src/lintrans/gui/plots/classes.py
```

```
142 class VectorGridPlot(BackgroundPlot):
...
388     def draw_position_vector(self, painter: QPainter, point: tuple[float, float], colour: QColor) -> None:
389         """Draw a vector from the origin to the given point.
390
391         :param QPainter painter: The ``QPainter`` object to use to draw the arrowheads with
392         :param point: The tip of the position vector in grid coords
393         :type point: tuple[float, float]
394         :param QColor colour: The colour to draw the position vector in
395         """
396
397         painter.setPen(QPen(colour, self.width_vector_line))
398         painter.drawLine(*self.canvas_origin, *self.canvas_coords(*point))
399         self.draw_arrowhead_away_from_origin(painter, point)
400
401     def draw_basis_vectors(self, painter: QPainter) -> None:
402         """Draw arrowheads at the tips of the basis vectors.
403
404         :param QPainter painter: The ``QPainter`` object to use to draw the arrowheads with
405         """
406
407         self.draw_position_vector(painter, self.point_i, self.colour_i)
408         self.draw_position_vector(painter, self.point_j, self.colour_j)
...
454     def draw_eigenvectors(self, painter: QPainter) -> None:
455         """Draw the eigenvectors of the displayed matrix transformation."""
456         values, vectors = np.linalg.eig(self.matrix)
457         vectors = vectors.T
458
459         for value, vector in zip(values, vectors):
460             x = value * vector[0]
461             y = value * vector[1]
462
463             if x.imag != 0 or y.imag != 0:
464                 continue
465
466             self.draw_position_vector(painter, (x, y), self.colour_eigen)
```

When I was testing this refactor, I realised that the `draw_transformed_grid()` method originally drew the bodies of the basis vectors and the caller had to draw the arrowheads separately. This is silly and was never planned that way; it was an unfortunate consequence of implementing the lines and arrowheads at different times. But now after this refactor, the caller has to call `draw_basis_vectors()` to draw the whole basis vectors. So I had to add this call to `VisualizeTransformationWidget.paintEvent()` and `DefineVisuallyWidget.paintEvent()` in `src/lintrans/gui/plots/widgets.py` and remove the calls to `draw_vector_arrowheads()`.

### 3.7.4 Adding eigenlines

Drawing some eigenvectors that point in a general direction is fine, but drawing the whole span of the vector would be much more useful. These spans are called eigenlines, and are just lines in the direction of the vector. To implement these, I knew I would have to get the eigenvalues and eigenvectors, zip them, and iterate over them like I did in §3.7.1. To make this simpler, I decided to factor out this zipping into a separate `self.eigs` property<sup>16</sup>.

```
# e1606f1e45ba93102ddb74b45ab22649a63fa53
# src/lintrans/gui/plots/classes.py

144 class VectorGridPlot(BackgroundPlot):
...
187     @property
188     def eigs(self) -> Iterable[tuple[float, NDArray[(1, 2), Float]]]:
189         """Return the eigenvalues and eigenvectors zipped together to be iterated over.
190
191         :rtype: Iterable[tuple[float, NDArray[(1, 2), Float]]]
192         """
193         values, vectors = np.linalg.eig(self.matrix)
194         return zip(values, vectors.T)
...
465     def draw_eigenvectors(self, painter: QPainter) -> None:
466         """Draw the eigenvectors of the displayed matrix transformation."""
467         for value, vector in self.eigs:
468             x = value * vector[0]
469             y = value * vector[1]
470
471             if x.imag != 0 or y.imag != 0:
472                 continue
473
474             self.draw_position_vector(painter, (x, y), self.colour_eigen)
```

I could then create a new method to find the gradient of the vector line and draw an orthogonal or oblique line respectively. Like before, we only want to render the eigenlines for real-valued eigenvectors, so we have to check their imaginary part.

```
# 8d4d41fc4780cc037be39a0e574158e6cd34e997
# src/lintrans/gui/plots/classes.py

144 class VectorGridPlot(BackgroundPlot):
...
476     def draw_eigenlines(self, painter: QPainter) -> None:
477         """Draw the eigenlines (invariant lines).
478
479         :param QPainter painter: The painter to draw the lines with
480         """
481         painter.setPen(QPen(self.colour_eigen, self.width_transformed_grid))
482
483         for value, vector in self.eigs:
484             if value.imag != 0:
485                 continue
486
487             x, y = vector
488
489             if x == 0:
490                 x_mid = int(self.width() / 2)
491                 painter.drawLine(x_mid, 0, x_mid, self.height())
492
493             elif y == 0:
494                 y_mid = int(self.height() / 2)
495                 painter.drawLine(0, y_mid, self.width(), y_mid)
496
497             else:
498                 self.draw_oblique_line(painter, y / x, 0)
```

<sup>16</sup>A `@property` in Python is a value on a class which is dynamically evaluated only when it's needed. It functions just like a method with no arguments, but has more concise syntax for the caller.

I then just had to put these new eigenlines behind a display setting.

```
# 12cfabde606ebd3d48b2c3efaad0412f6100c3c5
# src/lintrans/gui/settings.py

9   class DisplaySettings:
...
44     draw_eigenlines: bool = False
45     """This controls whether we should draw the eigenlines of the transformation."""

# 12cfabde606ebd3d48b2c3efaad0412f6100c3c5
# src/lintrans/gui/dialogs/settings.py

63  class DisplaySettingsDialog(SettingsDialog):
...
66    def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
128      self.checkbox_draw_eigenlines = QCheckBox(self)
129      self.checkbox_draw_eigenlines.setText('Draw eigen&lines')
130      self.checkbox_draw_eigenlines.setToolTip('Draw the eigenlines (invariant lines) of the transformations')
131      self.dict_checkboxes['l'] = self.checkbox_draw_eigenlines

# 12cfabde606ebd3d48b2c3efaad0412f6100c3c5
# src/lintrans/gui/plots/widgets.py

13  class VisualizeTransformationWidget(VectorGridPlot):
...
42    def paintEvent(self, event: QPaintEvent) -> None:
...
58      if self.display_settings.draw_eigenlines:
59        self.draw_eigenlines(painter)
```

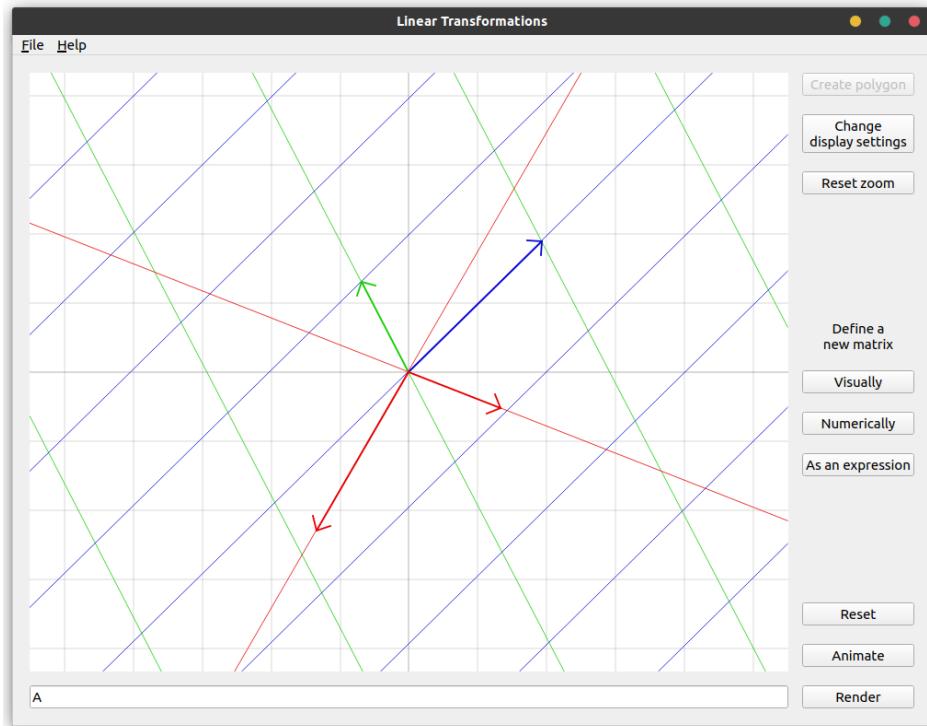


Figure 3.7.2: The eigenvectors being displayed for a similar matrix as in Figure 3.7.1

### 3.7.5 Adding eigenvalues as text

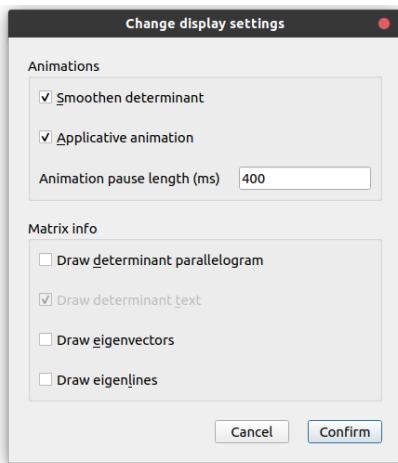
The next thing I wanted to do was tell the user what the actual eigenvalue numbers were. I decided the best way to do this would be to have the eigenvectors labelled with their associated eigenvalues.

To align the text properly, I decided to do something similar to what I did for determinants in §3.6.8. There, I enclosed the parallelogram in a rectangle and drew the text in the centre of it. Here, I decided to create a rectangle based on which quadrant the eigenvector was in. The rectangle would have corners of the tip of the eigenvector, and the appropriate corner of the viewport. I also had to choose a suitable alignment for each quadrant, so that the text would appear in the correct corner of the rectangle, next to the tip of the eigenvector.

```
# a7e9a17ecdb2a585e9f766b13029116d7ba29bdc
# src/lintrans/gui/plots/classes.py

144 class VectorGridPlot(BackgroundPlot):
...
466     def draw_eigenvectors(self, painter: QPainter) -> None:
467         """Draw the eigenvectors of the displayed matrix transformation."""
468         for value, vector in self.eigs:
469             x = value * vector[0]
470             y = value * vector[1]
471
472             if x.imag != 0 or y.imag != 0:
473                 continue
474
475             self.draw_position_vector(painter, (x, y), self.colour_eigen)
476
477             # Now we need to draw the eigenvalue at the tip of the eigenvector
478
479             offset = 3
480             top_left: QPoint
481             bottom_right: QPoint
482             alignment_flags: int
483
484             if x >= 0 and y >= 0: # Q1
485                 top_left = QPoint(self.canvas_x(x) + offset, 0)
486                 bottom_right = QPoint(self.width(), self.canvas_y(y) - offset)
487                 alignment_flags = Qt.AlignLeft | Qt.AlignBottom
488
489             elif x < 0 and y >= 0: # Q2
490                 top_left = QPoint(0, 0)
491                 bottom_right = QPoint(self.canvas_x(x) - offset, self.canvas_y(y) - offset)
492                 alignment_flags = Qt.AlignRight | Qt.AlignBottom
493
494             elif x < 0 and y < 0: # Q3
495                 top_left = QPoint(0, self.canvas_y(y) + offset)
496                 bottom_right = QPoint(self.canvas_x(x) - offset, self.height())
497                 alignment_flags = Qt.AlignRight | Qt.AlignTop
498
499             else: # Q4
500                 top_left = QPoint(self.canvas_x(x) + offset, self.canvas_y(y) + offset)
501                 bottom_right = QPoint(self.width(), self.height())
502                 alignment_flags = Qt.AlignLeft | Qt.AlignTop
503
504             painter.setPen(QPen(self.colour_text, self.width_vector_line))
505             painter.drawText(QRectF(top_left, bottom_right), alignment_flags, f'{value:.2f}')
```

### 3.7.6 A tiny UI change



This bit isn't really related to eigenvectors, but it's a tiny change that doesn't really have a good place anywhere else, and it fits roughly here chronologically.

I really liked the groupboxes used in the display settings (left) and I'd quite like to enclose the matrix definition buttons in their own groupbox to separate them from the rest of the UI and better associate them with the label above them. This was a trivial addition.

Figure 3.7.3: The display settings

```
# 90425137edd4596219ab564ccbeccd65b5754008
# src/lintrans/gui/main_window.py

27 class LintransMainWindow(QMainWindow):
...
33     def __init__(self):
...
173         self.vlay_define_new_matrix = QVBoxLayout()
174         self.vlay_define_new_matrix.setSpacing(20)
175         self.vlay_define_new_matrix.addWidget(self.button_define_visually)
176         self.vlay_define_new_matrix.addWidget(self.button_define_numerically)
177         self.vlay_define_new_matrix.addWidget(self.button_define_as_expression)
178
179         self.groupbox_define_new_matrix = QtWidgets.QGroupBox('Define a new matrix', self)
180         self.groupbox_define_new_matrix.setLayout(self.vlay_define_new_matrix)
...
226         self.vlay_right.addWidget(self.groupbox_define_new_matrix)
```

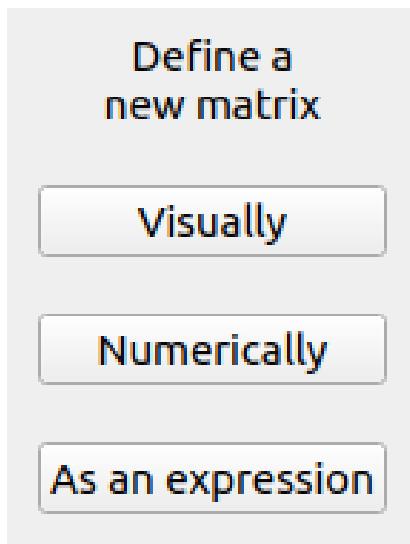


Figure 3.7.4: The old matrix definition buttons

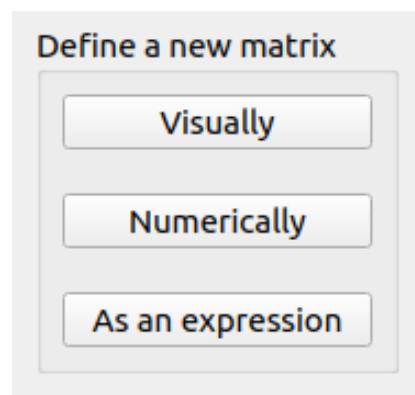


Figure 3.7.5: The new matrix definition buttons

## 3.8 Fumbling with SemVer

### 3.8.1 The first version numbers

At this point, I've been developing lintrans for quite a while, but I don't have any kind of version numbers yet. I wanted to fix this, to keep track of versions through history. SemVer[49] is a system of numbering versions of software that ensures compatibility across versions and gives semantic meaning to the version numbers.

My first foray into using SemVer was to declare `lintrans` at this point to be `0.1.0-alpha`. In retrospect, these early versions don't make much sense. I didn't release anything for anyone else to use until version `0.3.0`, so everything before then doesn't make much sense and should probably just be ignored.

I then made a few adjustments to syntax and documentation before declaring version `0.1.1-alpha` just over 24 hours later. This one was completely unnecessary in hindsight and I think I was just excited about being able to tag git commits. Additionally, there is a `__version__` variable in the root of the package, and the value of this variable is still "`0.1.0-alpha`" at the `v0.1.1-alpha` tag because I forgot to update it before I tagged the commit, and I didn't know how to fix it at the time.

### 3.8.2 Licensing

Using version numbers reminded me of licensing. I was already using the GNU GPLv3[17] for `lintrans` and most of my other projects, so I just wanted to add the copyright notice to all the source files of the project, as per the license. I already had the `COPYING` file in the project root with the full license, as required.

The notice looks like this<sup>17</sup>:

```

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>

```

### 3.8.3 Making the package executable

So far, I'd been running the program by running a separate script called `run_gui.py`, but Python lets you make a package executable by creating a file called `__main__.py` in the project root. You can then run it by using the command `python -m package_name`. This will make the whole program more cohesive by integrating the execution into the same directory as the source library code. I just moved the script here and changed its docstring a little bit.

```

# 847cdf61f64b30e81edf0821b7a8d2eb060fb825
# src/lintrans/__main__.py

9 """This module very simply runs the app by calling :func:`lintrans.gui.main_window.main`.
10
11 This allows the user to run the app like ``python -m lintrans`` from the command line.
12 """
13
14 import sys
15
16 from lintrans.gui import main_window

```

---

<sup>17</sup>I'm calling myself D. Dyson here because my name is Dyson, and I was in the process of getting it legally changed to Dyson Dyson when I made this change. I can't attribute this copyright to Dyson, since that's already a registered trademark of Dyson Limited. Calling myself Dyson Dyson felt strange, especially since it wasn't even my legal name at the time. So I chose to use D. Dyson instead.

```

17
18 if __name__ == '__main__':
19     main_window.main(sys.argv)

```

Somehow this caused a conflict between my `lintrans.typing` package, which contained custom types like `MatrixType`, and the standard library `typing` package, so I had to rename mine to `lintrans.typing_`.

### 3.8.4 Adding a graph of internal imports

Throughout the whole project, I've been using GitHub Actions[15] to automatically do things like test and lint my code, as well as compile the documentation whenever I push my changes to GitHub. I recently learned about `pylint`'s ability to generate a graph of all the internal imports in a package[34]. This graph shows how modules in the project depend on each other internally. It doesn't include external imports like `numpy`. I decided to generate this graph automatically and add it to my documentation.

```

# 39a3727fca69ea65571a15c55741578abce1e763
# .github/workflows/compile-docs.yaml

1 name: Compile docs for gh-pages
2
3 on:
4   push:
5     branches: [ main ]
6
7 jobs:
8   compile-docs:
9     runs-on: ubuntu-latest
10
11   concurrency:
12     group: ${{ github.workflow }}-${{ github.ref }}
13
14   steps:
15     - uses: actions/checkout@v2
16
17     - name: Set up Python 3.10
18       uses: actions/setup-python@v2
19       with:
20         python-version: '3.10'
21
22     - name: Install dependencies
23       run: |
24         pip install --upgrade pip
25         pip install -r requirements.txt -r docs/docs_requirements.txt
26         pip install -e .
27         pip install pylint
28         sudo apt-get install -y graphviz
29
30     - name: Create pylint import graphs
31       run: |
32         shopt -s globstar
33         pylint --rcfile=/dev/null --exit-zero --reports=y --disable=all --enable=imports,RP0402
34         --int-import-graph=docs/source/int-imports.png src/lintrans/**/*.py
35
36     - name: Build docs
37       run: cd docs/ && make html && cd ..
38
39     - name: Deploy
40       uses: peaceiris/actions-gh-pages@v3.8.0
41       if: ${{ github.ref == 'refs/heads/main' }}
42       with:
43         github_token: ${{ secrets.GITHUB_TOKEN }}
44         publish_dir: ./docs/build/html/
45         keep_files: true
46         destination_dir: docs
47         user_name: 'github-actions[bot]'

```

47  
48

```
user_email: 'github-actions[bot]@users.noreply.github.com'
commit_message: 'compile docs:'
```

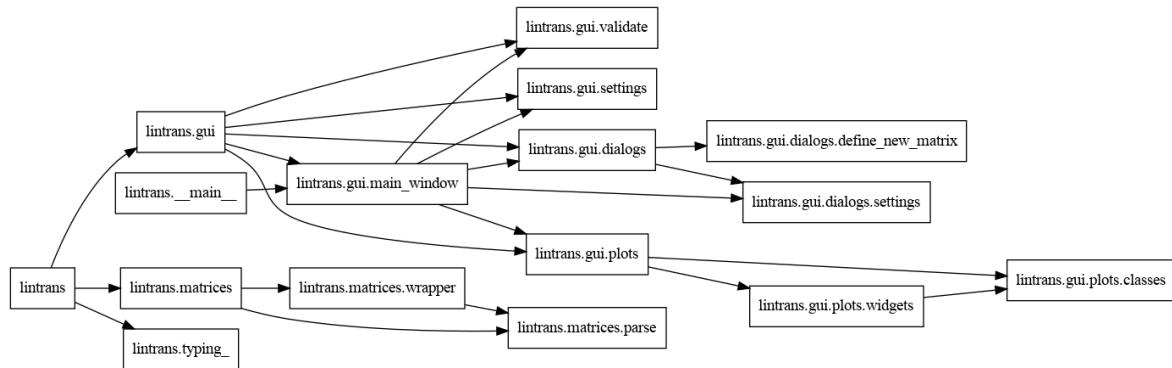


Figure 3.8.1: The internal imports graph

### 3.8.5 Fixing the colours

Now that I was using version numbers, I thought it was finally time to fix the colours in accordance with §2.4. I decided to use red and blue for the basis vectors, since these are the most easily distinguished colours for colour blind users. I decided to keep the green colour and use it for the eigenvectors and eigenlines. These are very visually distinct from the basis vectors, so I don't think I need to further distinguish them with colours. Red-green colour blind users should be able to tell them apart with ease.

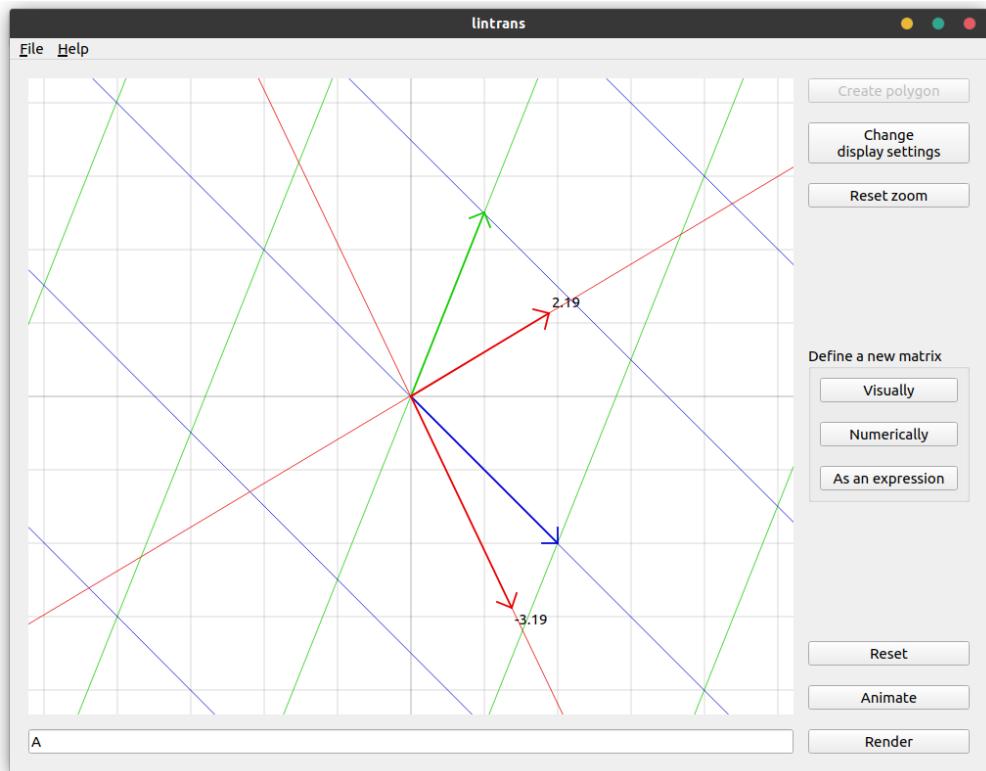


Figure 3.8.2: The old colours

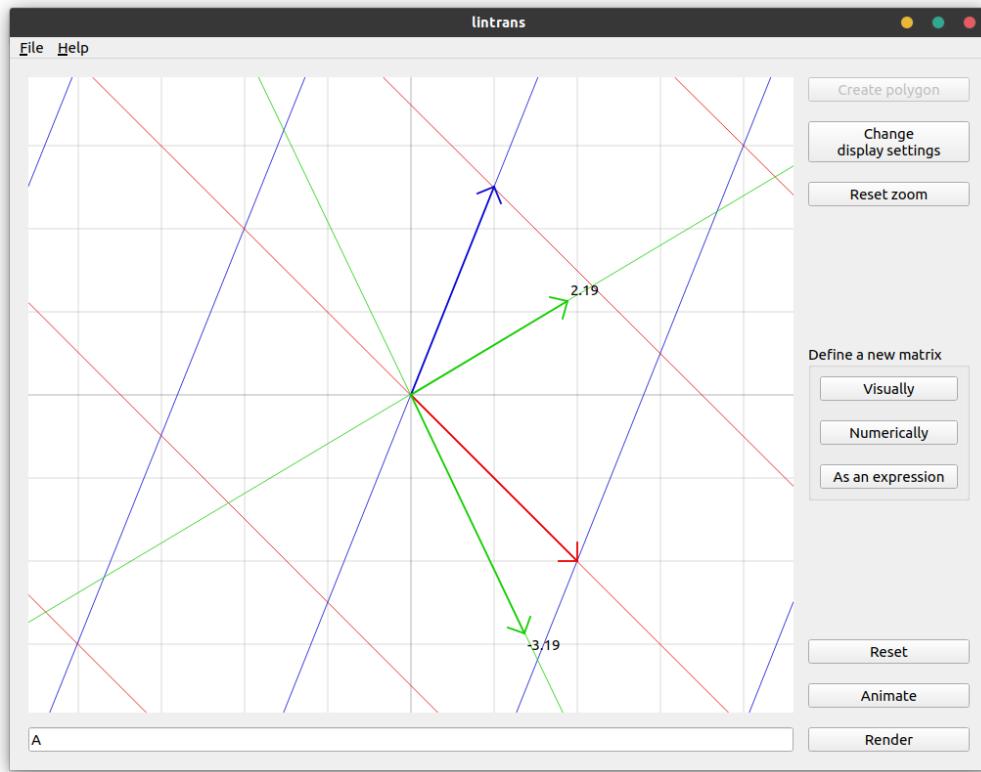


Figure 3.8.3: The new colours

### 3.8.6 Compiling for release

At this point, I felt ready to show `lintrans` to some teachers. Obviously I didn't expect them to have a modern version of Python to run the program, especially not on a school laptop, so I had to compile the program. I had a look at things like Nuitka[29], but I had a few issues with it and it took ages to compile. Eventually I chose PyInstaller[32], which I've used to compile Python programs before. It's fast and effective and works very well.

I use Ubuntu as my daily driver, so I don't really want to spin up a Windows virtual machine and following some exact steps every time I want to compile `lintrans` for release, so I automated the process with GitHub Actions.

```

# 9d0cbe69c596c04a07809a288d72b5e624f485d7
# .github/workflows/compile-release.yaml

1  name: Compile and release
2
3  on:
4    push:
5      tags:
6        - 'v*.*/'
7
8  jobs:
9    check:
10      runs-on: ubuntu-latest
11      steps:
12        - uses: actions/checkout@v2
13
14        - name: Set up Python ${{ matrix.python-version }}
15        uses: actions/setup-python@v2
16        with:
17          python-version: '3.10'
18

```

```
19      - name: Install dependencies
20        run: |
21          pip install --upgrade pip
22          pip install -r requirements.txt -r dev_requirements.txt
23          pip install -e .
24
25      - name: Check
26        run: |
27          mypy src/ tests/
28          flake8 src/ tests/
29          pycodestyle src/ tests/
30          pydocstyle src/ tests/
31
32  test:
33    needs: check
34    runs-on: ${{ matrix.os }}
35
36  strategy:
37    matrix:
38      os: [ubuntu-latest, macos-latest, windows-latest]
39
40  steps:
41    - uses: actions/checkout@v2
42
43    - name: Set up Python 3.10
44      uses: actions/setup-python@v2
45      with:
46        python-version: '3.10'
47
48    - name: Install dependencies
49      run: |
50        pip install --upgrade pip
51        pip install -r requirements.txt -r dev_requirements.txt
52        pip install -e .
53
54    - name: Test
55      run: |
56        pytest
57        pytest --doctest-modules src/
58
59  compile:
60    needs: test
61    runs-on: ${{ matrix.os }}
62
63  strategy:
64    matrix:
65      os: [ubuntu-latest, macos-latest, windows-latest]
66
67  steps:
68    - uses: actions/checkout@v2
69
70    - name: Set up Python 3.10
71      uses: actions/setup-python@v2
72      with:
73        python-version: '3.10'
74
75    - name: Install dependencies
76      run: |
77        pip install --upgrade pip
78        pip install -r requirements.txt -r dev_requirements.txt
79        pip install -e .
80        pip install pyinstaller
81
82    - name: Compile
83      run: pyinstaller --onefile --windowed --distpath=dist --name lintrans-${{ runner.os }}  
↳ src/lintrans/__main__.py
84
85    - name: Upload artifact
86      uses: actions/upload-artifact@v3
87      with:
88        name: ${{ matrix.os }}-binary
89        path: dist/lintrans*
90
```

```

91  publish:
92    needs: compile
93    runs-on: ubuntu-latest
94
95    steps:
96      - uses: actions/checkout@v2
97
98      - name: Download Windows binary
99        uses: actions/download-artifact@v3
100       with:
101         name: windows-latest-binary
102         path: dist/
103
104      - name: Download macOS binary
105        uses: actions/download-artifact@v3
106       with:
107         name: macos-latest-binary
108         path: dist/
109
110      - name: Download Linux binary
111        uses: actions/download-artifact@v3
112       with:
113         name: ubuntu-latest-binary
114         path: dist/
115
116      - name: Check for alpha
117        id: checkalpha
118        run: |
119          isalpha=$(if [ -n "$(echo $GITHUB_REF | grep -o -- 'alpha')" ]; then echo 1; else echo 0; fi)
120          echo "::set-output name=isalpha::$isalpha"
121
122      - name: Upload binaries (normal release)
123        if: steps.checkalpha.outputs.isalpha == 0
124        uses: softprops/action-gh-release@v1
125       with:
126         fail_on_unmatched_files: true
127         prerelease: false
128         draft: true # I'll manually add the title and description when the draft is online
129         files: |
130           dist/lintrans-Windows.exe
131           dist/lintrans-macOS
132           dist/lintrans-Linux
133
134      - name: Upload binaries (pre-release)
135        if: steps.checkalpha.outputs.isalpha == 1
136        uses: softprops/action-gh-release@v1
137       with:
138         fail_on_unmatched_files: true
139         prerelease: true
140         draft: true # I'll manually add the title and description when the draft is online
141         files: |
142           dist/lintrans-Windows.exe
143           dist/lintrans-macOS
144           dist/lintrans-Linux

```

This workflow only runs when I push a tag containing a version number. It firstly installs Python<sup>18</sup> and then lints and tests everything. If that all passes, then it compiles lintrans on Ubuntu, macOS, and Windows. Then it publishes the compiled binaries to a GitHub draft release. I then go in when it's finished to add a description to the release and publish it.

Now that I had this in place, I released version v0.2.0-alpha.

After some minor adjustments, such as including the tag name in the binary name, and installing UPX[57] for the Linux compilation<sup>19</sup>, I released v0.2.0 just 6 hours later.

<sup>18</sup>There's a mistake on line 14. There is no strategy matrix, so '\${{ matrix.python-version }}' is treated as plain text rather than an actual version number. This was caused by copying a previous workflow. The actual version that it installs is fine, though. It's only the name of the step that doesn't look right.

<sup>19</sup>UPX is designed to compress executable files, but I later learned that PyInstaller doesn't even use UPX on Linux; it only uses it on Windows.

I made a few minor adjustments to the workflows, but soon moved on from this version number fiasco and started doing more actual work.

## 3.9 Preparing for v0.2.1

### 3.9.1 Fixing slots and signals

I was perusing the Qt5 documentation when I learned about the difference between the `dialog.finished` signal and the `dialog.accepted` signal. I decided to rework some old code to make better use of these signals.

When defining a new matrix or dialog settings, we only want to save the new data if the user actually accepted the dialog by clicking the confirm button. We don't want to save it if they clicked cancel. However, in the case of the error message dialog, we always want to update the render buttons when it's closed, no matter how the user closed the dialog.

```
# 66242465222a153a5f37c4a1a3c2bd50bfd90933
# src/lintrans/gui/main_window.py

35  class LintransMainWindow(QMainWindow):
...
447  @pyqtSlot(DefineDialog)
448  def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
...
461      # We create a dialog with a deepcopy of the current matrix_wrapper
462      # This avoids the dialog mutating this one
463      dialog = dialog_class(deepcopy(self.matrix_wrapper), self)
464
465      # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
466      dialog.open()
467
468      # So we have to use the accepted signal to call a method when the user accepts the dialog
469      dialog.accepted.connect(self.assign_matrix_wrapper)
...
478  @pyqtSlot()
479  def dialog_change_display_settings(self) -> None:
    """Open the dialog to change the display settings."""
    dialog = DisplaySettingsDialog(self.plot.display_settings, self)
    dialog.open()
    dialog.accepted.connect(lambda: self.assign_display_settings(dialog.display_settings))
...
493  def show_error_message(self, title: str, text: str, info: str | None = None) -> None:
...
511      # This is `finished` rather than `accepted` because we want to update the buttons no matter what
512      dialog.finished.connect(self.update_render_buttons)
```

I also added the `@pyqtSlot()` decorator to all the relevant methods in the matrix definition dialogs. The types in the brackets indicate the signature of the method.

A slot in Qt5 is just a method that is expected to be connected to a signal, so it gets called from the event loop. Using the decorator makes it clear that a method is a slot, and also allows slightly better performance.

```
# 9beff9cf25d3af655e134205572a5668279f42cc
# src/lintrans/gui/dialogs/define_new_matrix.py

67  class DefineDialog(QDialog):
...
138      @abc.abstractmethod
139      @pyqtSlot()
140      def update_confirm_button(self) -> None:
...
143      @pyqtSlot(int)
144      def load_matrix(self, index: int) -> None:
...
155      @abc.abstractmethod
156      @pyqtSlot()
157      def confirm_matrix(self) -> None:
```

```

...
164     class DefineVisuallyDialog(DefineDialog):
...
194         @pyqtSlot()
195         def update_confirm_button(self) -> None:
...
203         @pyqtSlot(int)
204         def load_matrix(self, index: int) -> None:
...
214         @pyqtSlot()
215         def confirm_matrix(self) -> None:
...
226     class DefineNumericallyDialog(DefineDialog):
...
276         @pyqtSlot()
277         def update_confirm_button(self) -> None:
...
288         @pyqtSlot(int)
289         def load_matrix(self, index: int) -> None:
...
305         @pyqtSlot()
306         def confirm_matrix(self) -> None:
...
317     class DefineAsAnExpressionDialog(DefineDialog):
...
348         @pyqtSlot()
349         def update_confirm_button(self) -> None:
...
356         @pyqtSlot(int)
357         def load_matrix(self, index: int) -> None:
...
364         @pyqtSlot()
365         def confirm_matrix(self) -> None:

```

### 3.9.2 Linking in documentation

I've been using Sphinx[52] for my documentation this whole time, and I've been using the Sphinx extension `intersphinx` to link to the Python standard library documentation. It uses a system of binary inventory files which define a reference map between names to use in the documentation, and where to link those names to. I recently learned of the `sphobjinv` Python package, which allows you to easily create your own local inventory files to reference some external source of documentation, such as the Qt5 documentation. I read through the `sphobjinv` documentation[51] and designed a small script to read a custom text file, and create the binary inventory file needed by Sphinx.

```

# 5455265a51666e29ab976152c1a758a422e1004a
# docs/create_objects_inv.py

9     """A simple script to convert my manually curated text file to an inventory file that intersphinx can use.
10
11     ... note::: The URIs in the text file must not have .html suffices
12     """
13
14     import re
15     from glob import glob
16
17     import sphobjinv as soi
18
19
20     pattern = re.compile(r'^(\S+)\s+([^\s]+):([^\s]+)\s+(\d+)\s+(\S+)\s+(\S+$)')
21
22
23     def generate_objects_inv(prefix: str) -> None:
24         """Generate the ``objects.inv`` file for PyQt5.
25
26         We read from ``prefix-objects.txt`` and write to ``prefix-objects.inv``,
27         so if you want to use ``pyqt5-objects.txt``, then the prefix should be ``pyqt5``.
28
29         :param str prefix: The prefix for the object files

```

```

30     """
31     inv = soi.Inventory()
32     inv.project = 'PyQt5'
33     inv.version = '5.15'
34
35     with open(prefix + '-objects.txt', 'r', encoding='utf-8') as f:
36         text = f.read().splitlines()
37
38     for line in text:
39         if line == '' or line.lstrip().startswith('#'):
40             continue
41
42         if (match := re.match(pattern, line)) is None:
43             raise ValueError(f'Every line in {prefix}-objects.txt must match the pattern')
44
45         name, domain, role, priority, uri, disp_name = match.groups()
46
47         inv.objects.append(soi.DataObjStr(
48             name=name, domain=domain, role=role, priority=priority, uri=uri, dispname=disp_name
49         ))
50
51     compressed_text = soi.compress(inv.data_file(contract=True))
52     soi.writebytes(f'source/{prefix}-objects.inv', compressed_text)
53
54
55 def main() -> None:
56     """Call :func:`generate_objects_inv` for every file matching the glob pattern '*-objects.txt'."""
57     for filename in glob('*-objects.txt'):
58         prefix = filename[:-12]
59         print(f'Generating {prefix}-objects.inv')
60         generate_objects_inv(prefix)
61
62
63 if __name__ == '__main__':
64     main()

```

Line 11 should say ‘must have .html suffices’.

```

# aab8e88b0e2cd8e8038c9935031c74bcd8e0ad5c
# docs/pyqt5-objects.txt

1 # This format is:
2 # <reference name> <domain><role> <priority> <URI> <display name>
3 # Sphinx handles the prefix for the URI
4 # If the display name is '-', then it's the same as the reference name
5
6 # === Classes
7
8 QApplication py:class 1 qapplication.html -
9 QDialog      py:class 1 qdialog.html      -
10 QKeyEvent    py:class 1 qkeyevent.html   -
11 QPainter     py:class 1 qpainter.html    -
12 QPaintEvent   py:class 1 qpaintevent.html -
13 QWheelEvent   py:class 1 qwheelevent.html -
14 QWidget      py:class 1 qwidget.html     -
15
16 # === Methods
17
18 QPainter.drawLine:iiii py:method 1 qpainter.html#drawLine-2 QPainter.drawLine()
19
20 # === Signals
21
22 QComboBox.activated py:method 1 qcombobox.html#activated -
23 QDialog.accepted   py:method 1 qdialog.html#accepted   -
24
25 # These are in full form so that autodoc can reference base classes and param types
26
27 PyQt5.QtGui.QKeyEvent  py:class 1 qkeyevent.html   -
28 PyQt5.QtGui.QPainter   py:class 1 qpainter.html    -
29 PyQt5.QtGui.QPaintEvent py:class 1 qpaintevent.html -
30 PyQt5.QtGui.QWheelEvent py:class 1 qwheelevent.html -

```

```

31 PyQt5.QtWidgets.QDialog py:class 1 qdialog.html      -
32 PyQt5.QtWidgets.QWidget py:class 1 qwidget.html     -

```

I then just had to change all the references to Qt5 things in the documentation and then Sphinx would automatically link all the Qt5 references to their appropriate links, as defined in this file.

### 3.9.3 Improving tests

I made some small improvements to the unit tests by making sure they handled greedy index parsing, which means that something like A^2 3B will get parsed as A^{23}B because whitespace is ignored, as well asserting that all invalid expressions raise `MatrixParseError`. I also added the copyright comment to the test files.

This was a tiny change, but worth noting.

```

# c07d97024e1fe00ab110f43e5c7e6737c955d680
# tests/matrices/test_parse_and_validate_expression.py

41 expressions_and_parsed_expressions: list[tuple[str, MatrixParseList]] = [
...
50     ('A^12', [[(' ', 'A', '12')]]),
51     ('A^234', [[(' ', 'A', '234')]]),
...
55     ('A^2 3B', [[(' ', 'A', '23'), (' ', 'B', '')]]),
...
72     ('2.14A^{3} 4.5\rot(14.5)^{-1} + 8.5B^T 5.97C^{14} - 3.14D^{-1} 6.7E^T',
73      [[('2.14', 'A', '3'), ('4.5', '\rot(14.5)', '-1'), [('8.5', 'B', 'T'), ('5.97', 'C', '14')]]],
...
75 ]
...
78 def test_parse_matrix_expression() -> None:
    """Test the parse_matrix_expression() function."""
    for expression, parsed_expression in expressions_and_parsed_expressions:
        # Test it with and without whitespace
        assert parse_matrix_expression(expression) == parsed_expression
        assert parse_matrix_expression(expression.replace(' ', '')) == parsed_expression

# 70e1a7271a61f3009cc4d342f46743b248498a1c
# tests/matrices/test_parse_and_validate_expression.py

26 invalid_inputs: list[str] = [
27     ' ', 'rot()', 'A^', 'A^{1.2}', 'A^{3.4}', '1,2A', 'ro(12)', '5', '12^2', '^T', '^{12}',
28     'A^{13}', 'A^3', 'A^A', '^2', 'A--B', '--A', '+A', '--1A', 'A--B', 'A--1B', '.A', '1.A'
29
30     'This is 100% a valid matrix expression, I swear'
31 ]
...
86 def test_parse_error() -> None:
    """Test that parse_matrix_expression() raises a MatrixParseError."""
    for expression in invalid_inputs:
        with pytest.raises(MatrixParseError):
            parse_matrix_expression(expression)

```

```
(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 30 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [  3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [  6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED [ 10%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 13%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 16%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression PASSED [ 20%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED [ 23%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED [ 26%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 30%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 33%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 36%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 40%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 43%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 46%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 50%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 53%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED [ 56%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED [ 60%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 63%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED [ 66%]
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED [ 70%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED [ 73%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 76%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED [ 80%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED [ 83%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED [ 86%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED [ 90%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 93%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 96%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [100%]

===== 30 passed in 0.36s =====
```

Figure 3.9.1: Running pytest with the new tests

### 3.9.4 The Windows version file

Windows stores metadata for .exe files inside the .exe files themselves[58][59]. PyInstaller lets you embed that metadata when compiling on Windows, using a version file[33]. Obviously, I wanted to include this metadata in my compiled .exe in the release.

I created a simple `precompile.py` script that would create different pre-compilation artefacts. I could then use these in the compilation workflow for GitHub Actions. I started with just Windows, but obviously I'm going to expand into Linux and macOS as well later.

```
# 2126959cb6f836b1bc6c92dad859b43cbd86e1ab
# precompile.py

9     """A simple pre-compile script for the automated GitHub page compilation action."""
10
11    import re
12    import sys
13
14
15    def precompile_macos() -> None:
16        """Run the pre-compile steps for macOS."""
17        print('Pre-compile for macOS not implemented yet')
18
19
20    def precompile_windows(args: list[str]) -> None:
21        """Run the pre-compile steps for Windows."""
22        print('Pre-compiling for Windows')
23
24        if len(args) < 1:
25            raise ValueError('Windows pre-compile needs tag name argument')
26
27        tag_name = args[0]
28
29        if (m := re.match(r'v(\d+)\.(.\d+)\.(.\d+)(-\alpha)?', tag_name)) is not None:
30            major, minor, patch, alpha = m.groups()
```

```
32     else:
33         raise ValueError('Tag name must match format')
34
35     if alpha is not None:
36         flags = '0x2'
37     else:
38         flags = '0x0'
39
40     version_tuple = f'{major}, {minor}, {patch}, 0'
41
42     version_info = f'''VSVersionInfo(
43     ffi=FixedFileInfo(
44         filevers=({version_tuple}),
45         prodvers=({version_tuple}),
46         mask=0x3f,
47         flags={flags},
48         OS=0x40004,
49         fileType=0x1,
50         subtype=0x0,
51         date=(0, 0)
52     ),
53     kids=[

54         StringFileInfo(
55             [
56                 StringTable(
57                     '040904B0',
58                     kids=[
59                         StringStruct('CompanyName', 'D. Dyson (DoctorDalek1963)'),
60                         StringStruct('FileDescription', 'Linear transformation visualizer'),
61                         StringStruct('FileVersion', '{tag_name}'),
62                         StringStruct('InternalName', 'lintrans'),
63                         StringStruct('LegalCopyright', '(C) D. Dyson (DoctorDalek1963) under GPLv3'),
64                         StringStruct('OriginalFilename', 'lintrans-Windows-{tag_name}.exe'),
65                         StringStruct('ProductName', 'lintrans'),
66                         StringStruct('ProductVersion', '{tag_name}')
67                     ]
68                 )
69             ]
70         ),
71         VarFileInfo([VarStruct('Translation', [2057, 1200])])
72     ]
73 )
74 ...
75
76     with open('version_info.txt', 'w', encoding='utf-8') as f:
77         f.write(version_info)
78
79     print('Version file written to version_info.txt')
80
81
82 def main(args: list[str]) -> None:
83     """Evaluate the arguments and pre-compile accordingly."""
84     if len(args) < 1:
85         raise ValueError('Script must be supplied with the name of an operating system.')
86
87     os_name = args[0].lower()
88
89     if os_name == 'linux':
90         print("Linux doesn't need any pre-compilation")
91
92     elif os_name == 'macos':
93         precompile_macos()
94
95     elif os_name == 'windows':
96         precompile_windows(args[1:])
97
98     else:
99         raise ValueError(f'Unsupported operating system "{os_name}"')
100
101
102 if __name__ == '__main__':
103     main(sys.argv[1:])
```

```
8   jobs:
...
60     compile:
...
68       steps:
...
87         - name: Pre-compile
88           run: python precompile.py ${{ runner.os }} $GITHUB_REF_NAME
89           shell: bash
90
91         - name: Compile (Linux)
92           if: runner.os == 'Linux'
93           run: pyinstaller --onefile --windowed --distpath=./dist --name lintrans-${{ runner.os }}-$GITHUB_REF_NAME
94           → src/lintrans/_main_.py
95           shell: bash
96
97         - name: Compile (macOS)
98           if: runner.os == 'macOS'
99           run: pyinstaller --onefile --windowed --distpath=./dist --name lintrans-${{ runner.os }}-$GITHUB_REF_NAME
100          → src/lintrans/_main_.py
101          shell: bash
102
103         - name: Compile (Windows)
104           if: runner.os == 'Windows'
105           run: pyinstaller --onefile --windowed --distpath=./dist --version-file version_info.txt --name
106           → lintrans-${{ runner.os }}-$GITHUB_REF_NAME src/lintrans/_main_.py
107           shell: bash
```

I quickly realised that this design would make the compilation process more complicated, since the process would be in separate parts. Instead, I decided to create a unified compilation script, which runs a pre-compile step dependent on the operating system, and then compiles the program with the `PyInstaller.__main__.run()` function.

```
# ca674c7f7d61e8eed3410d456787cf5b2bc28e5
# compile.py

"""A simple pre-compile script for the automated GitHub page compilation action."""

import argparse
import os
import re
import shutil
import sys
from textwrap import dedent

from PyInstaller.__main__ import run as run_pyi

import lintrans

class Compiler:
    """A simple class to encapsulate compilation logic."""

    def __init__(
        self, *,
        platform: str | None = None,
        version_name: str | None = None,
        filename: str | None = None
    ):
        """Create a Compiler object."""
        self.platform = platform if platform else sys.platform
        self.version_name = version_name if version_name else lintrans.__version__
        self.filename = filename if filename else 'lintrans'

    def _precompile_windows(self) -> None:
        """Pre-compile for Windows."""
        if (m := re.match(r'v?(?P<major>\d+)\.(?P<minor>\d+)\.(?P<patch>\d+)(-\alpha)?', self.version_name)) is not None:
```

```
40         major, minor, patch, alpha = m.groups()
41
42     else:
43         raise ValueError('Tag name must match format')
44
45     if alpha is not None:
46         flags = '0x2'
47     else:
48         flags = '0x0'
49
50     version_tuple = f'{major}, {minor}, {patch}, 0'
51
52     version_info = dedent(f'''
53     VSVersionInfo(
54         ffi=FixedFileInfo(
55             filevers=(version_tuple),
56             prodvers=(version_tuple),
57             mask=0x3f,
58             flags={flags},
59             OS=0x40004,
60             fileType=0x1,
61             subtype=0x0,
62             date=(0, 0)
63         ),
64         kids=[
65             StringFileInfo(
66                 [
67                     StringTable(
68                         '040904B0',
69                         kids=[
70                             StringStruct('CompanyName', 'D. Dyson (DoctorDalek1963)'),
71                             StringStruct('FileDescription', 'Linear transformation visualizer'),
72                             StringStruct('FileVersion', '{self.version_name}'),
73                             StringStruct('InternalName', 'lintrans'),
74                             StringStruct('LegalCopyright', '(C) D. Dyson (DoctorDalek1963) under GPLv3'),
75                             StringStruct('OriginalFilename', '{self.filename}.exe'),
76                             StringStruct('ProductName', 'lintrans'),
77                             StringStruct('ProductVersion', '{self.version_name}')
78                         ]
79                     )
80                 ]
81             ),
82             VarFileInfo([VarStruct('Translation', [2057, 1200])])
83         ]
84     )
85 ''')
86
87     with open('version_info.txt', 'w', encoding='utf-8') as f:
88         f.write(version_info)
89
90     print('Version file written to version_info.txt')
91
92     def precompile(self) -> None:
93         """Pre-compile for the appropriate operating system."""
94         if self.platform == 'linux':
95             print("Linux doesn't need any pre-compilation")
96
97         elif self.platform == 'darwin':
98             print("macOS doesn't need any pre-compilation")
99
100        elif self.platform == 'win32':
101            print('Pre-compiling for Windows')
102            self._precompile_windows()
103
104        else:
105            raise ValueError(f'Unsupported operating system "{self.platform}"')
106
107    def _get_pyi_args(self) -> list[str]:
108        """Return the common args for PyInstaller."""
109        return [
110            'src/lintrans/_main__.py',
111            '--onefile',
112            '--windowed',
```

```
113         '--distpath=./dist',
114         '--workpath=./build',
115         '--noconfirm',
116         '--clean',
117         f'--name={self.filename}'
118     ]
119
120     def _compile_macos(self) -> None:
121         """Compile for macOS."""
122         run_pyi(self._get_pyi_args())
123
124         os.rename(os.path.join('dist', self.filename + '.app'), self.filename + '.app')
125
126     def _compile_linux(self) -> None:
127         """Compile for Linux."""
128         run_pyi(self._get_pyi_args())
129
130         os.rename(os.path.join('dist', self.filename), self.filename)
131
132     def _compile_windows(self) -> None:
133         """Compile for Windows."""
134         if not os.path.isfile('version_info.txt'):
135             raise ValueError('Windows compilation requires version_info.txt from pre-compilation')
136
137         run_pyi([
138             *self._get_pyi_args(),
139             '--version-file',
140             'version_info.txt'
141         ])
142
143         os.remove('version_info.txt')
144
145         os.rename(os.path.join('dist', self.filename + '.exe'), self.filename + '.exe')
146
147     def compile(self) -> None:
148         """Compile for the appropriate operating system."""
149         if self.platform == 'darwin':
150             self._compile_macos()
151
152         elif self.platform == 'linux':
153             self._compile_linux()
154
155         elif self.platform == 'win32':
156             self._compile_windows()
157
158         else:
159             raise ValueError(f'Unsupported operating system "{self.platform}"')
160
161         shutil.rmtree('dist')
162         shutil.rmtree('build')
163         os.remove(self.filename + '.spec')
164
165
166     def main() -> None:
167         """Run any pre-compilation, and then compile."""
168         parser = argparse.ArgumentParser(description='Compile this version of lintrans for your operating system',
169                                         add_help=True)
170         parser.add_argument('-f', '--filename', type=str, required=False, default=None, help='the filename (without
171                                         extension)')
172         parser.add_argument('-v', '--version', type=str, required=False, default=None, help='the version name in the
173                                         format v1.2.3')
174
175         args = parser.parse_args()
176
177         compiler = Compiler(filename=args.filename, version_name=args.version)
178         compiler.precompile()
179         compiler.compile()
180
181
182         if __name__ == '__main__':
183             main()
```

This new compilation script captures the whole process. On Linux or macOS, it just compiles the program with PyInstaller. On Windows, it has to generate the version file, then compile the program with an additional argument to include the version file. I then updated the GitHub Actions workflow to use this new compilation script.

```
# e47fe732954bf018128bdcb5ee9c354910517f36
# .github/workflows/compile-release.yaml

8   jobs:
...
60     compile:
...
68       steps:
...
87         - name: Compile
          run: python compile.py -f lintrans-${{ runner.os }}-${{ env.GITHUB_REF_NAME }} -v $GITHUB_REF_NAME
```

### 3.9.5 Compiling for macOS

Compiling for macOS is considerably more difficult. I run Ubuntu as my primary operating system. I used to use Windows and I have a Windows 10 virtual machine, so compiling for Windows was never an issue. But I've never used a Mac, and Apple don't like people installing macOS on non-Apple hardware. Getting a virtual machine set up running macOS Monterey was quite difficult, but I eventually managed to get it working somewhat properly.

Once I had `lintrans` compiling on macOS, I wanted to do something similar to what I did with Windows, where I added extra metadata to the executable. In macOS, executables are bundled as `.app` files, which are just directory structures, containing the necessary files and metadata[12]. All the metadata for an application bundle is contained in the `Info.plist` file in the bundle[9][8]. After reading the documentation for these files, I created one for `lintrans`.

```
# e716000521c92259ed4a1b33ab37e3860a7b7875
# compile.py

23   class Compiler:
...
92     def _macos_replace_info_plist(self) -> None:
93         """Replace the Info.plist file in the macOS app."""
94         short_version_name = self.version_name
95
96         if short_version_name.startswith('v'):
97             short_version_name = short_version_name[1:]
98
99         if short_version_name.endswith('-alpha'):
100            short_version_name = short_version_name[:-6]
101
102         new_info_plist = dedent(f'''
103             <?xml version="1.0" encoding="UTF-8"?>
104             <!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/PropertyList-1.0.dtd"
105             <plist version="1.0">
106             <dict>
107                 <key>CFBundleDisplayName</key>
108                 <string>lintrans</string>
109                 <key>CFBundleExecutable</key>
110                 <string>lintrans</string>
111                 <key>CFBundleIconFile</key>
112                 <string>icon-windowed.icns</string>
113                 <key>CFBundleIdentifier</key>
114                 <string>lintrans</string>
115                 <key>CFBundleInfoDictionaryVersion</key>
116                 <string>6.0</string>
117                 <key>CFBundleName</key>
118                 <string>lintrans</string>
119                 <key>CFBundleType</key>
120                 <string>APPL</string>
```

```

121             <key>CFBundleVersion</key>
122             <string>{self.version_name}</string>
123             <key>CFBundleShortVersionString</key>
124             <string>{short_version_name}</string>
125             <key>NSHighResolutionCapable</key>
126             <true/>
127             <key>NSHumanReadableCopyright</key>
128             <string>(C) D. Dyson (DoctorDalek1963) under GPLv3</string>
129         </dict>
130     </plist>
131     '''[1:])
132
133     with open(os.path.join(self.filename + '.app', 'Contents', 'Info.plist'), 'w', encoding='utf-8') as f:
134         f.write(new_info_plist)
...
149     def _compile_macos(self) -> None:
150         """Compile for macOS."""
151         run_pyi(self._get_pyi_args())
152
153         os.rename(os.path.join('dist', self.filename + '.app'), self.filename + '.app')
154
155         self._macos_replace_info_plist()

```

This could would automatically generate the `Info.plist` file and write it to the correct place. However, I couldn't distribute this bundled app, since Apple requires an app to be signed by a trusted author before other people can download and run that code on their own Apple devices[7]. And unfortunately, Apple charges \$99 per year for membership to their 'Apple Developer Program', which is required to become a trusted developer[10]<sup>20</sup>.

Microsoft also wants its developers to sign their code for security and trust, and also charges for this privilege. But on Windows, you can run a foreign, unsigned app so long as you dismiss the potential virus warning. On macOS, it's completely forbidden.

I don't particularly want to pay \$99 per year to compile `lintrans` for macOS, when my audience on that platform is realistically almost zero, so I just removed macOS from the GitHub Actions publish workflow. For anyone that wants to run `lintrans` on macOS, I will provide instructions to compile it from source, since I can't distribute a binary file that I built myself. I will however continue to run the unit tests and compile the program on macOS in GitHub Actions, to ensure that everything works fine on that platform.

### 3.9.6 Supporting flags

Most Linux apps support command line arguments and/or flags<sup>21</sup>, and so I wanted to support these with `lintrans`. I wanted one flag to display help for the program, and one flag to display the version number of the program. Implementing this was very simple and I didn't bother using a library like `argparse`; I just used `sys.argv`.

```

# ffc603f1bf049811cb927f879ce7989456f6a537
# src/lintrans/__main__.py

9     """This module provides a :func:`main` function to interpret command line arguments and run the program."""
10
11    import sys
12    from textwrap import dedent
13
14    from lintrans import __version__
15    from lintrans.gui import main_window
16
17
18    def main(prog_name: str, args: list[str]) -> None:
19        """Interpret program-specific command line arguments and run the main window in most cases.

```

<sup>20</sup>The price is listed in the small print at the bottom of the page.

<sup>21</sup>For explanation and examples, see <https://betterdev.blog/command-line-arguments-anatomy-explained/>

```

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     ``prog_name`` is ``sys.argv[0]`` when this script is run with ``python -m lintrans``.
25
26     :param str prog_name: The name of the program
27     :param list[str] args: The other arguments to the program
28     """
29
30     if '-h' in args or '--help' in args:
31         print(dedent(f'''
32             Usage: {prog_name} [option]
33
34             Options:
35                 -h, --help      Display this help text and exit
36                 -V, --version   Display the version information and exit
37
38             Any other options will get passed to the QApplication constructor.
39             If you don't know what that means, then don't provide any arguments and just the run the program.'''[1:]))
40
41     elif '-V' in args or '--version' in args:
42         print(dedent(f'''
43             lintrans (version {__version__})
44             The linear transformation visualizer
45
46             Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
47
48             This program is licensed under GNU GPLv3, available here:
49             <https://www.gnu.org/licenses/gpl-3.0.html>'''[1:]))
50
51     else:
52         main_window.main(args)
53
54     if __name__ == '__main__':
55         main(sys.argv[0], sys.argv[1:])

```

Here is the expected output when using these flags at a shell prompt:

```

$ python -m lintrans --help
Usage: /home/dyson/repos/lintrans/src/lintrans/__main__.py [option]

Options:
    -h, --help      Display this help text and exit
    -V, --version   Display the version information and exit

Any other options will get passed to the QApplication constructor.
If you don't know what that means, then don't provide any arguments and just the run the program.
$ python -m lintrans --version
lintrans (version 0.2.0)
The linear transformation visualizer

Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)

This program is licensed under GNU GPLv3, available here:
<https://www.gnu.org/licenses/gpl-3.0.html>

```

### 3.9.7 Adding the about dialog

In addition to the help and version information available from the command line, most apps with a GUI provide a graphical way to access information about the app, typically in the form of an about box. I wanted to do this for `lintrans`. I had intended to have this from the start, but it now felt like the right time to implement it, since I was preparing to release version `0.2.1`.

To do this, I create a new file to house the new dialog class, and then added the functionality to the original button, so that it would now open the new dialog.

```
7 # 7423ffff72f09b5f5a3253c734d42c4e7c3182efe
8 # src/lintrans/gui/dialogs/misc.py
9
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74
75
```

```
# """This module provides miscellaneous dialog classes like :class:`AboutDialog`."""
from __future__ import annotations
import platform
from PyQt5 import QtWidgets
from PyQt5.QtCore import Qt
from PyQt5.QtWidgets import QDialog, QVBoxLayout
import lintrans

class AboutDialog(QDialog):
    """A simple dialog class to display information about the app to the user.

    It only has an :meth:`__init__` method because it only has label widgets, so no other methods are necessary
    here.
    """
    def __init__(self, *args, **kwargs):
        """Create an :class:`AboutDialog` object with all the label widgets."""
        super().__init__(*args, **kwargs)

        self.setWindowTitle('About lintrans')

    # === Create the widgets

    label_title = QtWidgets.QLabel(self)
    label_title.setText(f'lintrans {version {lintrans.__version__}}')
    label_title.setAlignment(Qt.AlignCenter)

    font_title = label_title.font()
    font_title.setPointSize(font_title.pointSize() * 2)
    label_title.setFont(font_title)

    label_version_info = QtWidgets.QLabel(self)
    label_version_info.setText(
        f'With Python version {platform.python_version()}\n'
        f'Running on {platform.platform()}\n'
    )
    label_version_info.setAlignment(Qt.AlignCenter)

    label_info = QtWidgets.QLabel(self)
    label_info.setText(
        'lintrans is a program designed to help visualise<br>'
        '2D linear transformations represented with matrices.<br><br>'
        'It\'s designed for teachers and students and any feedback<br>'
        'is greatly appreciated at <a href="https://github.com/DoctorDalek1963/lintrans" '
        'style="color: black;">my GitHub page</a><br>or via email '
        '<a href="mailto:dyson.dyson@icloud.com" style="color: black;">dyson.dyson@icloud.com</a>.'
    )
    label_info.setAlignment(Qt.AlignCenter)
    label_info.setTextFormat(Qt.RichText)
    label_info.setOpenExternalLinks(True)

    label_copyright = QtWidgets.QLabel(self)
    label_copyright.setText(
        'This program is free software.<br>Copyright 2021-2022 D. Dyson (DoctorDalek1963).<br>'
        'This program is licensed under GPLv3, which can be found '
        '<a href="https://www.gnu.org/licenses/gpl-3.0.html" style="color: black;">here</a>.'
    )
    label_copyright.setAlignment(Qt.AlignCenter)
    label_copyright.setTextFormat(Qt.RichText)
    label_copyright.setOpenExternalLinks(True)

    # === Arrange the widgets

    self.setContentsMargins(10, 10, 10, 10)
```

```

76     vlay = QVBoxLayout()
77     vlay.setSpacing(20)
78     vlay.addWidget(label_title)
79     vlay.addWidget(label_version_info)
80     vlay.addWidget(label_info)
81     vlay.addWidget(label_copyright)
82
83     self.setLayout(vlay)
84
85     self.setFixedSize(self.baseSize())
86
87
88
89
90
91
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99
100
101
102
103
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105
106
107
108
109
110
111
112
113
114
115
116
117
# 7423ffff72f09b5f5a3253c734d42c4e7c3182efe
# src/lintrans/gui/main_window.py

36 class LintransMainWindow(QMainWindow):
...
42     def __init__(self):
...
44         self.menu_help = QtWidgets.QMenu(self.menuBar())
45         self.menu_help.setTitle('&Help')
...
47         self.action_about = QtWidgets.QAction(self)
48         self.action_about.setText('&About')
49         self.action_about.triggered.connect(lambda: dialogs.AboutDialog(self).open())
...
51         self.menu_help.addAction(self.action_about)

```

This feature works just as expected.

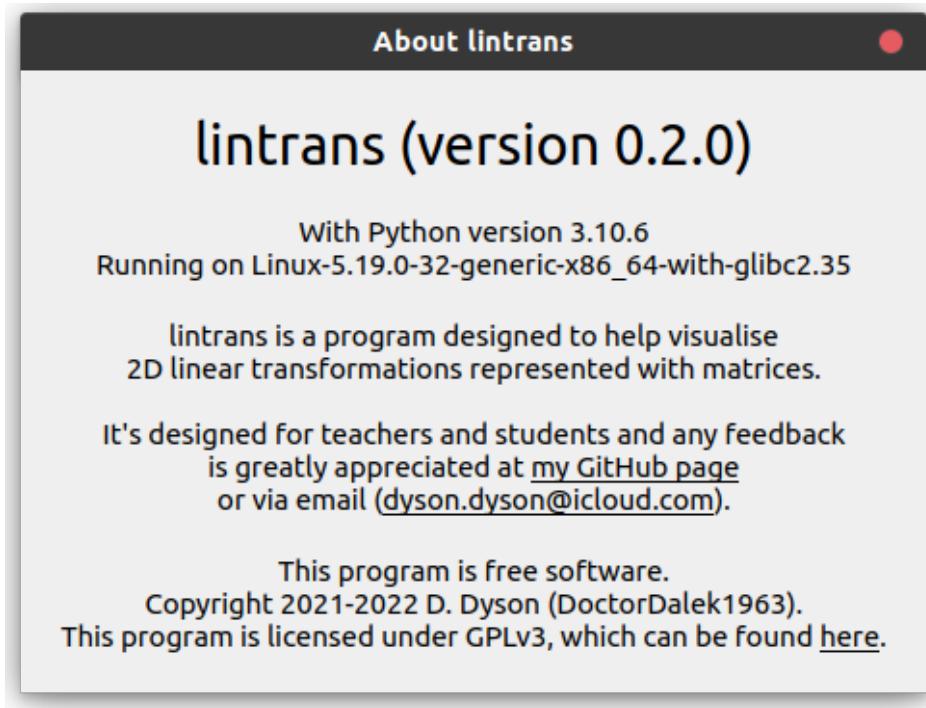


Figure 3.9.2: The about dialog

### 3.9.8 Creating the `FixedSizeDialog` class

Currently, several dialogs are a fixed size, meaning they can't be resized. Qt5 doesn't have the option to make a dialog non-resizable - that's only available for whole windows - so to achieve this effect, I had to add the line `self.setFixedSize(self.baseSize())` to the end of the constructor for every fixed

size dialog<sup>22</sup>. This was easy to forget and it didn't make it immediately clear which dialogs were fixed size and which weren't.

To fix this, I decided to use a different technique, by overriding the `open()` method of the dialog. This method gets called when the dialog is first opened. If I called the superclass' implementation first to do all the actual opening logic, then I could use that same previous technique to set the fixed size to whatever Qt5 had calculated it to be. By overriding a method, I could put that override into a simple superclass called `FixedSizeDialog` and then make all fixed size dialogs inherit from this class instead of just `QDialog`.

```
# a59ea87fb37fc593cf0bae3066bdbd24be656798
# src/lintrans/gui/dialogs/misc.py

20  class FixedSizeDialog(QDialog):
21      """A simple superclass to create modal dialog boxes with fixed size.
22
23      We override the :meth:`open` method to set the fixed size as soon as the dialog is opened modally.
24      """
25
26      def open(self) -> None:
27          """Override :meth:`QDialog.open` to set the dialog to a fixed size."""
28          super().open()
29          self.setFixedSize(self.size())
...
32  class AboutDialog(FixedSizeDialog):

# a59ea87fb37fc593cf0bae3066bdbd24be656798
# src/lintrans/gui/dialogs/define_new_matrix.py

68  class DefineDialog(FixedSizeDialog):

# a59ea87fb37fc593cf0bae3066bdbd24be656798
# src/lintrans/gui/dialogs/settings.py

21  class SettingsDialog(FixedSizeDialog):
```

I used `self.size()` here instead of `self.baseSize()` like before. There doesn't seem to be much difference, but the docs seem to suggest that `self.size()` is more appropriate for this use case[43][46].

### 3.9.9 Increasing minimum grid spacing

When you zoom out, the grid lines get closer and closer together. I previously limited this to 1 pixel, since the program would hang or crash if it was any lower. However, having the grid lines that close together made it very hard to see what was happening. I could easily fix this by limiting the minimum grid spacing to say, 5 pixels.

---

<sup>22</sup>This works because Qt5 needs to arrange all the widgets and allocate space for all of them first, and then we can use that calculated size as the fixed size.

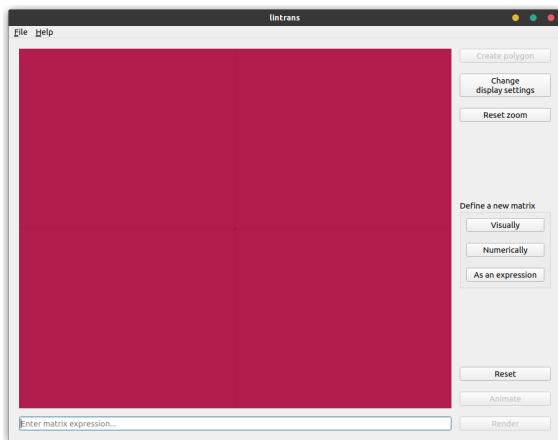


Figure 3.9.3: Fully zoomed out before

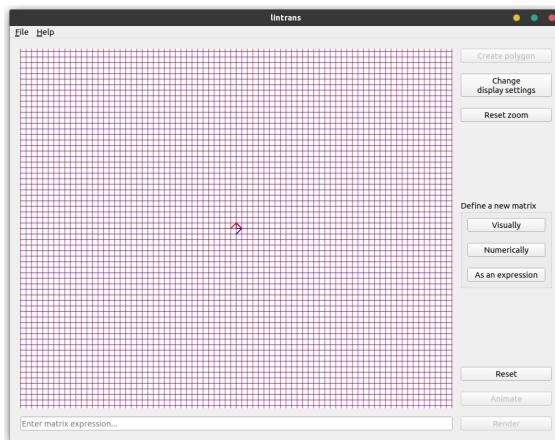


Figure 3.9.4: Fully zoomed out after

```
# 51d35018c81deaaf7e32646b1f99d6e46643bf24
# src/lintrans/gui/plots/classes.py

23 class BackgroundPlot(QWidget):
...
39     minimum_grid_spacing: int = 5
...
154     def wheelEvent(self, event: QWheelEvent) -> None:
155         """Handle a :class:`QWheelEvent` by zooming in or out of the grid."""
156         # angleDelta() returns a number of units equal to 8 times the number of degrees rotated
157         degrees = event.angleDelta() / 8
158
159         if degrees is not None:
160             new_spacing = max(1, self.grid_spacing + degrees.y())
161
162             if new_spacing >= self.minimum_grid_spacing:
163                 self.grid_spacing = new_spacing
164
165         event.accept()
166         self.update()
```

### 3.9.10 Creating a changelog

I've known about changelogs for a long time. They're used to keep track of changes to a project over time. I recently learned about the project 'keep a changelog', which tries to create a standard for changelog formats[25]. I want to have a proper changelog for lintrans, so I decided to implement one.

```
<!-- 47c68c7ff4780d0e2c374cf12b9b54c031277af6d -->
<!-- CHANGELOG.md -->

1 # Changelog
2
3 All notable changes to this project will be documented in this file.
4
5 The format is based on [Keep a Changelog](https://keepachangelog.com/en/1.0.0/),
6 and this project adheres to [Semantic Versioning](https://semver.org/spec/v2.0.0.html).
7
8 ## [Unreleased]
9
10 ### Added
11
12 - Explicit `@pyqtSlot` decorators
13 - Link to Qt5 docs in project docs with intersphinx
14 - Copyright comment in tests and `setup.py`
15 - Create version file for Windows compilation
16 - Create full compile.py script
17 - Add `Info.plist` file for macOS compilation
```

```

18 - Support --help and --version flags in `__main__.py`
19 - Create about dialog in help menu
20 - Implement minimum grid spacing
21
22 ### Fixed
23
24 - Fix problems with compile script
25 - Fix small bugs and docstrings
26
27 ## [0.2.0] - 2022-03-11
28
29 There were alpha tags before this, but I wasn't properly adhering to semantic versioning, so I'll start the
→ changelog here.
30
31 If I'd been using semantic versioning from the start, there would much more changelog here, but instead, I'll just
→ summarise the features.
32
33 ### Added
34
35 - Matrix context with the `MatrixWrapper` class
36 - Parsing and evaluating matrix expressions
37 - A simple GUI with a viewport to render linear transformations
38 - Simple dialogs to create matrices and assign them to names
39 - Ability to render and animate linear transformations parsed from defined matrices
40 - Ability to zoom in and out of the viewport
41 - Add dialog to change display settings
42
43 [Unreleased]: https://github.com/DoctorDalek1963/lintrans/compare/v0.2.0...HEAD
44 [0.2.0]: https://github.com/DoctorDalek1963/lintrans/compare/13600cc6ff6299dc4a8101a367bc52fe08607554...v0.2.0

```

### 3.9.11 Releasing v0.2.1

Now all I had to do for the release was update the version number in `__init__.py` and update the changelog to include the changes under the correct heading, and add a new, empty ‘Unreleased’ heading.

```

# d47f63eb0bcd89cff5ed19afe2fc63899edf1d9
# src/lintrans/__init__.py

13 __version__ = '0.2.1'

<!-- d47f63eb0bcd89cff5ed19afe2fc63899edf1d9 -->
<!-- CHANGELOG.md -->

1 # Changelog
2
3 All notable changes to this project will be documented in this file.
4
5 The format is based on [Keep a Changelog](https://keepachangelog.com/en/1.0.0/),
6 and this project adheres to [Semantic Versioning](https://semver.org/spec/v2.0.0.html).
7
8 ## [Unreleased]
9
10 Nothing here yet...
11
12 ## [0.2.1] - 2022-03-22
13
14 ### Added
15
16 - Explicit `@pyqtSlot` decorators
17 - Link to Qt5 docs in project docs with intersphinx
18 - Copyright comment in tests and `setup.py`
19 - Create version file for Windows compilation
20 - Create full compile.py script
21 - Add `Info.plist` file for macOS compilation
22 - Support --help and --version flags in `__main__.py`
23 - Create about dialog in help menu
24 - Implement minimum grid spacing

```

```

25
26 ### Fixed
27
28 - Fix problems with compile script
29 - Fix small bugs and docstrings
30
31 ## [0.2.0] - 2022-03-11
32
33 There were alpha tags before this, but I wasn't properly adhering to semantic versioning, so I'll start the
→ changelog here.
34
35 If I'd been using semantic versioning from the start, there would much more changelog here, but instead, I'll just
→ summarise the features.
36
37 ### Added
38
39 - Matrix context with the `MatrixWrapper` class
40 - Parsing and evaluating matrix expressions
41 - A simple GUI with a viewport to render linear transformations
42 - Simple dialogs to create matrices and assign them to names
43 - Ability to render and animate linear transformations parsed from defined matrices
44 - Ability to zoom in and out of the viewport
45 - Add dialog to change display settings
46
47 [Unreleased]: https://github.com/DoctorDalek1963/lintrans/compare/v0.2.1...HEAD
48 [0.2.1]: https://github.com/DoctorDalek1963/lintrans/compare/v0.2.0...v0.2.1
49 [0.2.0]: https://github.com/DoctorDalek1963/lintrans/compare/13600cc6ff6299dc4a8101a367bc52fe08607554...v0.2.0

```

**v0.2.1**

github-actions released this Mar 22, 2022 Compare [v0.2.1](#) ↗ d47f63e ↗

Make small improvements in code, such as slightly improving performance with slot decorators and adding minimum grid spacing. The main thing in this update is the compile script, which allows users to compile a standalone executable on their own machines.

The Linux binary should work fine, but if you use the Windows .exe file, you will get a warning that the program may be unsafe. This is expected and you can just ignore it. There's no binary for macOS due to Apple code signing issues.

If you're running macOS, then you will need to compile the program from source. This is also an option on Linux and Windows. Instructions can be found [here](#).

**Added**

- Explicit @pyqtslot decorators
- Link to Qt5 docs in project docs with intersphinx
- Copyright comment in tests and setup.py
- Create version file for Windows compilation
- Create full compile.py script
- Add Info.plist file for macOS compilation
- Support --help and --version flags in \_\_main\_\_.py
- Create about dialog in help menu
- Implement minimum grid spacing

**Fixed**

- Fix problems with compile script
- Fix small bugs and docstrings

**Assets** 4

<a href="#">lintrans-Linux-v0.2.1</a>	76.2 MB	Mar 22, 2022
<a href="#">lintrans-Windows-v0.2.1.exe</a>	47.5 MB	Mar 22, 2022
<a href="#">Source code (zip)</a>		Mar 22, 2022
<a href="#">Source code (tar.gz)</a>		Mar 22, 2022

Figure 3.9.5: The release of v0.2.1 on GitHub

### 3.9.12 Automating release note generation

I had to copy the changelog over and polish up the release notes myself for this release. It would be quite convenient to have a script that does this automatically, so I made one.

```
# 99a88575f9beb8fed2dcc41dacbb020b31bc8176
# generate_release_notes.py

9     """A very simple script to generate release notes."""
10    import re
11    import sys
12
13    TEXT = '''DESCRIPTION
14
15    ---
16
17    The Linux binary should work fine, but if you use the Windows `*.exe` file, you will get a warning that the program
18    → may be unsafe. This is expected and you can just ignore it. There's no binary for macOS due to Apple code
19    → signing issues.
20
21    If you're running macOS, then you will need to compile the program from source. This is also an option on Linux and
22    → Windows. Instructions can be found [here](https://doctordalek1963.github.io/lintrans/tutorial/compile/).
23
24    ---
25
26    CHANGELOG
27
28
29    # This RegEx is complicated because of the newlines
30    # It requires the current tag to have a header like
31    # ## [0.2.1] - 2022-03-22
32    # And all other tags to have similar headers
33    # It also won't work on the first tag, but that's fine
34    RE_PATTERN = r'''(?=<## \[TAG_NAME\] - \d{4}-\d{2}-\d{2}
35
36    ).*?(?=
37
38
39    def main(args: list[str]) -> None:
40        """Generate the release notes for this release and write them to `release_notes.md`."""
41        if len(args) < 1:
42            raise ValueError('Tag name is required to generate release notes')
43
44        tag_name = args[0]
45
46        print(f'Generating release notes for tag {tag_name}')
47
48        with open('CHANGELOG.md', 'r', encoding='utf-8') as f:
49            changelog_text = f.read()
50
51            if (m := re.search(
52                RE_PATTERN.replace('TAG_NAME', re.escape(tag_name[1:])),
53                changelog_text,
54                flags=re.S
55            )) is not None:
56                text = TEXT.replace('CHANGELOG', m.group(0))
57
58            else:
59                raise ValueError('Error in searching for changelog notes. Bad format')
60
61            with open('release_notes.md', 'w', encoding='utf-8') as f:
62                f.write(text)
63
64
65    if __name__ == '__main__':
66        main(sys.argv[1:])
```

This script just parses the changelog and generates a file called `release_notes.md`, which I can then automatically use as the body for the GitHub release by changing the workflow.

```
# 99a88575f9beb8fed2dcc41dacbb020b31bc8176
# .github/workflows/compile-release.yaml

8   jobs:
...
97    publish:
...
101   steps:
...
124     - name: Generate release notes
125       run: python generate_release_notes.py $GITHUB_REF_NAME
126
127     # This is practically the same step twice just to allow for pre-releases
128     - name: Upload binaries (normal release)
129       if: steps.checkprerelease.outputs.isprerelease == 0
130       uses: softprops/action-gh-release@v1
131       with:
132         fail_on_unmatched_files: true
133         prerelease: false
134         draft: true
135         body_path: release_notes.md
136         files: dist/lintrans*
137
138     - name: Upload binaries (pre-release)
139       if: steps.checkprerelease.outputs.isprerelease == 1
140       uses: softprops/action-gh-release@v1
141       with:
142         fail_on_unmatched_files: true
143         prerelease: true
144         draft: true
145         body_path: release_notes.md
146         files: dist/lintrans*
```

## 3.10 Making v0.2.2

### 3.10.1 Hiding the background and transformed grids

I spoke to my main stakeholder, who is the teacher that will be using lintrans when it's finished, and she said that the background grid and transformed grid can get a little bit in the way of the core action and make it harder to understand what's happening. Taking this feedback on board, I decided to add a display setting to toggle the background grid, and one to toggle the transformed grid.

I did the background grid first and then repeated everything for the transformed version of the grid as well. I am combining them here for brevity. The first step was of course to add a display setting for each of them. Then I had to add checkboxes for them in the display settings dialog, and then incorporate the settings into the actual drawing of the canvas.

```
# d045057d568ac133b621ee9ca9daed361d570d7a
# src/lintrans/gui/settings.py

14 @dataclass
15 class DisplaySettings:
16     """This class simply holds some attributes to configure display."""
17
18     # === Basic stuff
19
20     draw_background_grid: bool = True
21     """This controls whether we want to draw the background grid.
22
23     The background axes will always be drawn. This makes it easy to identify the center of the space.
24     """
25
26     draw_transformed_grid: bool = True
27     """This controls whether we want to draw the transformed grid. Vectors are handled separately."""

# d045057d568ac133b621ee9ca9daed361d570d7a
# src/lintrans/gui/dialogs/settings.py

70 class DisplaySettingsDialog(SettingsDialog):
...
73     def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
74         self.checkbox_draw_background_grid = QCheckBox(self)
75         self.checkbox_draw_background_grid.setText('Draw &background grid')
76         self.checkbox_draw_background_grid.setToolTip(
77             'Draw the background grid (axes are always drawn)'
78         )
79         self.dict_checkboxes['b'] = self.checkbox_draw_background_grid
80
81         self.checkbox_draw_transformed_grid = QCheckBox(self)
82         self.checkbox_draw_transformed_grid.setText('Draw t&transformed grid')
83         self.checkbox_draw_transformed_grid.setToolTip(
84             'Draw the transformed grid (vectors are handled separately)'
85         )
86         self.dict_checkboxes['r'] = self.checkbox_draw_transformed_grid
...
89     def load_settings(self) -> None:
...
90         self.checkbox_draw_background_grid.setChecked(self.display_settings.draw_background_grid)
91         self.checkbox_draw_transformed_grid.setChecked(self.display_settings.draw_transformed_grid)
...
94     def confirm_settings(self) -> None:
...
95         self.display_settings.draw_background_grid = self.checkbox_draw_background_grid.isChecked()
96         self.display_settings.draw_transformed_grid = self.checkbox_draw_transformed_grid.isChecked()

# d045057d568ac133b621ee9ca9daed361d570d7a
# src/lintrans/gui/plots/widgets.py
```

```

19  class VisualizeTransformationWidget(VectorGridPlot):
...
48      def paintEvent(self, event: QPaintEvent) -> None:
...
60          self.draw_background(painter, self.display_settings.draw_background_grid)
61
62          if self.display_settings.draw_transformed_grid:
63              self.draw_transformed_grid(painter)

# d045057d568ac133b621ee9ca9daed361d570d7a
# src/lintrans/gui/plots/classes.py

23  class BackgroundPlot(QWidget):
...
129     def draw_background(self, painter: QPainter, draw_grid: bool) -> None:
130         """Draw the background grid.
131
132         .. note:: This method is just a utility method for subclasses to use to render the background grid.
133
134         :param QPainter painter: The painter to draw the background with
135         :param bool draw_grid: Whether to draw the grid lines
136         """
137
138         if draw_grid:
139             painter.setPen(QPen(self.colour_background_grid, self.width_background_grid))
140
141             # Draw equally spaced vertical lines, starting in the middle and going out
142             # We loop up to half of the width. This is because we draw a line on each side in each iteration
143             for x in range(self.width() // 2 + self.grid_spacing, self.width(), self.grid_spacing):
144                 painter.drawLine(x, 0, x, self.height())
145                 painter.drawLine(self.width() - x, 0, self.width() - x, self.height())
146
147             # Same with the horizontal lines
148             for y in range(self.height() // 2 + self.grid_spacing, self.height(), self.grid_spacing):
149                 painter.drawLine(0, y, self.width(), y)
150                 painter.drawLine(0, self.height() - y, self.width(), self.height() - y)
151
152             # Now draw the axes
153             painter.setPen(QPen(self.colour_background_axes, self.width_background_grid))
154             painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
155             painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)

```

Then I added this change to the changelog.

```

<!-- d045057d568ac133b621ee9ca9daed361d570d7a -->
<!-- CHANGELOG.md -->

12  ### Added
13
14  - Add options to hide background grid and transformed grid

```

### 3.10.2 Hiding the basis vectors

While I was implementing new display settings, I decided to implement hiding basis vectors. This will give users the option of just seeing the grid get transformed. The process was exactly the same as before. Add the setting, add it to the dialog, use it when drawing.

```

# 11ffba71f9fe29e1832a62f2b127aa3939e520d
# src/lintrans/gui/settings.py

15  class DisplaySettings:
...
29      draw_basis_vectors: bool = True
30      """This controls whether we want to draw the transformed basis vectors."""

# 11ffba71f9fe29e1832a62f2b127aa3939e520d
# src/lintrans/gui/dialogs/settings.py

```

```

70  class DisplaySettingsDialog(SettingsDialog):
...
73      def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
...
103     self.checkbox_draw_basis_vectors = QCheckBox(self)
104     self.checkbox_draw_basis_vectors.setText('Draw basis &vectors')
105     self.checkbox_draw_basis_vectors.setToolTip(
106         'Draw the transformed basis vectors'
107     )
108     self.dict_checkboxes['v'] = self.checkbox_draw_basis_vectors
...
212     def load_settings(self) -> None:
...
217         self.checkbox_draw_basis_vectors.setChecked(self.display_settings.draw_basis_vectors)
...
230     def confirm_settings(self) -> None:
...
235         self.display_settings.draw_basis_vectors = self.checkbox_draw_basis_vectors.isChecked()

# 11ffbaf71f9fe29e1832a62f2b127aa3939e520d
# src/lintrans/gui/plots/widgets.py

19  class VisualizeTransformationWidget(VectorGridPlot):
...
48      def paintEvent(self, event: QPaintEvent) -> None:
...
65          if self.display_settings.draw_basis_vectors:
66              self.draw_basis_vectors(painter)

```

And then of course add it to the changelog.

```

<!-- 11ffbaf71f9fe29e1832a62f2b127aa3939e520d -->
<!-- CHANGELOG.md -->

12  ### Added
13
14  - Add options to hide background grid, transformed grid, and basis vectors

```

### 3.10.3 Improving argument parsing

Qt5 accepts arguments to its main method. I don't really know what these arguments can do, but it would be nice to be able to use them. I also want to be able to save sessions as files in the future, and it would be quite useful to open a session file by passing it as a command line argument. To make both of these easier, I decided to refactor my argument parsing.

Python has a built-in library called `argparse`, which allows for more sophisticated argument parsing. One of the things `argparse` can do is parse only some of the command line arguments with a method called `parse_known_args()`[39]. I can then pass the unconsumed arguments on to Qt5. `__main__.py` now looks like this:

```

# a688a14839caba2ee14f8551764b771ae803d935
# src/lintrans/__main__.py

9  """This module provides a :func:`main` function to interpret command line arguments and run the program."""
10
11 from argparse import ArgumentParser
12 import sys
13 from textwrap import dedent
14
15 from lintrans import __version__
16 from lintrans.gui import main_window
17
18

```

```

19 def main(args: list[str]) -> None:
20     """Interpret program-specific command line arguments and run the main window in most cases.
21
22     If the user supplies --help or --version, then we simply respond to that and then return.
23     If they don't supply either of these, then we run :func:`lintrans.gui.main_window.main`.
24
25     :param list[str] args: The full argument list (including program name)
26     """
27
28     parser = ArgumentParser(add_help=False)
29
30     parser.add_argument(
31         '-h',
32         '--help',
33         default=False,
34         action='store_true'
35     )
36
37     parser.add_argument(
38         '-V',
39         '--version',
40         default=False,
41         action='store_true'
42     )
43
44     parsed_args, unparsed_args = parser.parse_known_args()
45
46     if parsed_args.help:
47         print(dedent('''
48             Usage: lintrans [option]
49
50             Options:
51                 -h, --help      Display this help text and exit
52                 -V, --version   Display the version information and exit
53
54             Any other options will get passed to the QApplication constructor.
55             If you don't know what that means, then don't provide any arguments and just run the program.'''[1:]))
56         return
57
58     if parsed_args.version:
59         print(dedent(f'''
60             lintrans (version {__version__})
61             The linear transformation visualizer
62
63             Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
64
65             This program is licensed under GNU GPLv3, available here:
66             <https://www.gnu.org/licenses/gpl-3.0.html>'')[1:]))
67         return
68
69     for arg in unparsed_args:
70         print(f'Passing "{arg}" to QApplication. See --help for recognised args')
71
72     main_window.main(args[:1] + unparsed_args)
73
74     if __name__ == '__main__':
75         main(sys.argv)

```

The ‘args[:1] + unparsed\_args’ on line 71 means that we pass the name of the program first, and the rest of the unconsumed arguments after it.

And of course, I added it to the changelog, this time as a fix rather than an addition:

```

<!-- a688a14839caba2ee14f8551764b771ae803d935 -->
<!-- CHANGELOG.md -->

16 ### Fixed
17
18 - Improve command line argument handling

```

### 3.10.4 Respecting display settings in the visual definition dialog

`DefineVisuallyWidget` is a subclass of `VisualizeTransformationWidget`. If it had its own instance attribute of type `DisplaySettings`, then it could use its superclass's `paintEvent()` method, and that would respect the display settings in the visual definition dialog.

```
# 5850aa916b685992f31e58680267916927ed590d
# src/lintrans/gui/plots/widgets.py

84  class DefineVisuallyWidget(VisualizeTransformationWidget):
...
91      def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
92          """Create the widget and enable mouse tracking. ``*args`` and ``**kwargs`` are passed to ``super()``."""
93          super().__init__(*args, display_settings=display_settings, **kwargs)

# 5850aa916b685992f31e58680267916927ed590d
# src/lintrans/gui/dialogs/define_new_matrix.py

166  class DefineVisuallyDialog(DefineDialog):
...
169      def __init__(self, *args, matrix_wrapper: MatrixWrapper, display_settings: DisplaySettings, **kwargs):
170          """Create the widgets and layout of the dialog.
171
172          :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
173          """
174          super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
175
176          self.setMinimumSize(700, 550)
177
178          # === Create the widgets
179
180          self.plot = DefineVisuallyWidget(self, display_settings=display_settings)
```

Since the `DefineVisuallyDialog` now accepts display settings but the other definition dialogs don't, we need change the `LintransMainWindow.dialog_define_matrix()` method to treat the visual definition dialog differently.

```
# 5850aa916b685992f31e58680267916927ed590d
# src/lintrans/gui/main_window.py

36  class LintransMainWindow(QMainWindow):
...
447  @pyqtSlot(DefineDialog)
448  def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
449      """Open a generic definition dialog to define a new matrix.
450
451      The class for the desired dialog is passed as an argument. We create an
452      instance of this class and the dialog is opened asynchronously and modally
453      (meaning it blocks interaction with the main window) with the proper method
454      connected to the :meth:`QDialog.accepted` signal.
455
456      .. note:: ``dialog_class`` must subclass :class:`lintrans.gui.dialogs.define_new_matrix.DefineDialog`.
457
458      :param dialog_class: The dialog class to instantiate
459      :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineDialog]
460      """
461
462      # We create a dialog with a deepcopy of the current matrix_wrapper
463      # This avoids the dialog mutating this one
464      if dialog_class == DefineVisuallyDialog:
465          dialog = DefineVisuallyDialog(
466              self,
467              matrix_wrapper=deepcopy(self.matrix_wrapper),
468              display_settings=self.plot.display_settings
469          )
470      else:
471          dialog = dialog_class(self, matrix_wrapper=deepcopy(self.matrix_wrapper))
```

```

472     # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
473     dialog.open()
474
475     # So we have to use the accepted signal to call a method when the user accepts the dialog
476     dialog.accepted.connect(self.assign_matrix_wrapper)

```

And, of course, I updated the changelog:

```

<!-- 5850aa916b685992f31e58680267916927ed590d -->
<!-- CHANGELOG.md -->

12  ### Added
...
15  - Fully respect display settings in visual definition widget

```

### 3.10.5 Changing the order in which things are drawn

Currently, `VisualizeTransformationWidget` draws the background, then the transformed grid, then the basis vectors, then the eigenlines and eigenvectors, then the determinant parallelogram and text. This means that the determinant parallelogram gets drawn on top of the basis vectors, which doesn't look very good. To fix this, we can simply re-order the drawing of different things. If we instead draw the transformed grid and basis vectors last, then they will appear on top of everything else, which should look significantly better.

I also renamed the `draw_determinant_text` display setting attribute to `show_determinant_value`.

Before:

```

# e9da6737cbd68e800c245bcc34e1c5c3824458a
# src/lintrans/gui/plots/widgets.py

19  class VisualizeTransformationWidget(VectorGridPlot):
...
48      def paintEvent(self, event: QPaintEvent) -> None:
...
60          self.draw_background(painter, self.display_settings.draw_background_grid)
61
62          if self.display_settings.draw_transformed_grid:
63              self.draw_transformed_grid(painter)
64
65          if self.display_settings.draw_basis_vectors:
66              self.draw_basis_vectors(painter)
67
68          if self.display_settings.draw_eigenlines:
69              self.draw_eigenlines(painter)
70
71          if self.display_settings.draw_eigenvectors:
72              self.draw_eigenvectors(painter)
73
74          if self.display_settings.draw_determinant_parallelogram:
75              self.draw_determinant_parallelogram(painter)
76
77          if self.display_settings.draw_determinant_text:
78              self.draw_determinant_text(painter)

```

After:

```

# acdf206a69d346dce67f74f2c54ff4c512c96229
# src/lintrans/gui/plots/widgets.py

19  class VisualizeTransformationWidget(VectorGridPlot):
...
48      def paintEvent(self, event: QPaintEvent) -> None:

```

```

...
60         self.draw_background(painter, self.display_settings.draw_background_grid)
61
62     if self.display_settings.draw_eigenlines:
63         self.draw_eigenlines(painter)
64
65     if self.display_settings.draw_eigenvectors:
66         self.draw_eigenvectors(painter)
67
68     if self.display_settings.draw_determinant_parallelogram:
69         self.draw_determinant_parallelogram(painter)
70
71     if self.display_settings.show_determinant_value:
72         self.draw_determinant_text(painter)
73
74     if self.display_settings.draw_transformed_grid:
75         self.draw_transformed_grid(painter)
76
77     if self.display_settings.draw_basis_vectors:
78         self.draw_basis_vectors(painter)

```

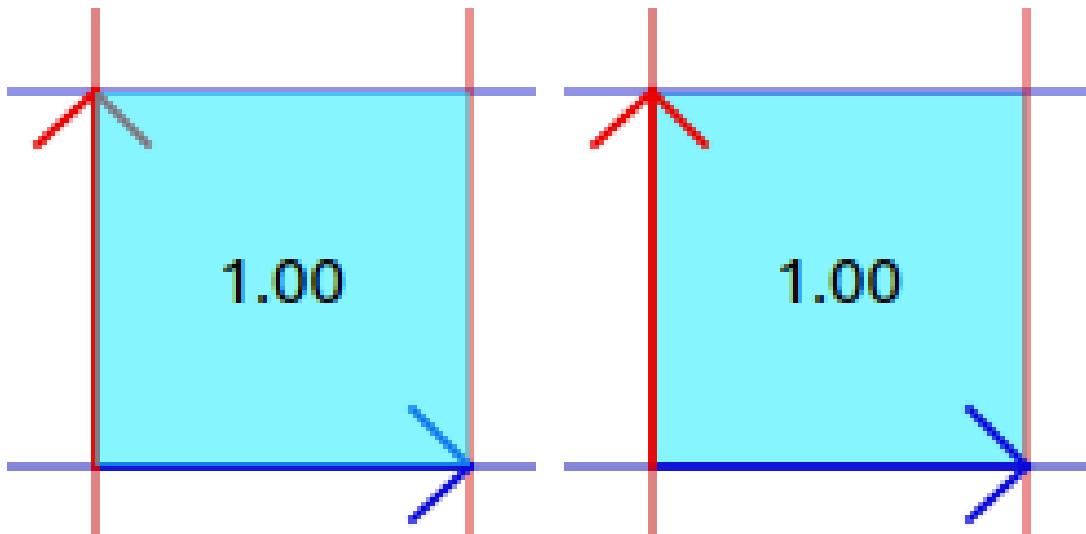


Figure 3.10.1: Before re-ordering drawing commands

Figure 3.10.2: After re-ordering drawing commands

### 3.10.6 Improving online documentation with *Read the Docs*

So far, I've been building my documentation automatically using a tool called `Sphinx`[52]. I've been using it to scan through my source code, extract all the docstrings[18], and compile a HTML version of the source code documentation. I then publish this documentation to GitHub Pages[16], and all that happens automatically along with the unit tests whenever I push my changes to GitHub.

However, this system can't track changes in documentation over time. There's a popular website for hosting open source documentation, especially for Python packages, called *Read the Docs*[48]. It would be nice to host my documentation on there, since it would provide a standard build for the docs, and would allow me to keep track of documentation for different versions over time. I read through their tutorial and followed along with it, and then I could use Read the Docs for `lintrans`.

```

# a7a8aa09148f4acf8591547d6d8b9cd8b8d52905
# .readthedocs.yaml

1  version: 2
2

```

```

3   build:
4     os: ubuntu-20.04
5     tools:
6       python: "3.10"
7     apt_packages:
8       - graphviz
9
10    jobs:
11      pre_build:
12        - cd docs/ && $(pwd | sed "s/checkouts\(\/\[^/]\+\)\$/docs\$envs\1/")/bin/python create_objects_inv.py
13        - $(pwd | sed "s/checkouts\(\/\[^/]\+\)\$/envs\1/")/bin/python -m pylint --rcfile=/dev/null --exit-zero
14      --reports=y --disable=all --enable=imports,RP0402 --int-import-graph=docs/source/int-imports.png $(find
15      ./src/lintrans/ -name "*.py" | tr "\n" " ")
16      - mkdir -p docs/source/_static
17      - $(pwd | sed "s/checkouts\(\/\[^/]\+\)\$/envs\1/")/bin/python -m pip install -e .
18      - $(pwd | sed "s/checkouts\(\/\[^/]\+\)\$/envs\1/")/bin/python -c "import lintrans" && echo success || echo
19      fail
20
21    sphinx:
22      builder: html
23      configuration: docs/source/conf.py
24      fail_on_warning: true
25
26    python:
27      install:
28        - requirements: requirements.txt
29        - requirements: docs/docs_requirements.txt
30
31    system_packages: false

```

This file governs the build pipeline for the documentation. It defines how the docs will be built on the remote machine. It basically just installs all the dependencies and `lintrans` itself in a virtual environment, generates the object inventory for `intersphinx` (see §3.9.2), builds the internal import graph (see §3.8.4), and makes sure that `lintrans` can be installed successfully in the virtual environment. The string ‘`$(pwd | sed "s/checkouts\(\/\[^/]\+\)\$/docs\$envs\1/")/bin/python`’ appears frequently. This string finds the version of Python that will be used for building the actual documentation at the end of the pipeline. `lintrans` has some issues with circular imports, which means that it can only be installed in editable mode<sup>23</sup>. This means that I have to bodge the build system to install `lintrans` properly.

Additionally, having a build system like this means that builds should be repeatable, which means I should pin the exact versions of all my dependencies, to avoid any breaking changes in the future.

```

# 152f9e59b5b4e22607cf2b687c85c70708054579
# requirements.txt

1 nptyping==1.4.4
2 numpy==1.21.0
3 pyqt5==5.15.6

# 152f9e59b5b4e22607cf2b687c85c70708054579
# dev_requirements.txt

1 flake8==4.0.1
2 mypy==0.942
3 pycodestyle==2.8.0
4 pydocstyle==6.1.1
5 pytest==6.2.5
6 pyqt5-stubs==5.15.2.0
7 toml==0.10.2

```

<sup>23</sup>Editable mode is an option that you can choose when installing a package with `pip`[30]. Instead of copying the source code to the installation directory like normal, it creates a link to the source code from the installation directory - basically a symlink in Linux. This means that if you change the source code, the installed version gets updated instantly, which is obviously very useful for fast, iterative development. It also has some strange effects with import order and resolution. Importing packages and modules is very complicated in Python[11], and I repeatedly failed to get `lintrans` to be installable without editable mode, so I had to resort to just using this bodge on Read the Docs instead.

```
# 152f9e59b5b4e22607cf2b687c85c70708054579
# docs/docs_requirements.txt

1 Sphinx==4.3.2
2 sphinx-rtd-theme==1.0.0
3 sphobjinv==2.2
```

Now that I was using Read the Docs, I could remove the old GitHub Actions workflow to compile the documentation.

### 3.10.7 Parsing parentheses

git has a feature called branches[14], which allow you to work on different things simultaneously. A branch is basically a sandbox where you can make changes and focus on a particular feature while not having to worry about the rest of the project. It's particularly good for teams where different people can work on different features at the same time, but it's also useful for individual developers. The first feature branch I merged for lintrans was called `dev/parse-parens`. I created it a week or two ago, and I used it to focus on improving the parser to understand parenthesised expressions like "`A(B+C)^2`".

#### 3.10.7.1 Extending validation

The first thing I needed to do was allow parenthesised expressions as valid. If the validator rejects them, then they can never be parsed. Any expression can be evaluated to a matrix, and a pair of balanced parentheses can contain any valid expression. As such, a parenthesised expression can be considered as a type of matrix.

```
# 1e49c1479939b8de04751ab1a798afb2145b1550
# docs/source/bnf.txt

1 expression      ::= [ "-" ] matrices { ( "+" | "-" ) matrices };
2 matrices        ::= matrix { matrix };
3 matrix          ::= [ real_number ] matrix_identifier [ index ] | "(" expression ")";
4 matrix_identifier ::= "A" .. "Z" | "rot(" [ "-" ] real_number ")";
5 index           ::= "^{" index_content "}" | "^" index_content;
6 index_content   ::= [ "-" ] integer_not_zero | "T";
7
8 digit_no_zero   ::= "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
9 digit           ::= "0" | digit_no_zero;
10 digits         ::= digit | digits digit;
11 integer_not_zero ::= digit_no_zero [ digits ];
12 real_number     ::= ( integer_not_zero [ "." digits ] | [ "0" ] "." digits );
```

```
# 1e49c1479939b8de04751ab1a798afb2145b1550
# src/lintrans/matrices/parse.py

16 NAIIVE_CHARACTER_CLASS = r'[-\sA-Z0-9.rot()^{}]'
...
23 def compile_naive_expression_pattern() -> Pattern[str]:
24     """Compile the single RegEx pattern that will match a valid matrix expression."""
25     digit_no_zero = '[123456789]'
26     digits = '\d+'
27     integer_no_zero = digit_no_zero + '(' + digits + ')?'
28     real_number = f'({{integer_no_zero}}({{{digits}}})?|0?{{digits}})'
29
30     index_content = f'(-{{integer_no_zero}}|T)'
31     index = f'(\^{{{index_content}}}|{{index_content}})'
32     matrix_identifier = f'([A-Z]rot\(-{{real_number}}\))|{{(NAIVE_CHARACTER_CLASS)+}})'
33     matrix = '(' + real_number + '?' + matrix_identifier + index + '?)'
34     expression = f'^-{{matrix}}+((\^|-){{matrix}}+)*$'
35
36     return re.compile(expression)
```

```
37
38
39 # This is an expensive pattern to compile, so we compile it when this module is initialized
40 naive_expression_pattern = compile_naive_expression_pattern()
41
42
43 def find_sub_expressions(expression: str) -> list[str]:
44     """Find all the sub-expressions in the given expression.
45
46     This function only goes one level deep, so may return strings like ``'A(BC)D'``.
47
48     :raises MatrixParseError: If there are unbalanced parentheses
49     """
50     sub_expressions: list[str] = []
51     string = ''
52     paren_depth = 0
53     pointer = 0
54
55     while True:
56         char = expression[pointer]
57
58         if char == '(' and expression[pointer - 3:pointer] != 'rot':
59             paren_depth += 1
60
61             # This is a bit of a manual bodge, but it eliminates extraneous parens
62             if paren_depth == 1:
63                 pointer += 1
64                 continue
65
66         elif char == ')' and re.match(f'{NAIVE_CHARACTER_CLASS}*?rot\\([-\\d.]+$', expression[:pointer]) is None:
67             paren_depth -= 1
68
69         if paren_depth > 0:
70             string += char
71
72         if paren_depth == 0 and string:
73             sub_expressions.append(string)
74             string = ''
75
76         pointer += 1
77
78         if pointer >= len(expression):
79             break
80
81     if paren_depth != 0:
82         raise MatrixParseError('Unbalanced parentheses in expression')
83
84     return sub_expressions
85
86
87 def validate_matrix_expression(expression: str) -> bool:
88     """Validate the given matrix expression.
89
90     This function simply checks the expression against the BNF schema documented in
91     :ref:`expression-syntax-docs`. It is not aware of which matrices are actually defined
92     in a wrapper. For an aware version of this function, use the
93     :meth:`lintrans.matrices.wrapper.MatrixWrapper.is_valid_expression` method.
94
95     :param str expression: The expression to be validated
96     :returns bool: Whether the expression is valid according to the schema
97     """
98
99     # Remove all whitespace
100    expression = re.sub(r'\s', '', expression)
101
102    match = naive_expression_pattern.match(expression)
103
104    if match is None:
105        return False
106
107    # Check that the whole expression was matched against
108    if expression != match.group(0):
109        return False
```

```

110     try:
111         sub_expressions = find_sub_expressions(expression)
112     except MatrixParseError:
113         return False
114
115     if not sub_expressions:
116         return True
117
118     return all(validate_matrix_expression(m) for m in sub_expressions)

```

We create a naïve character class that just contains all characters that could possibly be in a valid expression. Then when we compile the naïve expression pattern, we say that a matrix identifier can be one of three things: it can be a capital letter, the `rot()` command with a real number angle, or a balanced pair of parentheses around some characters. The characters in the parentheses are not validated at this stage (hence why this pattern is naïve), but we know that those characters are only allowed to be from the naïve character class.

Then we have a function that finds sub-expressions in a given expression. It simply scans through the given string with a pointer and keeps track of the current sub-expression. It uses the `paren_depth` variable to keep track of how deep into a sub-expression it currently is. This function deliberately avoids counting the parentheses from `rot()` commands towards the `paren_depth`. This is to avoid scanning an expression like "`3rot(45)^2`" and finding "`45`" as a sub-expression.

Then we have to actually use this function when validating. All we do is recursively check that each sub-expression is a valid expression on its own. The `find_sub_expressions()` function only goes one level deep, so in an expression like "`A(B+C(D^2-E))`", it will only find "`B+C(D^2-E)`" as a sub-expression, so recursion is needed to make the validation work properly.

There's actually a small mistake in the BNF that I didn't notice until much much later. The validation code is correct - it treats a parenthesised expression as a matrix identifier, so it can accept a multiplier on the left and an index on the right - but the BNF treats a parenthesised expression as a full matrix, which means it can't accept a multiplier or index. This doesn't affect the code, but does make the documentation slightly confusing.

And of course, I then added to the automatic unit tests to make sure this new validation worked.

```

# 1e49c1479939b8de04751ab1a798afb2145b1550
# tests/matrices/test_parse_and_validate_expression.py

16 expected_sub_expressions: list[tuple[str, list[str]]] = [
17     ('2(AB)^-1', ['AB']),
18     ('-3(A+B)^2-C(B^TA)^-1', ['A+B', 'B^TA']),
19     ('rot(45)', []),
20     ('()', []),
21     ('(')', ['()']),
22     ('2.3A^-1(AB)^-1+(BC)^2', ['AB', 'BC']),
23     ('(2.3A^-1(AB)^-1+(BC)^2)', ['2.3A^-1(AB)^-1+(BC)^2']),
24 ]
25
26
27 def test_find_sub_expressions() -> None:
28     """Test the :func:`lintrans.matrices.parse.find_sub_expressions` function."""
29     for inp, output in expected_sub_expressions:
30         assert find_sub_expressions(inp) == output
31
32     valid_inputs: list[str] = [
33
34         '(A)', '(AB)^-1', '2.3(3B^TA)^2', '-3.4(9D^{2}3F^{-1})^T+C', '(AB)(C)',
35         '3(rot(34)^{-7}A)^{-1}+B', '3A^2B+4A(B+C)^{-1}D^TA(C(D+E)B)'
36     ]
37
38     invalid_inputs: list[str] = [
39
40         '2.3AB)^T', '(AB+', '-4.6(9A', '-2(3.4A^{-1}-C)^2', '9.2)', '3A^2B+4A(B+C)^{-1}D^T-A(C(D+EB)'
41     ]

```

```

...
70    expressions_and_parsed_expressions: list[tuple[str, MatrixParseList]] = [
...
105   # Parenthesized expressions
106   ('(AB)^{-1}', [[(' ', 'AB', '-1')]]),
107   ('-3(A+B)^2-(B^TA)^{-1}', [[(-3, 'A+B', '2')], [(-1, 'C', ''), (' ', 'B^TA', '-1')]]),
108   ('2.3(3B^TA)^2', [[('2.3', '3B^TA', '2')]]),
109   ('-3.4(9D^{2}3F^{-1})^T+C', [[(-3.4, '9D^{2}3F^{-1}', 'T')], [('', 'C', '')]]),
110   ('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', '-1')]])
111 ]

```

I also added `@pytest.mark.xfail` to `test_parse_matrix_expression()`, since parsing should fail with the parenthesised expressions because I haven't implemented it yet.

```

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED [ 9%]
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED [ 12%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 16%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 19%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression XFAIL [ 22%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED [ 25%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED [ 29%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 32%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 35%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 38%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 41%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 45%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 48%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 51%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 54%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED [ 58%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED [ 61%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 64%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED [ 67%]
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED [ 70%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED [ 74%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 77%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED [ 80%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED [ 83%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED [ 87%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED [ 90%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 93%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 96%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [ 100%]

=====
30 passed, 1 xfailed in 0.38s =====

```

Figure 3.10.3: Running `pytest` with the new tests

### 3.10.7.2 Creating the parser class

I previously used regular expressions to parse matrix expressions. The algorithm would replace various parts of the expression to coerce it into the correct format, and then use a big RegEx at the end to find all the parts necessary for parsing. This was hard to understand and hard to maintain. It's now time to overhaul this parsing system and use a parser class to scan through the input and parse character-by-character, keeping track of the state as it goes.

```

# 736809714e0ad7579c419db03c4b5d8b8fd0c1a1
# src/lintrans/matrices/parse.py

122 @dataclass
123 class MatrixToken:
124     """A simple dataclass to hold information about a matrix token being parsed."""
125
126     multiplier: str = ''
127     identifier: str = ''

```

```
128     exponent: str = ''
129
130     @property
131     def tuple(self) -> tuple[str, str, str]:
132         """Create a tuple of the token for parsing."""
133         return self.multiplier, self.identifier, self.exponent
134
135
136     class ExpressionParser:
137         """A class to hold state during parsing."""
138
139         def __init__(self, expression: str):
140             """Create an instance of the parser with the given expression."""
141             # Remove all whitespace
142             expression = re.sub(r'\s', '', expression)
143
144             # Check if it's valid
145             if not validate_matrix_expression(expression):
146                 raise MatrixParseError('Invalid expression')
147
148             # Wrap all exponents and transposition powers with {}
149             expression = re.sub(r'(?=<\^)(?-d+|T)(?=[^\^]|$)', r'{\g<0>}', expression)
150
151             # Remove any standalone minuses
152             expression = re.sub(r'-(?=|[A-Z])', '-1', expression)
153
154             # Replace subtractions with additions
155             expression = re.sub(r'-(?=d+\.?d*([A-Z]|rot))', '+-', expression)
156
157             # Get rid of a potential leading + introduced by the last step
158             expression = re.sub(r'^+', '', expression)
159
160             self.expression = expression
161             self.pointer: int = 0
162
163             self.current_token: MatrixToken = MatrixToken()
164             self.current_group: list[tuple[str, str, str]] = []
165
166             self.final_list: MatrixParseList = []
167
168         def __repr__(self) -> str:
169             """Return a simple repr."""
170             return f'{self.__class__.__module__}.{self.__class__.__name__}({self.expression})'
171
172         @property
173         def char(self) -> str:
174             """Return the char pointed to by the pointer."""
175             return self.expression[self.pointer]
176
177         def parse(self) -> MatrixParseList:
178             """Parse the instance's matrix expression and return the MatrixParseList.
179
180             :returns MatrixParseList: The parsed expression
181             """
182             self._parse_multiplication_group()
183
184             while self.pointer < len(self.expression):
185                 if self.expression[self.pointer] != '+':
186                     raise MatrixParseError('Expected "+" between multiplication groups')
187
188                 self.pointer += 1
189                 self._parse_multiplication_group()
190
191             return self.final_list
192
193         def _parse_multiplication_group(self) -> None:
194             """Parse a group of matrices to be multiplied.
195
196             :returns bool: Success or failure
197             """
198             while self._parse_matrix():
199                 if self.pointer >= len(self.expression) or self.char == '+':
200                     self.final_list.append(self.current_group)
```

```
201         self.current_group = []
202         self.pointer += 1
203
204     def _parse_matrix(self) -> bool:
205         """Parse a full matrix using :meth:`_parse_matrix_part`.
206
207         :returns bool: Success or failure
208         """
209         self.current_token = MatrixToken()
210
211         while self._parse_matrix_part():
212             pass # The actual execution is taken care of in the loop condition
213
214         if self.current_token.identifier == '':
215             return False
216
217         self.current_group.append(self.current_token.tuple)
218
219         return True
220
221     def _parse_matrix_part(self) -> bool:
222         """Parse part of a matrix (multiplier, identifier, or exponent) from the expression and pointer.
223
224         .. note:: This method mutates ``self.current_token``.
225
226         :returns bool: Success or failure
227         :raises MatrixParseError: If we fail to parse this part of the token
228         """
229
230         if self.pointer >= len(self.expression):
231             return False
232
233         if self.char.isdigit() or self.char == '-':
234             if self.current_token.multiplier != '':
235                 return False
236
237             self._parse_multiplier()
238
239         elif self.char.isalpha() and self.char.isupper():
240             if self.current_token.identifier != '':
241                 return False
242
243             self.current_token.identifier = self.char
244             self.pointer += 1
245
246         elif self.char == 'r':
247             if self.current_token.identifier != '':
248                 return False
249
250             self._parse_rot_identifier()
251
252         elif self.char == '(':
253             if self.current_token.identifier != '':
254                 return False
255
256             self._parse_sub_expression()
257
258         elif self.char == '^':
259             if self.current_token.exponent != '':
260                 return False
261
262             self._parse_exponent()
263
264         elif self.char == '+':
265             return False
266
267         else:
268             raise MatrixParseError(f'Unrecognised character "{self.char}" in matrix expression')
269
270         return True
271
272     def _parse_multiplier(self) -> None:
273         """Parse a multiplier from the expression and pointer.
274
275         .. note:: This method mutates ``self.current_token.multiplier``.
```

```

274
275     :raises MatrixParseError: If we fail to parse this part of the token
276     """
277     multiplier = ''
278
279     while self.char.isdigit() or self.char in ('.', '-'):
280         multiplier += self.char
281         self.pointer += 1
282
283     # There can only be one dot in the multiplier
284     if len(multiplier.split('.')) > 2:
285         raise MatrixParseError(f'Multiplier "{multiplier}" has more than one dot')
286
287     if '-' in multiplier and '-' in multiplier[1:]:
288         raise MatrixParseError('Character "-" can only occur at the start of a multiplier')
289
290     self.current_token.multiplier = multiplier
291
292 def _parse_rot_identifier(self) -> None:
293     """Parse a ``rot()``-style identifier from the expression and pointer.
294
295     .. note:: this method mutates ``self.current_token.identifier``.
296
297     :raises MatrixParseError: If we fail to parse this part of the token
298     """
299     if match := re.match(r'rot\(([^\)]+)\)', self.expression[self.pointer:]):
300         self.current_token.identifier = match.group(0)
301         self.pointer += len(match.group(0))
302     else:
303         raise MatrixParseError(f'Invalid rot-identifier "{self.expression[self.pointer:self.pointer + 15]}')
304     ...
305
306 def _parse_sub_expression(self) -> None:
307     """Parse a parenthesized sub-expression as the identifier, from the expression and pointer.
308
309     .. note:: this method mutates ``self.current_token.identifier``.
310
311     :raises MatrixParseError: If we fail to parse this part of the token
312     """
313     # TODO
314     raise MatrixParseError('Sub-expressions are currently not supported as identifiers')
315
316 def _parse_exponent(self) -> None:
317     """Parse a matrix exponent from the expression and pointer.
318
319     .. note:: this method mutates ``self.current_token.exponent``.
320
321     :raises MatrixParseError: If we fail to parse this part of the token
322     """
323     if match := re.match(r'\^{(-?\d+|T)}', self.expression[self.pointer:]):
324         self.current_token.exponent = match.group(1)
325         self.pointer += len(match.group(0))
326     else:
327         raise MatrixParseError(f'Invalid exponent "{self.expression[self.pointer:self.pointer + 10]}...''')
328
329 def parse_matrix_expression(expression: str) -> MatrixParseList:
330     """Parse the matrix expression and return a :data:`lintrans.typing_.MatrixParseList`.  

331
332     :Example:
333
334     >>> parse_matrix_expression('A')
335     [[(' ', 'A', '')]]
336     >>> parse_matrix_expression('-3M^2')
337     [[(-3, 'M', '2')]]
338     >>> parse_matrix_expression('1.2rot(12)^{3}2B^T')
339     [[[('1.2', 'rot(12)', '3'), ('2', 'B', 'T')]]]
340     >>> parse_matrix_expression('A^2 + 3B')
341     [[[(' ', 'A', '2')], [('3', 'B', '')]]]
342     >>> parse_matrix_expression('-3A^{-1}3B^T - 45M^2')
343     [[[(-3, 'A', '-1'), ('3', 'B', 'T')], [(-45, 'M', '2')]]]
344     >>> parse_matrix_expression('5.3A^{4} 2.6B^{-2} + 4.6D^T 8.9E^{-1}')
345     [[[('5.3', 'A', '4'), ('2.6', 'B', '-2')], [(('4.6', 'D', 'T'), ('8.9', 'E', '-1'))]]]

```

```

346
347     :param str expression: The expression to be parsed
348     :returns: A list of parsed components
349     :rtype: :data:`lintrans.typing_.MatrixParseList`
350     """
351
351     return ExpressionParser(expression).parse()

```

The `MatrixToken` class just holds data about a matrix multiplier, identifier, and exponent. It's just a simple way to package up this data into a single dataclass to keep track of which matrices we've parsed.

The `ExpressionParser` class works like so: when you create a new instance, you give it an expression to parse and it cleans up the expression by removing whitespace, making sure it's valid, wrapping exponents with {}, etc. Most of these replacement steps are taken from the previous RegEx-based parser. It then sets up some internal state to keep track of the expression, the pointer, the token that it's currently parsing, the group that it's currently parsing, and its progress so far.

When you've created a new instance, you should call the public `parse()` method, which will return the parsed expression at the end, in the same format that the old parser used. The `parse_matrix_expression()` function is a wrapper that just creates an `ExpressionParser` and calls `parse()`.

The `parse()` method itself just delegates to `_parse_multiplication_group()`. A multiplication group is a group of matrices that will be multiplied together in a particular order. An expression should start with a multiplication group, and may have extra ones separated with plus signs. When all the multiplication groups have been parsed, it returns the final parse list.

`_parse_multiplication_group()` tries to parse matrices until it reaches the end of the expression or it finds a plus sign, at which point it appends the current group to the final list and returns.

`_parse_matrix()` returns a boolean to indicate success. It just attempts to parse a ‘matrix part’ (multiplier, identifier, or exponent) until that fails, and then ensures that the resultant matrix token has a valid identifier. It then appends the matrix token to the current group.

`_parse_matrix_part()` is where most of the selection happens. This method has to determine if it's looking at a multiplier, which would start with a digit or a minus sign; a normal identifier, which would start with a capital letter; a rotation identifier, which would start with a lowercase letter r; a sub-expression, which would start with an open bracket; or an exponent, which would start with a caret. If it encounters a plus sign, then that's a soft error, so it can return `False`, but if it encounters something it doesn't recognise, then that's a hard error.

`_parse_multiplier()` just parses a real number into `self.current_token.multiplier`.

`_parse_rot_identifier()` parses a `rot()` command with a real number angle<sup>24</sup>.

`_parse_sub_expression()` hasn't been implemented yet, but it will eventually parse sub-expressions, hence the name.

`_parse_exponent()` parses a caret, and then a balanced pair of braces, containing an integer or a capital letter T.

And of course, this new parser should still pass all the unit tests for the previous parser, which it does.

---

<sup>24</sup>It doesn't need to parse the real number itself to make sure it's valid, since the expression validator already ensured that it was a valid real number.

```
(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED [ 9%]
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED [ 12%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 16%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 19%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression XFAIL [ 22%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED [ 25%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED [ 29%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 32%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 35%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 38%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 41%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 45%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 48%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 51%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 54%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED [ 58%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED [ 61%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 64%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED [ 67%]
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED [ 70%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED [ 74%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 77%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED [ 80%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED [ 83%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED [ 87%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED [ 90%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 93%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 96%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [100%]

===== 30 passed, 1 xfailed in 0.38s =====
```

Figure 3.10.4: Running `pytest` with the new tests

### 3.10.7.3 Implementing sub-expression parsing

Of course, the next step was to actually implement sub-expression parsing. To do this, I used a very similar method to finding the sub-expressions, where I kept track of the depth of the parentheses. Except with this method, we only wanted the first sub-expression starting at the pointer. We can then assign this whole sub-expression to `self.current_token.identifier` at the end.

Much like when finding sub-expressions, this parser method only goes one level deep, but the `MatrixWrapper` will use recursion when evaluating the parsed expressions, so it will handle nested sub-expressions with.

```
# 493f8cf3fb658408466f099f978d276fc2262243
# src/lintrans/matrices/parse.py

136 class ExpressionParser:
...
305     def _parse_sub_expression(self) -> None:
306         """Parse a parenthesized sub-expression as the identifier, from the expression and pointer.
307
308         .. note:: this method mutates ``self.current_token.identifier``.
309
310         :raises MatrixParseError: If we fail to parse this part of the token
311         """
312         if self.char != '(':
313             raise MatrixParseError('Sub-expression must start with "("')
314
315         self.pointer += 1
316         paren_depth = 1
317         identifier = ''
318
319         while paren_depth > 0:
320             if self.char == '(':
321                 paren_depth += 1
322             elif self.char == ')':
323                 paren_depth -= 1
324
325             self.pointer += 1
```

```
323     paren_depth -= 1
324
325     if paren_depth == 0:
326         self.pointer += 1
327         break
328
329     identifier += self.char
330     self.pointer += 1
331
332     self.current_token.identifier = identifier
```

### 3.10.7.4 Fixing little bugs

Since I've now implemented sub-expression parsing, I should be able to just remove the `@pytest.mark.xfail` line from before and all the tests should pass with no problem.

```
(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression FAILED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_evaluate_matrix_and_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgeerror PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_setitem_error PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_getitem_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED
=====
FAILURES =====
test_parse_matrix_expression
-----
def test_parse_matrix_expression() -> None:
    """Test the parse_matrix_expression() function."""
    for expression, parsed_expression in expressions_and_parsed_expressions:
        # Test it with and without whitespace
        >>> assert parse_matrix_expression(expression) == parsed_expression
tests/matrices/test_parse_and_validate_expression.py:119:
src/lintrans/matrices/parse.py:370: in parse_matrix_expression
    return ExpressionParser(expression).parse()
src/lintrans/matrices/parse.py:182: in parse
    self._parse_multiplication_group()
src/lintrans/matrices/parse.py:198: in _parse_multiplication_group
    while self._parse_matrix():
src/lintrans/matrices/parse.py:211: in _parse_matrix
    while self._parse_matrix_part():

self = lintrans.matrices.parse.ExpressionParser(".1A")
-----
def _parse_matrix_part(self) -> bool:
    """Parse part of a matrix (multiplier, identifier, or exponent) from the expression and pointer.
    .. note:: This method mutates ``self.current_token``.

    :returns bool: Success or failure
    :raises MatrixParseError: If we fail to parse this part of the token
    """
    if self.pointer >= len(self.expression):
        return False

    if self.char.isdigit() or self.char == '-':
        if self.current_token.multiplier != '':
            return False

        self._parse_multiplier()

    elif self.char.isalpha() and self.char.isupper():
        if self.current_token.identifier != '':
            return False

        self.current_token.identifier = self.char
        self.pointer += 1

    elif self.char == 'r':
        if self.current_token.identifier != '':
            return False

        self._parse_rot_identifier()

    elif self.char == '(':
        if self.current_token.identifier != '':
            return False

        self._parse_sub_expression()

    elif self.char == '^':
        if self.current_token.exponent != '':
            return False

        self._parse_exponent()

    elif self.char == '+':
        return False

    else:
        >>> raise MatrixParseError(f'Unrecognised character "{self.char}" in matrix expression')
E       lintrans.matrices.parse.MatrixParseError: Unrecognised character "." in matrix expression
src/lintrans/matrices/parse.py:266: MatrixParseError
=====
short test summary info =====
FAILED tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression - lintrans.matrices.parse.MatrixParseError: Unrecognised character "." in matrix expression
===== 1 failed, 30 passed in 0.41s =====
=====
```

Figure 3.10.5: One of the tests failing

Ah. That's not good. So what went wrong? Well, we can see from the output that `test_parse_matrix_expression()` is the one that failed. This test iterates over a whole list, so which element broke it? Well, we can see from the line '`self = lintrans.matrices.parse.ExpressionParser(".1A")`' that it was trying to parse the expression `".1A"`. This doesn't work, not because `ExpressionParser._parse_multiplier()` doesn't understand this type of multiplier, but because `ExpressionParser._parse_matrix_part()` doesn't recognise a dot as the start of a multiplier, so never calls `_parse_multiplier()`.

This would be a very easy fix, but this error got me thinking about these multipliers and I decided to just forbid them. They can create confusion; "**0.1A**" is easier to understand than "**.1A**". Implementing this change just meant removing this type of multiplier from the tests.

Once I'd done that, the parser should work fine, right?

```
(lintrans) dysonHarold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.8.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error FAILED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED
tests/matrices/test_parse_and_validate_expression.py::test_simple_matrix_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED
===== FAILURES =====
===== test_parse_matrix_expression =====
>     def test_parse_matrix_expression() -> None:
      """Test the parse_matrix_expression() function."""
      for expression, parsed_expression in expressions_and_parsed_expressions:
          # Test it with and without whitespace
          assert parse_matrix_expression(expression) == parsed_expression
E         AssertionError: assert [[["0.1", "A'...", "B", "..."]]] == [[("", "A", "...1", "B", "")]]
E           At index 0 diff: [[("0.1", "A", "..."), ("", "B", "...")]] != [[("", "A", "...1"), ("0.1", "B", "")]]
E             Full diff:
E             - [[("", "A", "..."), ("0.1", "B", "")]]
E             + [[("0.1", "A", "..."), ("", "B", "...")]]
E
E     tests/matrices/test_parse_and_validate_expression.py:119: AssertionError
===== short test summary info =====
FAILED tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression - AssertionError: assert [[("0.1", "A'...", "B", "...")]] == [[("", "A", "...1", "B", "")]]
===== 1 failed, 30 passed in 0.39s =====
```

Figure 3.10.6: Another test failing

Well, that's strange. It was trying to parse the expression "**A 0.1B**" but it thought the **0.1** was part of the **A**. Why did that happen? Well, it's because of line 232 in this snippet:

```
# 9b1c69926c225574161d32dcbe086055edb4065
# src/lintrans/matrices/parse.py

136 class ExpressionParser:
...
220     def _parse_matrix_part(self) -> bool:
...
231         if self.char.isdigit() or self.char == '_':
232             if self.current_token.multiplier != '':
233                 return False
234
235         self._parse_multiplier()
```

The parser parsed "**A**" as the matrix identifier and then encountered "**0**". Since the current token didn't have a multiplier, it started parsing a multiplier for the matrix **A**. To fix this, we can just fail to parse a matrix part if we encounter the start of a multiplier when the current token already has an identifier. Failing to parse a matrix part here means that the parser will start parsing a new matrix.

```
# 8d7143fc33ea7bd4199e0f01b6a5308dfcf03ff9
# src/lintrans/matrices/parse.py
```

```
136 class ExpressionParser:
...
```

```

220     def _parse_matrix_part(self) -> bool:
...
231         if self.char.isdigit() or self.char == '-':
232             if self.current_token.multiplier != '' \
233                 or (self.current_token.multiplier == '' and self.current_token.identifier != ''):
234                 return False
235
236             self._parse_multiplier()

```

That should fix the tests, right?

```

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.8.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED
[  3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED
[  6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED
[  9%]
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED
[ 12%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED
[ 16%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED
[ 19%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression FAILED
[ 22%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression PASSED
[ 25%]
tests/matrices/test_parse_and_validate_expression.py::test_create_rotation_matrix PASSED
[ 28%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED
[ 32%]
tests/matrices/test_parse_and_validate_expression.py::test_evaluate_expression PASSED
[ 35%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED
[ 38%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED
[ 41%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED
[ 45%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED
[ 48%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED
[ 51%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED
[ 54%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED
[ 58%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED
[ 61%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED
[ 64%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED
[ 67%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED
[ 70%]
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED
[ 74%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED
[ 77%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_setitem_getitem PASSED
[ 80%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED
[ 83%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED
[ 87%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED
[ 90%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED
[ 93%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED
[ 96%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED
[ 99%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED
[100%]

===== FAILURES =====
test_parse_matrix_expression

def test_parse_matrix_expression() -> None:
    """Test the parse_matrix_expression() function."""
    for expression, parsed_expression in expressions_and_parsed_expressions:
        # Test it with and without whitespace
>       assert parse_matrix_expression(expression) == parsed_expression
E       AssertionError: assert [[(-3, 'A+B...{T}A', '-1')]] == [[((-3, 'A+B...B^TA', '-1'))]
E   At index 0 diff: [[(-1, 'C', '')], ('+', 'B^{T}A', '-1')] != [[(-1, 'C', ''), ('+', 'B^TA', '-1')]]
E   Full diff:
E   - [[(-3, 'A+B...', '2')], [(-1, 'C', ''), ('+', 'B^TA', '-1')]]
E   + [[(-3, 'A+B...', '2')], [(-1, 'C', ''), ('+', 'B^TA', '-1')]]
E   ?
E           +
tests/matrices/test_parse_and_validate_expression.py:119: AssertionWarning
===== short test summary info =====
FAILED tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression - AssertionError: assert [[(-3, 'A+B...{T}A', '-1')]] == [[((-3, 'A+B...B^TA', '-1'))]]
===== 1 failed, 30 passed in 0.39s =====

```

Figure 3.10.7: Another test failing

I'm getting tired of this now. What's broken this time? Well, the parser processes its input to remove whitespace and add braces around exponents before any parsing takes place. This includes processing the contents of sub-expressions. That was never a problem before, since parsing wasn't affected by whitespace or braces, but now those changes propagate into the sub-expressions. I wrote the sub-expression parsing tests in §3.10.7.1 by using my literal expression input in the parsed sub-expressions. So to fix this error, I just had to account for the syntax transformations in the test input.

Now the tests should all pass, right?

```
(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 31 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression PASSED
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED

=====
31 passed in 0.34s =====
```

Figure 3.10.8: All the tests finally passing

Thank god.

### 3.10.7.5 Making recursive evaluation work

When `MatrixWrapper.__getitem__(name)` tries to retrieve a matrix which is defined in terms of an expression, it has to call `MatrixWrapper.evaluate_expression()`. This method in turn calls `__getitem__(name)` again to evaluate the matrices used in the expression. Now that sub-expressions exist, `__getitem__(name)` might get called with a sub-expression identifier, so it needs to be able to evaluate these expressions. To do this, we can simply add another call to `evaluate_expression()`, as seen on lines 120-121.

```
# ba1ee72fcfad5129aed76992f743e5966f5c199d
# src/lintrans/matrices/wrapper.py

23 class MatrixWrapper:
...
100     def __getitem__(self, name: str) -> Optional[MatrixType]:
101         """Get the matrix with the given name.
102
103         If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)``, with
104         a given angle in degrees, then we return a new matrix representing a rotation by that angle.
105
106         .. note::
107             If the named matrix is defined as an expression, then this method will return its evaluation.
108             If you want the expression itself, use :meth:`get_expression`.
109
110         :param str name: The name of the matrix to get
111         :returns Optional[MatrixType]: The value of the matrix (could be None)
112
113         :raises NameError: If there is no matrix with the given name
114         """
115
116         # Return a new rotation matrix
117         if (match := re.match(r'rot\((-?\d*\.\d*)\)', name)) is not None:
118             return create_rotation_matrix(float(match.group(1)))
119
120         if name not in self._matrices:
121             if validate_matrix_expression(name):
122                 return self.evaluate_expression(name)
123
124         raise NameError(f'Unrecognised matrix name "{name}"')
```

```

125     # We copy the matrix before we return it so the user can't accidentally mutate the matrix
126     matrix = copy(self._matrices[name])
127
128     if isinstance(matrix, str):
129         return self.evaluate_expression(matrix)
130
131     return matrix
...
134
135     def evaluate_expression(self, expression: str) -> MatrixType:
136         """Evaluate a given expression and return the matrix evaluation.
137
138         :param str expression: The expression to be parsed
139         :returns MatrixType: The matrix result of the expression
140
141         :raises ValueError: If the expression is invalid
142         """
143
144         if not self.is_valid_expression(expression):
145             raise ValueError('The expression is invalid')
146
147         parsed_result = parse_matrix_expression(expression)
148         final_groups: list[list[MatrixType]] = []
149
150         for group in parsed_result:
151             f_group: list[MatrixType] = []
152
153             for multiplier, identifier, index in group:
154                 if index == 'T':
155                     m = self[identifier]
156
157                     # This assertion is just so mypy doesn't complain
158                     # We know this won't be None, because we know that this matrix is defined in this wrapper
159                     assert m is not None
160                     matrix_value = m.T
161
162                 else:
163                     matrix_value = np.linalg.matrix_power(self[identifier], 1 if index == '' else int(index))
164
165                     matrix_value *= 1 if multiplier == '' else float(multiplier)
166                     f_group.append(matrix_value)
167
168             final_groups.append(f_group)
169
170         return reduce(add, [reduce(matmul, group) for group in final_groups])

```

I then added a new unit test function to make sure parenthesised expressions get evaluated properly.

```

# ba1ee72fcfad5129aed76992f743e5966f5c199d
# tests/matrices/matrix_wrapper/test_evaluate_expression.py

229     def test_parenthesized_expressions(test_wrapper: MatrixWrapper) -> None:
230         """Test evaluation of parenthesized expressions."""
231         assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
232             test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
233             test_wrapper['G'] is not None
234
235         assert (test_wrapper.evaluate_expression('(A^T)^2') == la.matrix_power(test_wrapper['A'].T, 2)).all()
236         assert (test_wrapper.evaluate_expression('(B^T)^3') == la.matrix_power(test_wrapper['B'].T, 3)).all()
237         assert (test_wrapper.evaluate_expression('(C^T)^4') == la.matrix_power(test_wrapper['C'].T, 4)).all()
238         assert (test_wrapper.evaluate_expression('(D^T)^5') == la.matrix_power(test_wrapper['D'].T, 5)).all()
239         assert (test_wrapper.evaluate_expression('(E^T)^6') == la.matrix_power(test_wrapper['E'].T, 6)).all()
240         assert (test_wrapper.evaluate_expression('(F^T)^7') == la.matrix_power(test_wrapper['F'].T, 7)).all()
241         assert (test_wrapper.evaluate_expression('(G^T)^8') == la.matrix_power(test_wrapper['G'].T, 8)).all()
242
243         assert (test_wrapper.evaluate_expression('D^3(A+6.2F-0.397G^TE)^-2+A') ==
244                 la.matrix_power(test_wrapper['D'], 3) @ la.matrix_power(
245                     test_wrapper['A'] + 6.2 * test_wrapper['F'] - 0.397 * test_wrapper['G'].T @ test_wrapper['E'],
246                     -2
247                 ) + test_wrapper['A']).all()
248
249         assert (test_wrapper.evaluate_expression('-1.2F^{3}4.9D^T(A^2(B+3E^TF)^{-1})^2') ==
250                 -1.2 * la.matrix_power(test_wrapper['F'], 3) @ (4.9 * test_wrapper['D'].T) @

```

```

251         la.matrix_power(
252             la.matrix_power(test_wrapper['A'], 2) @ la.matrix_power(
253                 test_wrapper['B'] + 3 * test_wrapper['E'].T @ test_wrapper['F'],
254                 -1
255             ),
256             2
257         )).all()

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *=]
$ pytest -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bln/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 32 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED [ 9%]
tests/matrices/test_parse_and_validate_expression.py::test_find_sub_expressions PASSED [ 12%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 15%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 18%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression PASSED [ 21%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED [ 25%]
tests/matrices/test_rotation_matrices.py::test_create_rotation_matrix PASSED [ 28%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 31%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 34%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 37%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 40%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 43%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 46%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 50%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 53%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED [ 56%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED [ 59%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_parenthesized_expressions PASSED [ 62%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 65%]
tests/matrices/matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED [ 68%]
tests/matrices/matrix_wrapper/test_misc.py::test_get_expression PASSED [ 71%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED [ 75%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 78%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED [ 81%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED [ 84%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED [ 87%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED [ 90%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 93%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 96%]
tests/matrices/matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [100%]

=====
32 passed in 0.36s =====

```

Figure 3.10.9: Running pytest with the new tests

I also improved the doctests for `parse_matrix_expression()` by adding a case for these new parenthesised expressions, and I added a doctest for the expression parser.

```

# e3d633133f293fc1308d6fc0c60a1febaf67dda0
# src/lintrans/matrices/parse.py

349 def parse_matrix_expression(expression: str) -> MatrixParseList:
350     """Parse the matrix expression and return a :data:`lintrans.typing_.MatrixParseList`.  

351
352     :Example:
353
354     >>> parse_matrix_expression('A')
355     [[(' ', 'A', '')]]
356     >>> parse_matrix_expression('-3M^2')
357     [[(-'3', 'M', '2')]]
358     >>> parse_matrix_expression('1.2rot(12)^{3}2B^T')
359     [[[('1.2', 'rot(12)', '3'), ('2', 'B', 'T')]]]
360     >>> parse_matrix_expression('A^2 + 3B')
361     [[[(' ', 'A', '2')], [('3', 'B', '')]]]
362     >>> parse_matrix_expression('-3A^{1}3B^T - 45M^2')
363     [[[(-'3', 'A', '-1'), ('3', 'B', 'T')], [(-'45', 'M', '2')]]]
364     >>> parse_matrix_expression('5.3A^{4} 2.6B^{2} + 4.6D^T 8.9E^{1}')
365     [[[('5.3', 'A', '4'), ('2.6', 'B', '2')], [('4.6', 'D', 'T'), ('8.9', 'E', '-1')]]]
366     >>> parse_matrix_expression('2(A+B^TC)^2D')
367     [[[('2', 'A+B^TC', '2'), (' ', 'D', '')]]]

368     :param str expression: The expression to be parsed
369     :returns: A list of parsed components
370     :rtype: :data:`lintrans.typing_.MatrixParseList`
371     """
372
373     return ExpressionParser(expression).parse()

# bf1f5a1eaac60d23964a44c9a6b8235c5e0fcab2
# src/lintrans/matrices/parse.py

```

```

136 class ExpressionParser:
137     """A class to hold state during parsing.
138
139     Most of the methods in this class are class-internal and should not be used from outside.
140
141     This class should be used like this:
142
143     >>> ExpressionParser('3A^-1B').parse()
144     [[('3', 'A', '-1'), ('', 'B', '')]]
145     >>> ExpressionParser('4(M^TA^2)^-2').parse()
146     [[('4', 'M^{T}A^{2}', '-2')]]
147     """

```

```

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *]
$ pytest --doctest-modules src -v
=====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml
collected 4 items

src/lintrans/matrices/parse.py::lintrans.matrices.parse.ExpressionParser PASSED [ 25%]
src/lintrans/matrices/parse.py::lintrans.matrices.parse.parse_matrix_expression PASSED [ 50%]
src/lintrans/matrices/wrapper.py::lintrans.matrices.wrapper.MatrixWrapper PASSED [ 75%]
src/lintrans/matrices/wrapper.py::lintrans.matrices.wrapper.create_rotation_matrix PASSED [100%]

===== 4 passed in 0.33s =====

```

Figure 3.10.10: Running `pytest` with the new and improved doctests

And of course, I updated the changelog:

```

<!-- 9e26079475e33f3ab2e02e76ea59a66217d18f76 -->
<!-- CHANGELOG.md -->

12  ### Added
...
16  - Support parenthesized sub-expressions as matrix identifiers

```

### 3.10.7.6 Ensuring numerical formats

The validation checks the format of the numbers in multipliers, exponents and `rot()` commands, but it would be quite good to also validate the format of these numbers when parsing, just to make absolutely sure that they will be able to be correctly evaluated. To do this, we can simply perform the conversion in a try/except block. It would also be good to validate the sub-expressions.

```

# 761c6ed255ed65c3396c6a551acfa60bb7485a17
# src/lintrans/matrices/parse.py

136 class ExpressionParser:
...
282     def _parse_multiplier(self) -> None:
283         """Parse a multiplier from the expression and pointer.
284
285         .. note:: This method mutates ``self.current_token.multiplier``.
286
287         :raises MatrixParseError: If we fail to parse this part of the token
288         """
289         multiplier = ''
290
291         while self.char.isdigit() or self.char in ('.', '-'):
292             multiplier += self.char
293             self.pointer += 1

```

```
294
295     try:
296         float(multiplier)
297     except ValueError as e:
298         raise MatrixParseError(f'Invalid multiplier "{multiplier}"') from e
299
300     self.current_token.multiplier = multiplier
301
302 def _parse_rot_identifier(self) -> None:
303     """Parse a ``rot()``-style identifier from the expression and pointer.
304
305     .. note:: This method mutates ``self.current_token.identifier``.
306
307     :raises MatrixParseError: If we fail to parse this part of the token
308     """
309     if match := re.match(r'rot\(([.\d-]+)\)', self.expression[self.pointer:]):
310         # Ensure that the number in brackets is a valid float
311         try:
312             float(match.group(1))
313         except ValueError as e:
314             raise MatrixParseError(f'Invalid angle number "{match.group(1)}" in rot-identifier') from e
315
316         self.current_token.identifier = match.group(0)
317         self.pointer += len(match.group(0))
318     else:
319         raise MatrixParseError(f'Invalid rot-identifier "{self.expression[self.pointer:self.pointer + 15]}')
320
321     ...
322
323 def _parse_sub_expression(self) -> None:
324     """Parse a parenthesized sub-expression as the identifier, from the expression and pointer.
325
326     .. note:: This method mutates ``self.current_token.identifier``.
327
328     :raises MatrixParseError: If we fail to parse this part of the token
329     """
330     if self.char != '(':
331         raise MatrixParseError('Sub-expression must start with "("')
332
333     self.pointer += 1
334     paren_depth = 1
335     identifier = ''
336
337     while paren_depth > 0:
338         if self.char == '(':
339             paren_depth += 1
340         elif self.char == ')':
341             paren_depth -= 1
342
343         if paren_depth == 0:
344             self.pointer += 1
345             break
346
347         identifier += self.char
348         self.pointer += 1
349
350     if not validate_matrix_expression(identifier):
351         raise MatrixParseError(f'Invalid sub-expression identifier "{identifier}"')
352
353     self.current_token.identifier = identifier
354
355 def _parse_exponent(self) -> None:
356     """Parse a matrix exponent from the expression and pointer.
357
358     .. note:: This method mutates ``self.current_token.exponent``.
359
360     :raises MatrixParseError: If we fail to parse this part of the token
361     """
362     if match := re.match(r'\^{\{-?\d+|T\}\}}', self.expression[self.pointer:]):
363         exponent = match.group(1)
364
365         try:
366             if exponent != 'T':
367                 int(exponent)
```

```

366         except ValueError as e:
367             raise MatrixParseError(f'Invalid exponent "{match.group(1)}"') from e
368
369             self.current_token.exponent = exponent
370             self.pointer += len(match.group(0))
371     else:
372         raise MatrixParseError(f'Invalid exponent "{self.expression[self.pointer:self.pointer + 10]}..."'")

```

### 3.10.8 Fixing premature rot() evaluation

Now that parenthesised expressions are done, I can focus on other improvements.

When playing around with this new feature, I discovered a bug where an expression like "rot(45)^2" would be evaluated in the same way as "rot(45)". After lots of confusion and debugging, I discovered that this bug was in `MatrixWrapper.__getitem__()` when it tries to evaluate `rot()` commands. It does this by eagerly searching for the `rot()` RegEx in the string. This was never an issue before, but now that this method might get called with a whole expression, this RegEx can trigger too early. If it's given an expression which contains a `rot()` command anywhere in it, then it will return a rotation matrix immediately. To fix this, we just have to ensure that the `rot()` command takes up the whole string before returning a rotation matrix. We can do this by anchoring the RegEx with ^ and \$.

```

# c23d540aa3b8df91b9478fb113cb42df4c7d5e42
# src/lintrans/matrices/wrapper.py

23 class MatrixWrapper:
...
100     def __getitem__(self, name: str) -> Optional[MatrixType]:
...
115         # Return a new rotation matrix
116         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
117             return create_rotation_matrix(float(match.group(1)))
118
119         if name not in self._matrices:
120             if validate_matrix_expression(name):
121                 return self.evaluate_expression(name)
122
123         raise NameError(f'Unrecognised matrix name "{name}"')
124
125         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
126         matrix = copy(self._matrices[name])
127
128         if isinstance(matrix, str):
129             return self.evaluate_expression(matrix)
130
131     return matrix

```

I also added cases to the parenthesised expressions test to cover this change.

```

# c23d540aa3b8df91b9478fb113cb42df4c7d5e42
# tests/matrices/matrix_wrapper/test_evaluate_expression.py

229 def test_parenthesized_expressions(test_wrapper: MatrixWrapper) -> None:
...
243     assert (test_wrapper.evaluate_expression('rot(45)^1)^T') == create_rotation_matrix(45).T).all()
244     assert (test_wrapper.evaluate_expression('rot(45)^2)^T') == la.matrix_power(create_rotation_matrix(45),
245     ↪ 2).T).all()
245     assert (test_wrapper.evaluate_expression('rot(45)^3)^T') == la.matrix_power(create_rotation_matrix(45),
246     ↪ 3).T).all()
246     assert (test_wrapper.evaluate_expression('rot(45)^4)^T') == la.matrix_power(create_rotation_matrix(45),
247     ↪ 4).T).all()
247     assert (test_wrapper.evaluate_expression('rot(45)^5)^T') == la.matrix_power(create_rotation_matrix(45),
248     ↪ 5).T).all()

```

And then added it to the changelog.

```
<!-- c23d540aa3b8df91b9478fb113cb42df4c7d5e42 -->
<!-- CHangelog.md -->
```

```
18  ### Fixed
...
21 - Fixed bug with premature rot evaluation in sub-expressions
```

### 3.10.9 Animating rotations

When animating a rotation like "`rot(170)`", it animates a rotation of 170°, but it doesn't look very good. I fixed an old rotation issue in §3.3.6, but the speed is still a problem.

The speed of rotation is significantly higher during the middle of the rotation, which makes it look unnatural. I want to fix this to make rotations look more natural. Ideally, the program would detect a rotation and animate it in a different way, by moving the tips of the basis vectors along the edge of a circle with the radius equal to the length of the basis vectors. That shouldn't be too hard. However, I'd also like to animate scaled rotations like "`2rot(170)`". Animating in a circle won't work for this type of transformation, so I'll need to use a spiral.

This is a big feature, so I split it into a `dev/anim-rot` branch.

#### 3.10.9.1 Factoring out animation frames

The `LintransMainWindow.animate_expression()` method obviously handles animating expressions. It does this by calling a separate method called `LintransMainWindow.animate_between_matrices()` after parsing and evaluating the expression. The first step of improving my rotational animation code is to factor out the generation of individual frames when animating between matrices. This separate method will make it easier to work on the new feature.

Here's the old code, including the `animate_expression()` method, which wasn't changed:

```
# 751f185a2b64d31fe7ddd53aafab110008cff50b
# src/lintrans/gui/main_window.py

36 class LintransMainWindow(QMainWindow):
...
376     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
377         None:
378             """Animate from the start matrix to the target matrix."""
379             det_target = linalg.det(matrix_target)
380             det_start = linalg.det(matrix_start)
381
382             self.animating = True
383
384             for i in range(0, steps + 1):
385                 if not self.animating:
386                     break
387
388                 # This proportion is how far we are through the loop
389                 proportion = i / steps
390
391                 # matrix_a is the start matrix plus some part of the target, scaled by the proportion
392                 # If we just used matrix_a, then things would animate, but the determinants would be weird
393                 matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
394
395                 if self.plot.display_settings.smoothen_determinant and det_start * det_target > 0:
396                     # To fix the determinant problem, we get the determinant of matrix_a and use it to normalize
397                     det_a = linalg.det(matrix_a)
398
399                     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
400                     # We want B = cA such that det(B) = det(S), where S is the start matrix,
401                     # so then we can scale it with the animation, so we get
402                     # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
```

```

402         # Then we scale A to get the determinant we want, and call that matrix_b
403         if det_a == 0:
404             c = 0
405         else:
406             c = np.sqrt(abs(det_start / det_a))
407
408         matrix_b = c * matrix_a
409         det_b = linalg.det(matrix_b)
410
411         # matrix_to_render is the final matrix that we then render for this frame
412         # It's B, but we scale it over time to have the target determinant
413
414         # We want some C = dB such that det(C) is some target determinant T
415         # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
416
417         # We're also subtracting 1 and multiplying by the proportion and then adding one
418         # This just scales the determinant along with the animation
419
420         # That is all of course, if we can do that
421         # We'll crash if we try to do this with det(B) == 0
422         if det_b != 0:
423             scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
424             matrix_to_render = scalar * matrix_b
425
426         else:
427             matrix_to_render = matrix_a
428
429     else:
430         matrix_to_render = matrix_a
431
432     if self.is_matrix_too_big(matrix_to_render):
433         self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
434         return
435
436     self.plot.visualize_matrix_transformation(matrix_to_render)
437
438     # We schedule the plot to be updated, tell the event loop to
439     # process events, and asynchronously sleep for 10ms
440     # This allows for other events to be processed while animating, like zooming in and out
441     self.plot.update()
442     QApplication.processEvents()
443     QThread.msleep(1000 // steps)
444
445     self.animating = False

```

And here's the new code, not including the unchanged `animate_expression()` method:

```

# d47bb0165304d496caf7bbe3e09e4bbd12e45453
# src/lintrans/gui/mainwindow.py

36 class LintransMainWindow(QMainWindow):
...
376     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
377         """Get the matrix to render for this frame of the animation.
378
379         This method will smoothen the determinant if that setting is enabled and if the determinant is positive.
380         It also animates rotation-like matrices using a logarithmic spiral to rotate around and scale continuously.
381         Essentially, it just makes things look good when animating.
382
383         :param MatrixType start: The starting matrix
384         :param MatrixType start: The target matrix
385         :param float proportion: How far we are through the loop
386         """
387         det_target = linalg.det(target)
388         det_start = linalg.det(start)
389
390         # This is the matrix that we're applying to get from start to target
391         # We want to check if it's rotation-like
392         matrix_application = target @ linalg.inv(start)
393
394         if linalg.det(matrix_application) > 0 and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) <
395             0.1:

```

```

395     # TODO: Use logarithmic spiral here and return
396     pass
397
398     # matrix_a is the start matrix plus some part of the target, scaled by the proportion
399     # If we just used matrix_a, then things would animate, but the determinants would be weird
400     matrix_a = start + proportion * (target - start)
401
402     if not self.plot.display_settings.smoothen_determinant or det_start * det_target <= 0:
403         return matrix_a
404
405     # To fix the determinant problem, we get the determinant of matrix_a and use it to normalize
406     det_a = linalg.det(matrix_a)
407
408     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
409     # We want B = cA such that det(B) = det(S), where S is the start matrix,
410     # so then we can scale it with the animation, so we get
411     # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
412     # Then we scale A to get the determinant we want, and call that matrix_b
413     if det_a == 0:
414         c = 0
415     else:
416         c = np.sqrt(abs(det_start / det_a))
417
418     matrix_b = c * matrix_a
419     det_b = linalg.det(matrix_b)
420
421     # matrix_to_render is the final matrix that we then render for this frame
422     # It's B, but we scale it over time to have the target determinant
423
424     # We want some C = dB such that det(C) is some target determinant T
425     # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
426
427     # We're also subtracting 1 and multiplying by the proportion and then adding one
428     # This just scales the determinant along with the animation
429
430     # That is all of course, if we can do that
431     # We'll crash if we try to do this with det(B) == 0
432     if det_b == 0:
433         return matrix_a
434
435     scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
436     return scalar * matrix_b
437
438     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
439         None:
440             """Animate from the start matrix to the target matrix."""
441             self.animating = True
442
443             for i in range(0, steps + 1):
444                 if not self.animating:
445                     break
446
447                 matrix_to_render = self._get_animation_frame(matrix_start, matrix_target, i / steps)
448
449                 if self.is_matrix_too_big(matrix_to_render):
450                     self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
451                     self.animating = False
452                     return
453
454                 self.plot.visualize_matrix_transformation(matrix_to_render)
455
456                 # We schedule the plot to be updated, tell the event loop to
457                 # process events, and asynchronously sleep for 10ms
458                 # This allows for other events to be processed while animating, like zooming in and out
459                 self.plot.update()
460                 QApplication.processEvents()
461                 QThread.msleep(1000 // steps)
462
463             self.animating = False

```

Notice the `if` statement on line 394. This checks if the determinant is positive and the dot product of the basis vectors is close to 0. If these are both true, then the application matrix is a rotation

matrix<sup>25</sup>.

### 3.10.9.2 Utility functions and logarithmic spirals

I moved the `create_rotation_matrix()` function from `lintrans.matrices.wrapper` to a new `lintrans.matrices.utility` module, which will contain utility functions to help with animating rotations. And for the sake of consistency, I decided to only care about positive angles, so I adapted the function to make all angles positive by taking them modulo  $360^\circ$  or  $2\pi$  radians.

I also added some other utility functions - `polar_coords()` and `rect_coords()` - which will convert rectilinear (Cartesian) coordinates to polar coordinates and back again, respectively.

```
# 183dd02b4194c93aad51a21b7ad4147418c387c5
# src/lintrans/matrices/utility.py

7 """This module provides simple utility methods for matrix and vector manipulation."""
8
9 from __future__ import annotations
10
11 import math
12
13 import numpy as np
14
15 from lintrans.typing_ import MatrixType
16
17
18 def polar_coords(x: float, y: float, *, degrees: bool = False) -> tuple[float, float]:
19     """Return the polar coordinates of a given (x, y) Cartesian coordinate.
20
21     .. note:: We're returning the angle in the range [0, 2pi)
22     """
23     radius = math.hypot(x, y)
24
25     # PyCharm complains about np.angle taking a complex argument even though that's what it's designed for
26     # noinspection PyTypeChecker
27     angle = float(np.angle(x + y * 1j, degrees))
28
29     if angle < 0:
30         angle += 2 * np.pi
31
32     return radius, angle
33
34
35 def rect_coords(radius: float, angle: float, *, degrees: bool = False) -> tuple[float, float]:
36     """Return the rectilinear coordinates of a given polar coordinate."""
37     if degrees:
38         angle = np.radians(angle)
39
40     return radius * np.cos(angle), radius * np.sin(angle)
41
42
43 def create_rotation_matrix(angle: float, *, degrees: bool = True) -> MatrixType:
44     """Create a matrix representing a rotation (anticlockwise) by the given angle.
45
46     :Example:
47
48     >>> create_rotation_matrix(30)
49     array([[ 0.8660254, -0.5       ],
50            [ 0.5       ,  0.8660254]])
51     >>> create_rotation_matrix(45)
52     array([[ 0.70710678, -0.70710678],
53            [ 0.70710678,  0.70710678]])
54     >>> create_rotation_matrix(np.pi / 3, degrees=False)
55     array([[ 0.5       , -0.8660254],
56            [ 0.8660254,  0.5       ]])
```

---

<sup>25</sup>This isn't actually true. An enlargement matrix would also satisfy these conditions, but I didn't realise that at the time.

```

57
58     :param float angle: The angle to rotate anticlockwise by
59     :param bool degrees: Whether to interpret the angle as degrees (True) or radians (False)
60     :returns MatrixType: The resultant matrix
61     """
62     rad = np.deg2rad(angle % 360) if degrees else angle % (2 * np.pi)
63     return np.array([
64         [np.cos(rad), -1 * np.sin(rad)],
65         [np.sin(rad), np.cos(rad)]
66     ])

```

I then added unit tests for these functions and to assert that `create_rotation_matrix()` always makes its angle positive.

```

# 7b0c374d586e487e547dad886cc24239f768b554
# tests/matrices/utility/test_coord_conversion.py

"""Test conversion between polar and rectilinear coordinates in :mod:`lintrans.matrices.utility`."""
from numpy import pi, sqrt
from pytest import approx

from lintrans.matrices.utility import polar_coords, rect_coords

expected_coords: list[tuple[tuple[float, float], tuple[float, float]]] = [
    ((0, 0), (0, 0)),
    ((1, 1), (sqrt(2), pi / 4)),
    ((0, 1), (1, pi / 2)),
    ((1, 0), (1, 0)),
    ((sqrt(2), sqrt(2)), (2, pi / 4)),
    ((-3, 4), (5, 2.214297436)),
    ((4, -3), (5, 5.639684198)),
    ((5, -0.2), (sqrt(626) / 5, 6.24320662)),
    ((-1.3, -10), (10.08414597, 4.583113976)),
    ((23.4, 0), (23.4, 0)),
    ((pi, -pi), (4.442882938, 1.75 * pi))
]

def test_polar_coords() -> None:
    """Test that :func:`lintrans.matrices.utility.polar_coords` works as expected."""
    for rect, polar in expected_coords:
        assert polar_coords(*rect) == approx(polar)

def test_rect_coords() -> None:
    """Test that :func:`lintrans.matrices.utility.rect_coords` works as expected."""
    for rect, polar in expected_coords:
        assert rect_coords(*polar) == approx(rect)

        assert rect_coords(1, 0) == approx((1, 0))
        assert rect_coords(1, pi) == approx((-1, 0))
        assert rect_coords(1, 2 * pi) == approx((1, 0))
        assert rect_coords(1, 3 * pi) == approx((-1, 0))
        assert rect_coords(1, 4 * pi) == approx((1, 0))
        assert rect_coords(1, 5 * pi) == approx((-1, 0))
        assert rect_coords(1, 6 * pi) == approx((1, 0))
        assert rect_coords(20, 100) == approx(rect_coords(20, 100 % (2 * pi)))

# 7b0c374d586e487e547dad886cc24239f768b554
# tests/matrices/utility/test_rotation_matrices.py

def test_create_rotation_matrix() -> None:
    """Test that create_rotation_matrix() works with given angles and expected matrices."""
    for degrees, radians, matrix in angles_and_matrices:
        assert create_rotation_matrix(degrees, degrees=True) == pytest.approx(matrix)
        assert create_rotation_matrix(radians, degrees=False) == pytest.approx(matrix)

        assert create_rotation_matrix(-1 * degrees, degrees=True) == pytest.approx(np.linalg.inv(matrix))
        assert create_rotation_matrix(-1 * radians, degrees=False) == pytest.approx(np.linalg.inv(matrix))

```

```

82
83     assert (create_rotation_matrix(-90, degrees=True) ==
84             create_rotation_matrix(270, degrees=True)).all()
85     assert (create_rotation_matrix(-0.5 * np.pi, degrees=False) ==
86             create_rotation_matrix(1.5 * np.pi, degrees=False)).all()

(lintrans) dyson@Harold-Ubuntu:~/repos/lintrans [main *=]
$ pytest -
===== test session starts =====
platform linux -- Python 3.11.0, pytest-7.2.1, pluggy-1.0.0 -- /home/dyson/temp/lintrans/venv/bin/python
cachedir: .pytest_cache
rootdir: /home/dyson/temp/lintrans, configfile: pyproject.toml, testpaths: tests
collected 32 items

tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs0=True] PASSED [ 3%]
tests/gui/test_dialog_utility_functions.py::test_is_valid_float[inputs1=False] PASSED [ 6%]
tests/gui/test_dialog_utility_functions.py::test_round_float PASSED [ 9%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs0=True] PASSED [ 12%]
tests/matrices/test_parse_and_validate_expression.py::test_validate_matrix_expression[inputs1=False] PASSED [ 15%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_matrix_expression PASSED [ 18%]
tests/matrices/test_parse_and_validate_expression.py::test_parse_error PASSED [ 21%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_simple_matrix_addition PASSED [ 25%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_simple_two_matrix_multiplication PASSED [ 28%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_identity_multiplication PASSED [ 31%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_simple_three_matrix_multiplication PASSED [ 34%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_matrix_inverses PASSED [ 37%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_matrix_powers PASSED [ 40%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_matrix_transpose PASSED [ 43%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_rotation_matrices PASSED [ 46%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_multiplication_and_addition PASSED [ 50%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_complicated_expressions PASSED [ 53%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_value_errors PASSED [ 56%]
tests/matrices/test_matrix_wrapper/test_evaluate_expression.py::test_linalgerror PASSED [ 59%]
tests/matrices/test_matrix_wrapper/test_misc.py::test_get_expression PASSED [ 62%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_basic_get_matrix PASSED [ 65%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_get_name_error PASSED [ 68%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_basic_set_matrix PASSED [ 71%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_set_expression PASSED [ 75%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_simple_dynamic_evaluation PASSED [ 78%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_recursive_dynamic_evaluation PASSED [ 81%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_set_identity_error PASSED [ 84%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_set_name_error PASSED [ 87%]
tests/matrices/test_matrix_wrapper/test_setitem_and_getitem.py::test_set_type_error PASSED [ 90%]
tests/matrices/utility/test_coord_conversion.py::test_polar_coords PASSED [ 93%]
tests/matrices/utility/test_coord_conversion.py::test_rect_coords PASSED [ 96%]
tests/matrices/utility/test_rotation_matrices.py::test_create_rotation_matrix PASSED [100%]

===== 32 passed in 0.36s =====

```

Figure 3.10.11: Running pytest with the new tests

Then I had to actually implement the logarithmic spiral. I spent several hours playing around with Desmos and various formulae on paper, and eventually devised a way to connect two points with a logarithmic spiral. Sometimes.

The formula I came up with was designed to give a polar coordinate  $(r, \theta)$  which was some proportion  $p$  between 0 and 1 along the logarithmic spiral connecting the polar coordinates  $(r_1, \theta_1)$  and  $(r_2, \theta_2)$ . A generic logarithmic spiral has the form  $r = b^\theta$ , where  $b$  is called the base. I came up with the following equations to define my connecting curve:

$$r = r_1 \times b^{(\theta - \theta_1)} \quad \text{where } b = \left( \frac{r_2}{r_1} \right)^{\frac{-1}{\theta_1 - \theta_2}}$$

To get an arbitrary point with a proportion  $p$  along the curve, you can find  $\theta$  by  $\theta = \theta_1 + p(\theta_2 - \theta_1)$  and then plug that back in to find  $r$ .

Then I just had to implement this formula in code to move each basis vector accordingly.

```

# 2c86b3a7f40deb760e852fe6d0213cba15afcf9e
# src/lintrans/gui/main_window.py

37
38 class LintransMainWindow(QMainWindow):
39
40     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
41
42         pass

```

```

...
388     det_target = linalg.det(target)
389     det_start = linalg.det(start)
390
391     # This is the matrix that we're applying to get from start to target
392     # We want to check if it's rotation-like
393     matrix_application = target @ linalg.inv(start)
394
395     if linalg.det(matrix_application) > 0 and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) <
396         → 0.1:
397         # Get the columns of the matrices
398         # We're going to move i and then move j
399         i_vectors = (start.T[0], target.T[0])
400         j_vectors = (start.T[1], target.T[1])
401
402         matrix_list: list[tuple[float, float]] = []
403
404         for start_vector, end_vector in [i_vectors, j_vectors]:
405             # We want the points in polar coordinates
406             s_length, s_angle = polar_coords(start_vector[0], start_vector[1])
407             e_length, e_angle = polar_coords(end_vector[0], end_vector[1])
408
409             # We're using the standard formula for a logarithmic spiral,
410             # but we want to connect two specific points
411             # This base is just the base that we raise the angle to in the formula
412             base = (e_length / s_length) ** (-1 / (s_angle - e_angle))
413
414             angle = s_angle + proportion * (e_angle - s_angle)
415
416             # Logarithmic spiral equation
417             radius = s_length * base ** (angle - s_angle)
418
419             matrix_list.append(rect_coords(radius, angle))
420
421         return np.array(
422             [
423                 [matrix_list[0][0], matrix_list[1][0]],
424                 [matrix_list[0][1], matrix_list[1][1]]
425             ]
426         )
427     )

```

It worked really well for simple rotations like "`rot(170)`" and even worked for "`2rot(180)`", which I was very happy with. However, if you start from **I**, which is the default starting position, and try to rotate any more than 270°, the *i* vector goes anticlockwise, and the *j* vector goes clockwise. If you start at **I** and try to animate "`rot(180)`" more than once, then any time after the first, the basis vectors will rotate in opposite directions and go through each other. Even though after applying "`rot(180)`" twice, you should be back to **I**, the floating point error adds up and that tiny deviation breaks it.

This approach was a good start, but I'm going to need something better.

### 3.10.9.3 Checking for enlargement matrices

I found a bug where any enlargement matrix would immediately crash the program when you tried to animate. Suffice it to say, that's not very good. Recall back to footnote 25, where I said that the check would count enlargement matrices as rotation matrices. The logarithmic spiral formula can't connect two points with the same angle, since it would end up dividing by zero to find the base. This, of course, results in a crash.

To fix this bug, I simply changed the check to ignore any matrix that looks like an enlargement. If you divide an enlargement matrix by its determinant, then it will look like **I**, so we can just check that. Additionally, I only want to animate rotations smoothly like this if the smoothen determinant setting is on.

```
# 31100f35e8d46fcddaad18ee801e28904dc3011d
# src/lintrans/gui/main_window.py
```

```

37 class LintransMainWindow(QMainWindow):
...
377     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
...
395         if self.plot.display_settings.smoothen_determinant \
396             and linalg.det(matrix_application) > 0 \
397             and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 0.1 \
398                 and not (matrix_application / linalg.det(matrix_application) - np.eye(2) < 1e-5).all():

```

### 3.10.9.4 Using incremental circles instead

The logarithmic spiral was a nice idea, but the instability made it unsuitable as a long term solution. Instead, I decided to use incremental circles instead. I would scale a radius according the start and end radii, as well as the proportion of the way through the animation. Then I would find an angle in the same way and combine them into one polar coordinate.

Also, if the starting matrix is singular, then NumPy can't invert it so it crashes. This is obviously also bad, so I just had to check for it.

```

# f97f6542a051c05896711a01eb48a04dba693f64
# src/lintrans/gui/main_window.py

37 class LintransMainWindow(QMainWindow):
...
377     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
...
388         det_target = linalg.det(target)
389         det_start = linalg.det(start)
390
391         # This is the matrix that we're applying to get from start to target
392         # We want to check if it's rotation-like
393         if linalg.det(start) == 0:
394             matrix_application = None
395         else:
396             matrix_application = target @ linalg.inv(start)
397
398         if matrix_application is not None \
399             and self.plot.display_settings.smoothen_determinant \
400                 and linalg.det(matrix_application) > 0 \
401                     and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 0.1:
402             # Get the columns of the matrices
403             # We're going to move i and then move j
404             i_vectors = (start.T[0], target.T[0])
405             j_vectors = (start.T[1], target.T[1])
406
407             matrix_list: list[tuple[float, float]] = []
408             TWO_PI = 2 * np.pi
409
410             for start_vector, end_vector in [i_vectors, j_vectors]:
411                 # We want the points in polar coordinates
412                 s_length, s_angle = polar_coords(start_vector[0], start_vector[1])
413                 e_length, e_angle = polar_coords(end_vector[0], end_vector[1])
414
415                 angle_difference = e_angle - s_angle % TWO_PI
416
417                 if angle_difference > np.pi + 0.01: # Extra 0.01 accounts for floating point error
418                     angle = s_angle + proportion * (TWO_PI - angle_difference)
419                 else:
420                     angle = s_angle + proportion * angle_difference
421
422                 radius = s_length + proportion * (e_length - s_length)
423                 # angle = s_angle % TWO_PI + proportion * angle_difference
424
425                 matrix_list.append(rect_coords(radius, angle))
426
427             return np.array(
428                 [

```

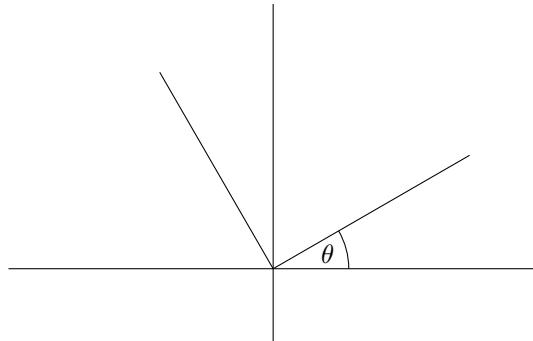
```

429     [matrix_list[0][0], matrix_list[1][0]],
430     [matrix_list[0][1], matrix_list[1][1]]
431   ]
432 )

```

Does this solve the instability problem with the basis vectors rotating in opposite directions? No.  
Does it make this algorithm simpler and easier to improve? Yes.

### 3.10.9.5 Treating the rotation as one thing



After much thought and deliberation, I realised that my fatal error was rotating the basis vectors independently. This allowed small floating point errors to cause the basis vectors to be rotated in opposite directions. What I need to do instead was to find the angle from one basis vector, and use that to rotate both.

I can find the angle  $\theta$  by using the first column of the application matrix, and then rotate both basis vectors by this same angle. By finding the angle just once and using a dedicated `rotate_coord()` utility function to avoid converting back and forth, it ensures that both the basis vectors get rotated by the same angle in the same direction.

I first added a type alias for a vector, mainly for convenience.

```

# c228904ab61cb33a6581fe28bb6330b5c2ece97
# src/lintrans/typing/_init__.py

27 VectorType = NDArray[(2,), Float]
28 """This type represents a 2D vector as a NumPy array, for use with :attr:`MatrixType`."""

```

I then created a utility function to rotate a rectilinear coordinate by a given angle.

```

# 425f3d653770724a01fd5f94314c7d076dadfef2
# src/lintrans/matrices/utility.py

43 def rotate_coord(x: float, y: float, angle: float, *, degrees: bool = False) -> tuple[float, float]:
44     """Rotate a rectilinear coordinate by the given angle."""
45     if degrees:
46         angle = np.radians(angle)
47
48     r, theta = polar_coords(x, y, degrees=degrees)
49     theta = (theta + angle) % (2 * np.pi)
50
51     return rect_coords(r, theta, degrees=degrees)

```

Then when generating a frame, I normalise the angle  $\theta$  to be  $-\pi \leq \theta < \pi$  (radians) and then rotate the coordinates of each basis vector by a proportion of the angle for each frame in the animation.

```

# 425f3d653770724a01fd5f94314c7d076dadfef2
# src/lintrans/gui/mainwindow.py

37 class LintransMainWindow(QMainWindow):
...
377     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:

```

```

378     """Get the matrix to render for this frame of the animation.
379
380     This method will smoothen the determinant if that setting is enabled and if the determinant is positive.
381     It also animates rotation-like matrices using a logarithmic spiral to rotate around and scale continuously.
382     Essentially, it just makes things look good when animating.
383
384     :param MatrixType start: The starting matrix
385     :param MatrixType target: The target matrix
386     :param float proportion: How far we are through the loop
387     """
388
389     det_target = linalg.det(target)
390     det_start = linalg.det(start)
390
391     # This is the matrix that we're applying to get from start to target
392     # We want to check if it's rotation-like
393     if linalg.det(start) == 0:
394         matrix_application = None
395     else:
396         matrix_application = target @ linalg.inv(start)
397
398     if matrix_application is not None \
399         and self.plot.display_settings.smooth_determinant \
400         and linalg.det(matrix_application) > 0 \
401         and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 0.1:
402         rotation_vector: VectorType = matrix_application.T[0] # Take the i column
403         radius, angle = polar_coords(*rotation_vector)
404
405     # We want the angle to be in [-pi, pi), so we have to subtract 2pi from it if it's too big
406     if angle > np.pi:
407         angle -= 2 * np.pi
408
409     i: VectorType = start.T[0]
410     j: VectorType = start.T[1]
411
412     # Scale the coords with a list comprehension
413     # It's a bit janky, but rotate_coords() will always return a 2-tuple,
414     # so new_i and new_j will always be lists of length 2
415     scale = (radius - 1) * proportion + 1
416     new_i = [scale * c for c in rotate_coord(i[0], i[1], angle * proportion)]
417     new_j = [scale * c for c in rotate_coord(j[0], j[1], angle * proportion)]
418
419     return np.array(
420         [
421             [new_i[0], new_j[0]],
422             [new_i[1], new_j[1]]
423         ]
424     )

```

And of course, I added this to the changelog.

```

<!-- 425f3d653770724a01fd5f94314c7d076dadfef2 -->
<!-- CHANGELOG.md -->

12     ### Added
...
16     - Add proper rotation animation that rotates at constant speed

```

Now rotations finally work properly!

### 3.10.10 Adding a setting for animation time

Once I'd merged the `dev/anim-rot` branch, I was basically done with v0.2.2, but I still wanted to add one last thing. I already had a display setting to control the delay between animating consecutive matrices in a sequence, but I also wanted a display setting to control how long the actual animation lasts. This would allow a teacher to animate something slowly to more precisely show an animation. Implementing it was very simple.

I just had to add the setting to the `DisplaySettings` dataclass, add code to the display settings dialog to allow changing it, and then use it in animations.

```
# 86343c4b0dd4ed9052184fd4ed924062a1cd9264
# src/lintrans/gui/settings.py

15  class DisplaySettings:
...
51      animation_time: int = 1200
52      """This is the number of milliseconds that an animation takes."""

# 86343c4b0dd4ed9052184fd4ed924062a1cd9264
# src/lintrans/gui/dialogs/settings.py

21  class SettingsDialog(FixedSizeDialog):
...
24      def __init__(self, *args, **kwargs):
...
127         self.label_animation_time = QtWidgets.QLabel(self)
128         self.label_animation_time.setText('Total animation length (ms)')
129         self.label_animation_time.setToolTip(
130             'How long it takes for an animation to complete'
131         )
132
133         self.lineEdit_animation_time = QtWidgets.QLineEdit(self)
134         self.lineEdit_animation_time.setValidator(QIntValidator(1, 9999, self))
...
226     def load_settings(self) -> None:
...
236         self.lineEdit_animation_time.setText(str(self.display_settings.animation_time))
...
245     def confirm_settings(self) -> None:
...
255         self.display_settings.animation_time = int(self.lineEdit_animation_time.text())

# 86343c4b0dd4ed9052184fd4ed924062a1cd9264
# src/lintrans/gui/main_window.py

37  class LintransMainWindow(QMainWindow):
...
465      def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType) -> None:
466          """Animate from the start matrix to the target matrix."""
467          self.animating = True
468
469          # Making steps depend on animation_time ensures a smooth animation without
470          # massive overheads for small animation times
471          steps = self.plot.display_settings.animation_time // 10
472
473          for i in range(0, steps + 1):
474              if not self.animating:
475                  break
476
477              matrix_to_render = self._get_animation_frame(matrix_start, matrix_target, i / steps)
478
479              if self.is_matrix_too_big(matrix_to_render):
480                  self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
481                  self.animating = False
482                  return
483
484              self.plot.visualize_matrix_transformation(matrix_to_render)
485
486              # We schedule the plot to be updated, tell the event loop to
487              # process events, and asynchronously sleep for 10ms
488              # This allows for other events to be processed while animating, like zooming in and out
489              self.plot.update()
490              QApplication.processEvents()
491              QThread.msleep(self.plot.display_settings.animation_time // steps)
492
493          self.animating = False
```

And then finally, I added it to the changelog.

```
<!-- 86343c4b0dd4ed9052184fd4ed924062a1cd9264 -->
<!-- CHANGELOG.md -->
```

```
10  ### Added
...
16  - Allow animation time to be varied
```

### 3.10.11 Releasing v0.2.2

Now I can just update the version number, tag the commit, and let GitHub Actions do the rest.

```
# 1139f94366be359aa5606c750c67b72c2777c961
# src/lintrans/__init__.py

11 __version__ = '0.2.2'
```

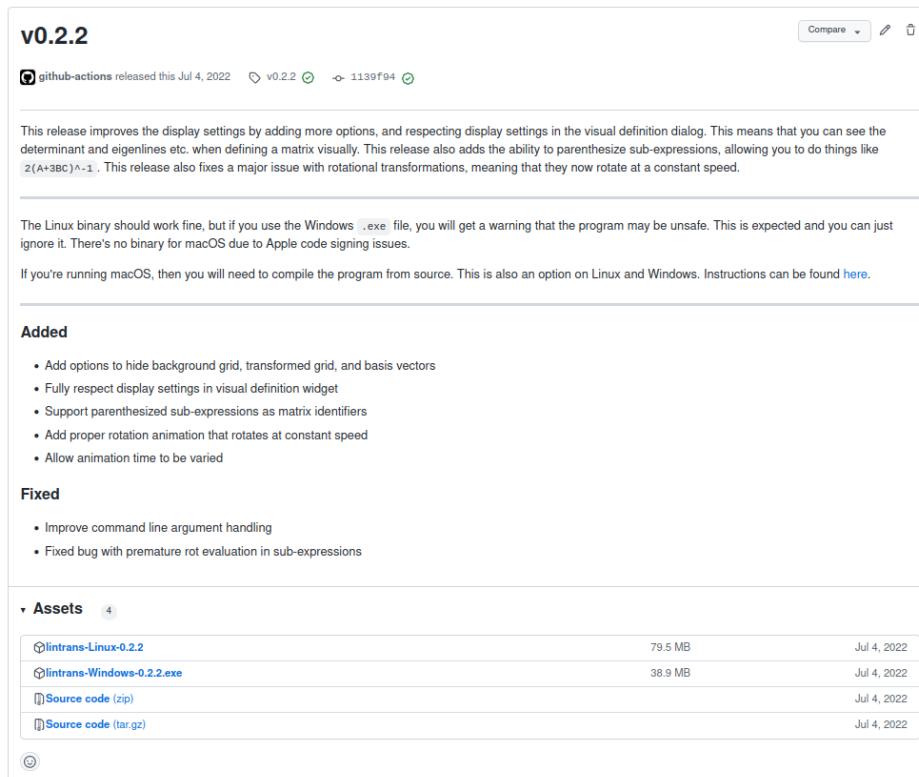


Figure 3.10.12: The release of v0.2.2 on GitHub

### 3.11 Teacher suggestions

Now that I've got v0.2.2 working and released, it's time to talk to some teachers. Ms Arnold is going to be the one that's actually using it, so obviously I needed to talk to her about it, but she wasn't available for a few days. I was talking to another maths teacher, Mr Dunkley, about my personal statement and took the opportunity to show him `lintrans` as well.

He was able to download and run it on a native Windows 10 installation, which was quite a relief. I'd been unable to test it on a real bare-metal Windows installation so far; I only had virtual machines.

He suggested two main improvements:

1. In the visual definition dialog, the basis vectors should snap to integer coordinates when they get close enough
2. There should be a dialog box which displays matrices that you've already defined

#### 3.11.1 Fixing a bug with animating stretches

While Mr Dunkley was playing around with `lintrans`, I noticed a bug where animating uniform stretches, where every direction gets stretched equally work, just fine, but a matrix like  $\begin{pmatrix} 3 & 0 \\ 0 & 1 \end{pmatrix}$  would be animated as if it was  $\begin{pmatrix} 3 & 0 \\ 0 & 3 \end{pmatrix}$  and the plane would stretch equally in all directions.

After looking at the code later, I realised this was a problem with my new animation code detecting this type of matrix as a rotation. To fix this, I could just add a check to the `if` statement before the rotation animation code. This new check would make sure that the basis vectors of the application matrix were approximately the same length. By checking this as well, I fixed the bug.

```
# eb118f02db9fb9c76ce15a976f81a037415d2a4e
# src/lintrans/gui/main_window.py

39  class LintransMainWindow(QMainWindow):
...
389     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
...
410         # For a matrix to represent a rotation, it must have a positive determinant,
411         # its vectors must be perpendicular, and its vectors must be the same length
412         # The checks for 'abs(value) < 1e-10' are to account for floating point error
413         if matrix_application is not None \
414             and self.plot.display_settings.smoothen_determinant \
415             and linalg.det(matrix_application) > 0 \
416             and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 1e-10 \
417             and abs(np.hypot(*matrix_application.T[0]) - np.hypot(*matrix_application.T[1])) < 1e-10:
```

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## A Project code

### A.1 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     
```

```
67      """
68      if not os.path.isfile(filename):
69          return lintrans.__version__, cls()
70
71      with open(filename, 'rb') as f:
72          file_data = pickle.load(f)
73
74      if not isinstance(file_data, tuple):
75          raise ValueError(f'File {filename} contains pickled object of the wrong type (must be tuple)')
76
77      # Create a default object and overwrite the fields that we have
78      data = cls()
79      for attr in file_data[1].__slots__:
80          # Try to get the attribute from the old data, but don't worry if we can't,
81          # because that means it's from an older version, so we can use the default
82          # values from 'cls()'
83          try:
84              setattr(data, attr, getattr(file_data[1], attr))
85          except AttributeError:
86              pass
87
88      return file_data[0], data
89
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
151         if self._executable_path is None:
152             executable_path = sys.executable
153             if os.path.isfile(executable_path):
154                 version_output = subprocess.run(
155                     [executable_path, '--version'],
156                     stdout=subprocess.PIPE,
157                     shell=(os.name == 'nt')
158                 ).stdout.decode()
159
160             if 'lintrans' in version_output:
161                 self._executable_path = executable_path
162             else:
163                 self._executable_path = ''
164
165     return self._executable_path or ''
166
167     def get_save_directory(self) -> str:
168         """Return the default directory for save files."""
169         return os.path.join(self._directory, 'saves')
170
171     def get_crash_reports_directory(self) -> str:
172         """Return the default directory for crash reports."""
173         return os.path.join(self._directory, 'crash_reports')
174
175     def get_settings_file(self) -> str:
176         """Return the full path of the settings file."""
177         return self._settings_file
178
179     def save_display_settings(self, settings: lintrans.gui.settings.DisplaySettings) -> None:
180         """Save the given display settings to the default file."""
181         settings.save_to_file(self._display_settings_file)
182
183     def get_display_settings(self) -> lintrans.gui.settings.DisplaySettings:
184         """Get the display settings from the default file, using the defaults for anything that's not available."""
185         return lintrans.gui.settings.DisplaySettings.load_from_file(self._display_settings_file)[1]
186
187     def get_update_download_filename(self) -> str:
188         """Return a name for a temporary file next to the executable.
189
190         This method is used when downloading a new version of lintrans into a temporary file.
191         This is needed to allow :func:`os.rename` instead of :func:`shutil.move`. The first
192         requires the src and dest to be on the same partition, but also allows us to replace
193         the running executable.
194         """
195
196         return str(Path(self.get_executable_path()).parent / 'lintrans-update-temp.dat')
197
198     def get_update_replace_batch_filename(self) -> str:
199         """Return the full path of the ``replace.bat`` file needed to update on Windows.
200
201         See :meth:`get_update_download_filename`.
202         """
203
204         return str(Path(self.get_executable_path()).parent / 'replace.bat')
205
206     def get_data(self) -> GlobalSettingsData:
207         """Return a copy of the internal global settings data."""
208         return copy(self._data)
209
210     def set_data(self, data: GlobalSettingsData) -> None:
211         """Set the internal global settings data and save it to a file."""
212         self._data = data
213         self._data.save_to_file(self._settings_file)
214
215     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.2 \_\_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.3 `__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.4 `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
48     widgets = [
49         x for x in QApplication.topLevelWidgets()
50         if isinstance(x, LintransMainWindow)
51     ]
52
53     if len(widgets) != 1:
54         raise RuntimeError(f'Expected 1 widget of type LintransMainWindow but found {len(widgets)}')
55
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
69     return info
70
71
72 def _get_error_origin(
73     *,
74     exc_type: Type[BaseException] | None,
75     exc_value: BaseException | None,
76     traceback: TracebackType | None,
77     signal_number: int | None,
78     stack_frame: FrameType | None
79 ) -> str:
80     """Return a string specifying the full origin of the error, as best as we can determine.
81
82     This function has effectively two signatures. If the fatal error is caused by an exception,
83     then the first 3 arguments will be used to match the signature of :func:`sys.excepthook`.
84     If it's caused by a signal, then the last two will be used to match the signature of the
85     handler in :func:`signal.signal`. This function should never be used outside this file, so
86     we don't account for a mixture of arguments.
87
88     :param exc_type: The type of the exception that caused the crash
89     :param exc_value: The value of the exception itself
90     :param traceback: The traceback object
91     :param signal_number: The number of the signal that caused the crash
92     :param stack_frame: The current stack frame object
93
94     :type exc_type: Type[BaseException] | None
95     :type exc_value: BaseException | None
96     :type traceback: types.TracebackType | None
97     :type signal_number: int | None
98     :type stack_frame: types.FrameType | None
99
100    """
101    origin = 'CRASH ORIGIN:\n'
102
103    if exc_type is not None and exc_value is not None and traceback is not None:
104        # We want the frame where the exception actually occurred, so we have to descend the traceback
105        # 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         origin += f'    on line {frame.f_lineno} of {frame.f_code.co_filename}'
112
113     elif signal_number is not None and stack_frame is not None:
114         origin += f'  Signal "{signal.strsignal(signal_number)}" received in call to
115         {stack_frame.f_code.co_name}()\n    '
116         origin += f'    on line {stack_frame.f_lineno} of {stack_frame.f_code.co_filename}'
117
118     else:
119         origin += '  UNKNOWN (not exception or signal)'
120
121     origin += '\n\n'
122
123     return origin
124
125 def _get_display_settings() -> str:
126     """Return a string representing all of the display settings."""
127     raw_settings = _get_main_window()._plot.display_settings
128     display_settings = {
129         k: getattr(raw_settings, k)
130         for k in raw_settings.__slots__
131         if not k.startswith('_')
132     }
133
134     string = 'Display settings:\n'
135
136     for setting, value in display_settings.items():
137         string += f'  {setting}: {value}\n'
138
139     return string
140
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
198     report = f'CRAASH REPORT at {datetime_string}\n\n'
199     report += _get_system_info()
200     report += error_origin
201     report += _get_post_mortem()
202
203     return report
204
205
206 def _report_crash(
207     *,
208     exc_type: Type[BaseException] | None = None,
209     exc_value: BaseException | None = None,
210     traceback: TracebackType | None = None,
211     signal_number: int | None = None,
212     stack_frame: FrameType | None = None
213 ) -> NoReturn:
214     """Generate a crash report and write it to a log file and stderr.
215
216     See :func:`_get_error_origin` for an explanation of the arguments. Everything is
217     handled internally if you just use the public functions :func:`set_excepthook` and
218     :func:`set_signal_handler`.
219
220     """
221
222     datetime_string = _get_datetime_string()
223
224     filename = os.path.join(
225         GlobalSettings().get_crash_reports_directory(),
226         datetime_string.replace(" ", "_") + '.log'
227     )
228     report = _get_crash_report(
229         datetime_string,
230         _get_error_origin(
231             exc_type=exc_type,
232             exc_value=exc_value,
233             traceback=traceback,
234             signal_number=signal_number,
235             stack_frame=stack_frame
236         )
237     )
238
239     print('\n\n' + report, end='', file=sys.stderr)
240     with open(filename, 'w', encoding='utf-8') as f:
241         f.write(report)
242
243     sys.exit(255)
244
245
246 def set_excepthook() -> None:
247     """Change :func:`sys.excepthook` to generate a crash report first."""
248     def _custom_excepthook(
249         exc_type: Type[BaseException],
250         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.5 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         (probably because 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/'
```

```

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_batch_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.6 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)

```

## A.7 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 = 'ABCDEFGHIJKLMNPQRSTUVWXYZ'
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
125         # Return a new rotation matrix
126         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
127             return create_rotation_matrix(float(match.group(1)))
128
129         if (match := re.match(
130             r'\[(-?\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?);(-?\d+(?:\.\d+)?)(-?\d+(?:\.\d+)?)\]', 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))
136             return np.array([[a, b], [c, d]])
137
138         if name not in self._matrices:
139             if validate_matrix_expression(name):
140                 return self.evaluate_expression(name)
141
142             raise NameError(f'Unrecognised matrix name "{name}"')
143
144         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
145         matrix = copy(self._matrices[name])
146
147         if isinstance(matrix, str):
148             return self.evaluate_expression(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

```

```
168         return
169
170     if isinstance(new_matrix, str):
171         if self.is_valid_expression(new_matrix):
172             if name not in new_matrix and \
173                 name not in self.get_expression_dependencies(new_matrix):
174                 self._matrices[name] = new_matrix
175             return
176         else:
177             raise ValueError('Cannot define a matrix recursively')
178
179     if not is_matrix_type(new_matrix):
180         raise TypeError('Matrix must be a 2x2 NumPy array')
181
182     # All matrices must have float entries
183     a = float(new_matrix[0][0])
184     b = float(new_matrix[0][1])
185     c = float(new_matrix[1][0])
186     d = float(new_matrix[1][1])
187
188     self._matrices[name] = np.array([[a, b], [c, d]])
189
190 def get_matrix_dependencies(self, matrix_name: str) -> Set[str]:
191     """Return all the matrices (as identifiers) that the given matrix (indirectly) depends on.
192
193     If A depends on nothing, B directly depends on A, and C directly depends on B,
194     then we say C depends on B 'and' A.
195     """
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
207     return s
208
209 def get_expression_dependencies(self, expression: str) -> Set[str]:
210     """Return all the matrices that the given expression depends on.
211
212     This method just calls :meth:`get_matrix_dependencies` on each matrix
213     identifier in the expression. See that method for details.
214
215     If an expression contains a matrix that has no dependencies, then the
216     expression is 'not' considered to depend on that matrix. But it 'is'
217     considered to depend on any matrix that has its own dependencies.
218     """
219     s = set()
220     for iden in get_matrix_identifiers(expression):
221         s.update(self.get_matrix_dependencies(iden))
222
223     return s
224
225 def get_expression(self, name: str) -> Optional[str]:
226     """If the named matrix is defined as an expression, return that expression, else return None.
227
228     :param str name: The name of the matrix
229     :returns Optional[str]: The expression that the matrix is defined as, or None
230
231     :raises NameError: If the name is invalid
232     """
233
234     if name not in self._matrices:
235         raise NameError('Matrix must have a legal name')
236
237     matrix = self._matrices[name]
238     if isinstance(matrix, str):
239         return matrix
240
241     return None
242
243 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
252     # Get rid of the transposes to check all capital letters
253     new_expression = expression.replace('^T', '').replace('^{\{T\}}', '')
254
255     # Make sure all the referenced matrices are defined
256     for matrix in [x for x in new_expression if re.match('[A-Z]', x)]:
257         if self[matrix] is None:
258             return False
259
260         if (expr := self.get_expression(matrix)) is not None:
261             if not self.is_valid_expression(expr):
262                 return False
263
264     return validate_matrix_expression(expression)
265
266 def evaluate_expression(self, expression: str) -> MatrixType:
267     """Evaluate a given expression and return the matrix evaluation.
268
269     :param str expression: The expression to be parsed
270     :returns MatrixType: The matrix result of the expression
271
272     :raises ValueError: If the expression is invalid
273     """
274     if not self.is_valid_expression(expression):
275         raise ValueError('The expression is invalid')
276
277     parsed_result = parse_matrix_expression(expression)
278     final_groups: List[List[MatrixType]] = []
279
280     for group in parsed_result:
281         f_group: List[MatrixType] = []
282
283         for multiplier, identifier, index in group:
284             if index == 'T':
285                 m = self[identifier]
286
287                 # This assertion is just so mypy doesn't complain
288                 # We know this won't be None, because we know that this matrix is defined in this wrapper
289                 assert m is not None
290                 matrix_value = m.T
291
292             else:
293                 # Again, this assertion is just for mypy
294                 # We know this will be a matrix, but since upgrading from NumPy 1.21 to 1.23
295                 # (to fix a bug with GH Actions on Windows), mypy complains about matrix_power()
296                 base_matrix = self[identifier]
297                 assert is_matrix_type(base_matrix)
298
299                 matrix_value = np.linalg.matrix_power(base_matrix, 1 if index == '' else int(index))
300
301                 matrix_value *= 1 if multiplier == '' else float(multiplier)
302                 f_group.append(matrix_value)
303
304             final_groups.append(f_group)
305
306     return reduce(add, [reduce(matmul, group) for group in final_groups])
307
308 def get_defined_matrices(self) -> List[Tuple[str, Union[MatrixType, str]]]:
309     """Return a list of tuples containing the name and value of all defined matrices in the wrapper.
310
311     :returns: A list of tuples where the first element is the name, and the second element is the value
312     :rtype: List[Tuple[str, Union[MatrixType, str]]]
313     """
314
315     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.8 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     """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     """Return the rectilinear coordinates of a given polar coordinate.
38     """
39     if degrees:
40         angle = np.radians(angle)
41
42     return radius * np.cos(angle), radius * np.sin(angle)
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     """
92     try:
93         float(string)
94         return True
95     except ValueError:
96         return False
97
98
99 def round_float(num: float, precision: int = 5) -> str:
100    """Round a floating point number to a given number of decimal places for pretty printing.
101
102    :param float num: The number to round
103    :param int precision: The number of decimal places to round to
104    :returns str: The rounded number for pretty printing
105
106    # Round to ``precision`` number of decimal places
107    string = str(round(num, precision))
108
109    # Cut off the potential final zero
110    if string.endswith('.0'):
111        return string[:-2]
112
113    elif 'e' in string: # Scientific notation
114        split = string.split('e')
115        # The leading 0 only happens when the exponent is negative, so we know there'll be a minus sign
116        return split[0] + 'e-' + split[1][1:].lstrip('0')
```

```

117     else:
118         return string

```

## A.9 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       anonymous\_matrix = r'\[(-?\d+(?:\\\\.\\\\d+)) (-?\d+(?:\\\\.\\\\d+));(-?\d+(?:\\\\.\\\\d+)) (-?\d+(?:\\\\.\\\\d+))\\]'
- 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    # This is an expensive pattern to compile, so we compile it when this module is initialized
- 48    \_naive\_expression\_pattern = compile\_naive\_expression\_pattern()
- 49
- 50
- 51    def find\_sub\_expressions(expression: str) -> List[str]:
- 52       """Find all the sub-expressions in the given expression.
- 53       This function only goes one level deep, so may return strings like ``A(BC)D``.
- 54       :raises MatrixParseError: If there are unbalanced parentheses
- 55       """
- 56       sub\_expressions: List[str] = []
- 57       string = ''
- 58       paren\_depth = 0
- 59       pointer = 0
- 60
- 61       expression = strip\_whitespace(expression)
- 62
- 63
- 64
- 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
105    # We replace the necessary whitespace with null bytes to preserve it
106    expression = re.sub(
107        r'[\s*(-?\d+(:\.\d+)?)\s+(-?\d+(:\.\d+)?)\s*;\s*(-?\d+(:\.\d+)?)\s+(-?\d+(:\.\d+)?)\s*\]', 
108        r'[\g<1> \g<2>;\g<3> \g<4>].replace(' ', '\x00'),
109        expression
110    )
111
112    expression = re.sub(r'\s', '', expression)
113    return re.sub('\x00', ' ', expression)
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
128     # Remove all whitespace
129     expression = strip_whitespace(expression)
130     match = _naive_expression_pattern.match(expression)
131
132     if match is None:
133         return False
134
135     if re.search(r'^-?\d*\.\d+', expression) is not None:
136         return False
137
138     # Check that the whole expression was matched against
139     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)(?=[^\]]|$)', r'{\g<0>}', expression)
191
192         # Remove any standalone minuses
193         expression = re.sub(r'-(?=[A-Z]|\\[)', '-1', expression)
194
195         # Replace subtractions with additions
196         expression = re.sub(r'-(?=\d+\\.?)\d*([A-Z]|rot|\\[))', '+-', 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
209     def __repr__(self) -> str:
210         """Return a simple repr containing the expression."""
211         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
243         # This loop continues to parse matrices until we fail to do so
244         while self._parse_matrix():
245             # Once we get to the end of the multiplication group, we add it the final list and reset the group list
246             if self._pointer >= len(self._expression) or self._char == '+':
247                 self._final_list.append(self._current_group)
248                 self._current_group = []
249                 self._pointer += 1
250
251     def _parse_matrix(self) -> bool:
252         """Parse a full matrix using :meth:`_parse_matrix_part`.
253
254         This method will parse an optional multiplier, an identifier, and an optional exponent. If we
255         do this successfully, we return True. If we fail to parse a matrix (maybe we've reached the
256         end of the current multiplication group and the next char is ``+``), then we return False.
257
258         :returns: bool: Success or failure
259         """
260         self._current_token = MatrixToken()
261
262         while self._parse_matrix_part():
263             pass # The actual execution is taken care of in the loop condition
264
265         if self._current_token.identifier == '':
266             return False
267
268         self._current_group.append(self._current_token.tuple)
269         return True
270
271     def _parse_matrix_part(self) -> bool:
272         """Parse part of a matrix (multiplier, identifier, or exponent).
273
274         Which part of the matrix we parse is dependent on the current value of the pointer and the expression.
275         This method will parse whichever part of matrix token that it can. If it can't parse a part of a matrix,
276         or it's reached the next matrix, then we just return False. If we succeeded to parse a matrix part, then
277         we return True.
278
279         :returns: bool: Success or failure
280         :raises MatrixParseError: If we fail to parse this part of the matrix
281         """
282         if self._pointer >= len(self._expression):
283             return False
```

```

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\(([^\d.-]+\)\)', 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_identifier(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
472     return ExpressionParser(expression).parse()
473
474
475 def get_matrix_identifiers(expression: str) -> Set[str]:
476     """Return all the matrix identifiers used in the given expression.  

477
478     This method works recursively with sub-expressions.
479     """
480
481     s = set()
482     top_level = [id for sublist in parse_matrix_expression(expression) for _, id, _ in sublist]
483
484     for body in top_level:
485         if body in _ALPHABET:
486             s.add(body)
487
488         elif re.match(r'rot\(\d+(\.\d+)?\)', body):
489             continue
490
491         else:
492             s.update(get_matrix_identifiers(body))
493
494     return s

```

## A.10 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.11 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 QCoreApplication
10
11
12 def qapp() -> QCoreApplication:
13     """Return the equivalent of the global :class:`qApp` pointer.
14
15     :raises RuntimeError: If :meth:`QCoreApplication.instance` returns ``None``.
16     """
17     instance = QCoreApplication.instance()
18
19     if instance is None:
20         raise RuntimeError('qApp undefined')
21
22     return instance

```

## A.12 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)
```

```
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 display 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)
306     self._button_info_panel.setToolTip(
307         'Open an info panel with all matrices that have been defined in this session<br><b>(Ctrl + M)</b>'
308     )
309     QShortcut(QKeySequence('Ctrl+M'), self).activated.connect(self._button_info_panel.click)
310
311     # Render buttons
312
313     button_reset = QPushButton(self)
314     button_reset.setText('Reset')
315     button_reset.clicked.connect(self._reset_transformation)
316     button_reset.setToolTip('Reset the visualized transformation back to the identity<br><b>(Ctrl + R)</b>')
317     QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(button_reset.click)
318
319     self._button_render = QPushButton(self)
320     self._button_render.setText('Render')
321     self._button_render.setEnabled(False)
322     self._button_render.clicked.connect(self._render_expression)
323     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 = QtWidgets.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._lineedit_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._lineedit_expression_box.setText('')
441         else:
442             self._lineedit_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.msleep(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 start: 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) => c = sqrt(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 => d = sqrt(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.msleep(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::
753                 .. note:: ``dialog_class`` must subclass
754                 :class:`~lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog`.
755
756                 :param dialog_class: The dialog class to instantiate
757                 :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog]
758                 """
759
760         # We create a dialog with a deepcopy of the current matrix_wrapper
761         # This avoids the dialog mutating this one
762         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
837         dialog = QMessageBox(self)
838         dialog.setWindowTitle(title)
839         dialog.setText(text)
840
841         if warning:
842             dialog.setIcon(QMessageBox.Warning)
843         else:
844             dialog.setIcon(QMessageBox.Critical)
845
846         if info is not None:
847             dialog.setInformativeText(info)
848
849         dialog.open()
850
851     # This is `finished` rather than `accepted` because we want to update the buttons no matter what
852     dialog.finished.connect(self._update_render_buttons)
853
854     def _is_matrix_too_big(self, matrix: MatrixType) -> bool:
855         """Check if the given matrix will actually fit on the grid.
856
857         We're checking against a 1000x1000 grid here, which is far less than the actual space we have available.
858         But even when fully zoomed out 1080p monitor, the grid is only roughly 170x90, so 1000x1000 is plenty.
859
860         :param MatrixType matrix: The matrix to check
861         :returns bool: Whether the matrix is too big to fit on the canvas
862         """
863
864         for x, y in matrix.T:
865             if not (-1000 <= x <= 1000 and -1000 <= y <= 1000):
866                 self._show_error_message(
867                     'Matrix too big',
868                     "This matrix doesn't fit on the grid.",
869                     "This grid is only 1000x1000, and this matrix\n"
870                     f'{int(matrix[0][0])} {int(matrix[0][1])}; {int(matrix[1][0])} {int(matrix[1][1])}\n'
871                     " doesn't fit."
872
873         return True
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
878         if self._save_filename:
879             title = os.path.split(self._save_filename)[-1] + '[*] - lintrans'
880         else:
881             title = '[*]lintrans'
882
883         self.setWindowTitle(title)
884
885     def _reset_session(self) -> None:
886         """Ask the user if they want to reset the current session.
887
888         Resetting the session means setting the matrix wrapper to a new instance, and rendering I.
889         """
890
891         dialog = QMessageBox(self)
892         dialog.setIcon(QMessageBox.Question)
893         dialog.setWindowTitle('Reset the session?')
894         dialog.setText('Are you sure you want to reset the current session?')
895         dialog.setStandardButtons(QMessageBox.Yes | QMessageBox.No)
896         dialog.setDefaultButton(QMessageBox.No)
897
898         if dialog.exec() == QMessageBox.Yes:
899             self._matrix_wrapper = MatrixWrapper()
900             self._plot.polygon_points = []
901             self._plot.display_settings = GlobalSettings().get_display_settings()
902
903             self._reset_transformation()
904             self._expression_history = []
905             self._expression_history_index = None
906             self._lineedit_expression_box.setText('')
907             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
919         try:
920             session, version, extra_attrs = Session.load_from_file(filename)
921
922             # load_from_file() can raise errors if the contents is not a valid pickled Python object,
923             # or if the pickled Python object is of the wrong type
924             except (AttributeError, EOFError, FileNotFoundError, ValueError, UnpicklingError):
925                 self._show_error_message(
926                     'Invalid file contents',
927                     'This is not a valid lintrans session file.',
928                     'Not all .lt files are lintrans session files. This file was probably created by an unrelated '
929                     'program.')
930
931         return
932
933     missing_parts = False
934
935     if session.matrix_wrapper is not None:
936         self._matrix_wrapper = session.matrix_wrapper
937     else:
938         self._matrix_wrapper = MatrixWrapper() # type: ignore[unreachable]
939         missing_parts = True
940
941     if session.polygon_points is not None:
942         self._plot.polygon_points = session.polygon_points
943     else:
944         self._plot.polygon_points = [] # type: ignore[unreachable]
945         missing_parts = True
946
947     if session.display_settings is not None:
948         self._plot.display_settings = session.display_settings
949     else:
950         self._plot.display_settings = DisplaySettings() # type: ignore[unreachable]
951         missing_parts = True
952
953     if session.input_vector is not None:
954         self._plot.point_input_vector = session.input_vector
955     else:
956         self._plot.point_input_vector = (1, 1) # type: ignore[unreachable]
957         missing_parts = True
958
959     if missing_parts:
960         if version != lintrans.__version__:
961             info = f"This may be a version conflict. This file was saved with lintrans v{version} " \
962                   f"but you're running lintrans v{lintrans.__version__}.""
963         else:
964             info = None
965
966         self._show_error_message(
967             'Session file missing parts',
968             'This session file is missing certain elements. It may not work correctly.',
969             info,
970             warning=True
971         )
972     elif extra_attrs:
973         if version != lintrans.__version__:
974             info = f"This may be a version conflict. This file was saved with lintrans v{version} " \
975                   f"but you're running lintrans v{lintrans.__version__}.""
976         else:
977             info = None
978
979         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._lineedit_expression_box.setText('')
990     self._lineedit_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
1079         app = QApplication([])
1080         app.setApplicationName('lintrans')
1081         app.setApplicationVersion(lintrans.__version__)
1082
1083         qapp().setStyle(QStyleFactory.create('fusion'))
1084
1085         window = LintransMainWindow()
1086         window.show()
1087         window.check_for_updates_and_prompt()
1088
1089         if filename:
1090             window.open_session_file(filename)
1091
1092         sys.exit(app.exec_())

```

### A.13 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_parallellogram: 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 drawn if :attr:`draw_determinant_parallellogram` 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
```

```

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
122         if not os.path.isfile(filename):
123             return lintrans.__version__, cls()
124
125         with open(filename, 'rb') as f:
126             file_data = pickle.load(f)
127
128         if not isinstance(file_data, tuple):
129             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be tuple)')
130
131         # Create a default object and overwrite the fields that we have
132         data = cls()
133         for attr in file_data[1].__slots__:
134             # Try to get the attribute from the old data, but don't worry if we can't,
135             # because that means it's from an older version, so we can use the default
136             # values from `cls()`
137             try:
138                 setattr(data, attr, getattr(file_data[1], attr))
139             except AttributeError:
140                 pass
141
142         return file_data[0], data

```

## A.14 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         extraAttrs = 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.15 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 .mainwindow import main
11
12 __all__ = ['dialogs', 'main', 'plots', 'session', 'settings', 'utility', 'validate']

```

### A.16 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.17 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
60            self.setWindowTitle('About lintrans')
61
62            # === Create the widgets
63
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
173         bold_font = self.font()
174         bold_font.setBold(True)
175
176         label_name = QLabel(self)
177         label_name.setText(name)
178         label_name.setFont(bold_font)
179
180         widget_matrix = self._get_matrix_data_widget(value)
181
182         hlay = QHBoxLayout()
183         hlay.setSpacing(10)
184         hlay.addWidget(label_name)
185         hlay.addWidget(QLabel('=', self))
186         hlay.addWidget(widget_matrix)
187
188         vlay = QVBoxLayout()
189         vlay.setSpacing(10)
190         vlay.addLayout(hlay)
191
192         if name != 'I':
193             button_undefine = QPushButton(self)
194             button_undefine.setText('Undefine')
195             button_undefine.clicked.connect(lambda: self._undefine_matrix(name))
196
197             vlay.addWidget(button_undefine)
198
199         groupbox = QGroupBox(self)
200         groupbox.setContentsMargins(10, 10, 10, 10)
201         groupbox.setLayout(vlay)
202
203         lay = QVBoxLayout()
204         lay.setSpacing(0)
205         lay.addWidget(groupbox)
206
207         container = QWidget(self)
208         container.setLayout(lay)
209
210         return container
211
212     def _get_matrix_data_widget(self, matrix: Union[MatrixType, str]) -> QWidget:
213         """Return a :class:`QWidget` containing the value of the matrix.
214
215         If the matrix is defined as an expression, it will be a simple :class:`QLabel`.
216         If the matrix is defined as a matrix, it will be a :class:`QWidget` container
217         with multiple :class:`QLabel` objects in it.
218         """
219
220         if isinstance(matrix, str):
221             label = QLabel(self)
222             label.setText(matrix)
223             return label
224
225         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.18 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
76     vlay_all = QVBoxLayout()
77     vlay_all.setSpacing(20)
78     vlay_all.addLayout(options_layout)
79     vlay_all.addLayout(self._hlay_buttons)
80
81     self.setLayout(vlay_all)
82
83     @abc.abstractmethod
84     def _load_settings(self) -> None:
85         """Load the current settings into the widgets."""
86
87     @abc.abstractmethod
88     def _confirm_settings(self) -> None:
89         """Confirm the settings chosen in the dialog."""
90
91     def _reset_settings(self) -> None:
92         """Reset the settings.
93
94         .. note:: This method is empty but not abstract because not all subclasses will need to implement it.
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')
```

```
132         self._checkbox_draw_basis_vectors.setToolTip(
133             'Draw the transformed basis vectors'
134         )
135         self._checkbox_draw_basis_vectors.clicked.connect(self._update_gui)
136         self._dict_checkboxes['v'] = self._checkbox_draw_basis_vectors
137
138         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_smoothen_determinant = QCheckBox(self)
148         self._checkbox_smoothen_determinant.setText('&Smoothen determinant')
149         self._checkbox_smoothen_determinant.setToolTip(
150             'Smoothly animate the determinant transition during animation (if possible)'
151         )
152         self._dict_checkboxes['s'] = self._checkbox_smoothen_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_parallelgram = QCheckBox(self)
184         self._checkbox_draw_determinant_parallelgram.setText('Draw &determinant parallelogram')
185         self._checkbox_draw_determinant_parallelgram.setToolTip(
186             'Shade the parallelogram representing the determinant of the matrix'
187         )
188         self._checkbox_draw_determinant_parallelgram.clicked.connect(self._update_gui)
189         self._dict_checkboxes['d'] = self._checkbox_draw_determinant_parallelgram
190
191         self._checkbox_show_determinant_value = QCheckBox(self)
192         self._checkbox_show_determinant_value.setText('Show de&terminant 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 eigen&lines')
```

```
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&nput 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._lineedit_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._lineedit_animation_pause_length)
255
256     vlay_groupbox_animations = QVBoxLayout()
257     vlay_groupbox_animations.setSpacing(20)
258     vlay_groupbox_animations.addWidget(self._checkbox_smoothen_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_parallellogram)
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_smoothen_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_parallellogram.setChecked(self.display_settings.draw_determinant_parallellogram)
337         self._checkbox_show_determinant_value.setChecked(self.display_settings.show_determinant_value)
338         self._checkbox_draw_eigenvectors.setChecked(self.display_settings.draw_eigenvectors)
339         self._checkbox_draw_eigenlines.setChecked(self.display_settings.draw_eigenlines)
340
341         # Polygon
342         self._checkbox_draw_untransformed_polygon.setChecked(self.display_settings.draw_untransformed_polygon)
343         self._checkbox_draw_transformed_polygon.setChecked(self.display_settings.draw_transformed_polygon)
344
345         # Input/output vectors
346         self._checkbox_draw_input_vector.setChecked(self.display_settings.draw_input_vector)
347         self._checkbox_draw_output_vector.setChecked(self.display_settings.draw_output_vector)
348
349     def _confirm_settings(self) -> None:
```

```

350     """Build a :class:`~lintrans.gui.settings.DisplaySettings` object and assign it."""
351     # Basic stuff
352     self.display_settings.draw_background_grid = self._checkbox_draw_background_grid.isChecked()
353     self.display_settings.draw_transformed_grid = self._checkbox_draw_transformed_grid.isChecked()
354     self.display_settings.draw_basis_vectors = self._checkbox_draw_basis_vectors.isChecked()
355     self.display_settings.label_basis_vectors = self._checkbox_label_basis_vectors.isChecked()
356
357     # Animations
358     self.display_settings.smoothen_determinant = self._checkbox_smoothen_determinant.isChecked()
359     self.display_settings.applicative_animation = self._checkbox_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_parallelgram =
365         self._checkbox_draw_determinant_parallelgram.isChecked()
366     self.display_settings.show_determinant_value = self._checkbox_show_determinant_value.isChecked()
367     self.display_settings.draw_eigenvectors = self._checkbox_draw_eigenvectors.isChecked()
368     self.display_settings.draw_eigenlines = self._checkbox_draw_eigenlines.isChecked()
369
370     # Polygon
371     self.display_settings.draw_untransformed_polygon = self._checkbox_draw_untransformed_polygon.isChecked()
372     self.display_settings.draw_transformed_polygon = self._checkbox_draw_transformed_polygon.isChecked()
373
374     # Input/output vectors
375     self.display_settings.draw_input_vector = self._checkbox_draw_input_vector.isChecked()
376     self.display_settings.draw_output_vector = self._checkbox_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._checkbox_show_determinant_value.setEnabled(self._checkbox_draw_determinant_parallelgram.isChecked())
392         self._checkbox_label_basis_vectors.setEnabled(self._checkbox_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
423     return

```

```
422
423     event.accept()
424
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 distance (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
503         self._load_settings()
504         self._update_gui()
505         self._setup_layout(options_layout)
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._checkbox_snap_to_int_coords.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.19 `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.20 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 = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
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
42     return 'A'
43
44
45     class DefineMatrixDialog(FixedSizeDialog):
46         """An abstract superclass for definitions dialogs.
47
48         .. warning:: This class should never be directly instantiated, only subclassed.
49         """
50
51         def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
52             """Create the widgets and layout of the dialog.
```

```
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    
```

```
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]
```

```
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
216 class DefineNumericallyDialog(DefineMatrixDialog):
217     """The dialog class that allows the user to define a new matrix numerically."""
218
219     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
220         """Create the widgets and layout of the dialog.
221
222         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
223         """
224         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
225
226         # === Create the widgets
227
228         # tl = top left, br = bottom right, etc.
229         self._element_tl = QLineEdit(self)
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()
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()
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.21 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.
59
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
305         cursor_pos = (event.x(), event.y())
306
307         if event.button() != Qt.LeftButton:
308             event.ignore()
309             return
310
311         for point in (self.point_i, self.point_j):
312             if self._is_within_epsilon(cursor_pos, point):
313                 self._dragged_point = point[0], point[1]
314
315         event.accept()
316
317     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
318         """Handle the mouse click being released by unsetting the dragged point."""
319         if event.button() == Qt.LeftButton:
320             self._dragged_point = None
321             event.accept()
322         else:
323             event.ignore()
324
325     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
362                 point."""
363                 if event.button() not in (Qt.LeftButton, Qt.RightButton):
364                     event.ignore()
365                     return
366
367                 canvas_pos = (event.x(), event.y())
368                 grid_pos = self._grid_coords(*canvas_pos)
369
370                 if event.button() == Qt.LeftButton:
371                     for i, point in enumerate(self.points):
372                         if self._is_within_epsilon(canvas_pos, point):
373                             self._dragged_point_index = i
374                             event.accept()
375                             return
376
377                 new_point = self._round_to_int_coord(grid_pos)
378
379                 if len(self.points) < 2:
380                     self.points.append(new_point)
381                     self._dragged_point_index = -1
382                 else:
383                     # FIXME: This algorithm doesn't work very well when the new point is far away
384                     # from the existing polygon; it just picks the longest side
385
386                     # Get a list of line segments and a list of their lengths
387                     line_segments = list(zip(self.points, self.points[1:])) + [(self.points[-1], self.points[0])]
388                     segment_lengths = map(lambda t: dist(*t), line_segments)
389
390                     # Get the distance from each point in the polygon to the new point
391                     distances_to_point = [dist(p, new_point) for p in self.points]
392
393                     # For each pair of list-adjacent points, zip their distances to
394                     # the new point into a tuple, and add them together
395                     # This gives us the lengths of the catheti of the triangles that
396                     # connect the new point to each pair of adjacent points
397                     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.22 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.23 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:ffff` 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_coords(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
195             x, y = point
196
197             possible_snaps: List[Tuple[int, int]] = [
198                 (floor(x), floor(y)),
199                 (floor(x), ceil(y)),
200                 (ceil(x), floor(y)),
201                 (ceil(x), ceil(y))
202             ]
203
204             snap_distances: List[Tuple[float, Tuple[int, int]]] = [
205                 (dist((x, y), coord), coord)
206                 for coord in possible_snaps
207             ]
208
209             for snap_dist, coord in snap_distances:
210                 if GlobalSettings().get_data().snap_to_int_coords and snap_dist < GlobalSettings().get_data().snap_dist:
211                     x, y = coord
212
213             return x, y
214
215         def _is_within_epsilon(self, cursor_pos: Tuple[float, float], point: Tuple[float, float]) -> bool:
216             """Check if the cursor position (in canvas coords) is within range of the given point."""
217             mx, my = cursor_pos
218             px, py = self.canvas_coords(*point)
219             cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
220             return (abs(px - mx) <= cursor_epsilon and abs(py - my) <= cursor_epsilon)
221
222         @abstractmethod
223         def mousePressEvent(self, event: QMouseEvent) -> None:
224             """Handle the mouse being pressed."""
225
226         @abstractmethod
227         def mouseReleaseEvent(self, event: QMouseEvent) -> None:
228             """Handle the mouse being released."""
229
230         @abstractmethod
231         def mouseMoveEvent(self, event: QMouseEvent) -> None:
232             """Handle the mouse moving on the widget."""
233
234
235     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."""
249
250     _COLOUR_J = QColor('#e90000')
251     """This is the colour of the `j` basis vector and associated transformed grid lines."""
252
253     _COLOUR_TEXT = QColor('#000000')
254     """This is the colour of the text."""
255
256     _WIDTH_VECTOR_LINE = 1.8
257     """This is the width of the transformed basis vector lines, as a multiple of the :class:`QPainter` line
258     ↪ width."""
259
260     _WIDTH_TRANSFORMED_GRID = 0.8
261     """This is the width of the transformed grid lines, as a multiple of the :class:`QPainter` line width."""
262
263     _ARROWHEAD_LENGTH = 0.15
264     """This is the minimum length (in grid coord size) of the arrowhead parts."""
265
266     _MAX_PARALLEL_LINES = 150
267     """This is the maximum number of parallel transformed grid lines that will be drawn.
268
269     The user can zoom out further, but we will stop drawing grid lines beyond this number.
270     """
271
272     def __init__(self, *args, **kwargs):
273         """Create the widget with ``point_i`` and ``point_j`` attributes.
274
275         .. note:: ``*args`` and ``**kwargs`` are passed to the superclass constructor (:class:`BackgroundPlot`).
276         """
277         super().__init__(*args, **kwargs)
278
279         self.point_i: Tuple[float, float] = (1., 0.)
280         self.point_j: Tuple[float, float] = (0., 1.)
281
282         @property
283         def _matrix(self) -> MatrixType:
284             """Return the assembled matrix of the basis vectors."""
285             return np.array([
286                 [self.point_i[0], self.point_j[0]],
287                 [self.point_i[1], self.point_j[1]]
288             ])
289
290         @property
291         def _det(self) -> float:
292             """Return the determinant of the assembled matrix."""
293             return float(np.linalg.det(self._matrix))
294
295         @property
296         def _eigs(self) -> 'Iterable[Tuple[float, VectorType]]':
297             """Return the eigenvalues and eigenvectors zipped together to be iterated over.
298
299             :rtype: Iterable[Tuple[float, VectorType]]
300             """
301             values, vectors = np.linalg.eig(self._matrix)
302             return zip(values, vectors.T)
303
304         @abstractmethod
305         def paintEvent(self, event: QPaintEvent) -> None:
306             """Handle a :class:`QPaintEvent`."""
```

```
305
306     def _draw_parallel_lines(self, painter: QPainter, vector: Tuple[float, float], point: Tuple[float, float]) ->
307         None:
308             """Draw a set of evenly spaced grid lines parallel to ``vector`` intersecting ``point``.
309
310             :param QPainter painter: The painter to draw the lines with
311             :param vector: The vector to draw the grid lines parallel to
312             :type vector: Tuple[float, float]
313             :param point: The point for the lines to intersect with
314             :type point: Tuple[float, float]
315             """
316
317         max_x, max_y = self._grid_corner()
318         vector_x, vector_y = vector
319         point_x, point_y = point
320
321         # If the determinant is 0
322         if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
323             rank = np.linalg.matrix_rank(
324                 np.array([
325                     [vector_x, point_x],
326                     [vector_y, point_y]
327                 ])
328             )
329
330             # If the matrix is rank 1, then we can draw the column space line
331             if rank == 1:
332                 # If the vector does not have a 0 x or y component, then we can just draw the line
333                 if abs(vector_x) > 1e-12 and abs(vector_y) > 1e-12:
334                     self._draw_oblique_line(painter, vector_y / vector_x, 0)
335
336                 # Otherwise, we have to draw lines along the axes
337                 elif abs(vector_x) > 1e-12 and abs(vector_y) < 1e-12:
338                     painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
339
340                 elif abs(vector_x) < 1e-12 and abs(vector_y) > 1e-12:
341                     painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
342
343             # If the vector is (0, 0), then don't draw a line for it
344             else:
345                 return
346
347             # If the rank is 0, then we don't draw any lines
348             else:
349                 return
350
351             # If both components of the vector are practically 0, then we can't render any grid lines
352             return
353
354             # Draw vertical lines
355             elif abs(vector_x) < 1e-12:
356                 painter.drawLine(self._canvas_x(0), 0, self._canvas_x(0), self.height())
357
358                 for i in range(min(abs(int(max_x / point_x)), self._MAX_PARALLEL_LINES)):
359                     painter.drawLine(
360                         self._canvas_x((i + 1) * point_x),
361                         0,
362                         self._canvas_x((i + 1) * point_x),
363                         self.height()
364                     )
365                     painter.drawLine(
366                         self._canvas_x(-1 * (i + 1) * point_x),
367                         0,
368                         self._canvas_x(-1 * (i + 1) * point_x),
369                         self.height()
370                     )
371
372             # Draw horizontal lines
373             elif abs(vector_y) < 1e-12:
374                 painter.drawLine(0, self._canvas_y(0), self.width(), self._canvas_y(0))
375
376                 for i in range(min(abs(int(max_y / point_y)), self._MAX_PARALLEL_LINES)):
377                     painter.drawLine(
```

```

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449
    0,
    self._canvas_y((i + 1) * point_y),
    self.width(),
    self._canvas_y((i + 1) * point_y)
)
painter.drawLine(
    0,
    self._canvas_y(-1 * (i + 1) * point_y),
    self.width(),
    self._canvas_y(-1 * (i + 1) * point_y)
)

# If the line is oblique, then we can use y = mx + c
else:
    m = vector_y / vector_x
    c = point_y - m * point_x

    self._draw_oblique_line(painter, m, 0)

# We don't want to overshoot the max number of parallel lines,
# but we should also stop looping as soon as we can't draw any more lines
for i in range(1, self._MAX_PARALLEL_LINES + 1):
    if not self._draw_pair_of_oblique_lines(painter, m, i * c):
        break

def _draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
    """Draw a pair of oblique lines, using the equation y = mx + c.

    This method just calls :meth:`_draw_oblique_line` with ``c`` and ``-c``,
    and returns True if either call returned True.

    :param QPainter painter: The painter to draw the vectors and grid lines with
    :param float m: The gradient of the lines to draw
    :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
    :returns bool: Whether we were able to draw any lines on the canvas
    """

    return any([
        self._draw_oblique_line(painter, m, c),
        self._draw_oblique_line(painter, m, -c)
    ])

def _draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
    """Draw an oblique line, using the equation y = mx + c.

    We only draw the part of the line that fits within the canvas, returning True if
    we were able to draw a line within the boundaries, and False if we couldn't draw a line

    :param QPainter painter: The painter to draw the vectors and grid lines with
    :param float m: The gradient of the line to draw
    :param float c: The y-intercept of the line to draw
    :returns bool: Whether we were able to draw a line on the canvas
    """

    max_x, max_y = self._grid_corner()

    # These variable names are shortened for convenience
    # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
    myi = (max_y - c) / m
    mmyi = (-max_y - c) / m
    mxi = max_x * m + c
    mmxi = -max_x * m + c

    # The inner list here is a list of coords, or None
    # If an intersection fits within the bounds, then we keep its coord,
    # else it is None, and then gets discarded from the points list
    # By the end, points is a list of two coords, or an empty list
    points: List[Tuple[float, float]] = [
        x for x in [
            (myi, max_y) if -max_x < myi < max_x else None,
            (mmyi, -max_y) if -max_x < mmyi < max_x else None,
            (max_x, mxi) if -max_y < mxi < max_y else None,
            (-max_x, mmxi) if -max_y < mmxi < max_y else None
        ] if x is not None
    ]

```

```

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
467     them.
468
469     :param QPainter painter: The painter to draw the grid lines with
470     """
471     # Draw all the parallel lines
472     painter.setPen(QPen(self._COLOUR_I, self._WIDTH_TRANSFORMED_GRID))
473     self._draw_parallel_lines(painter, self.point_i, self.point_j)
474     painter.setPen(QPen(self._COLOUR_J, self._WIDTH_TRANSFORMED_GRID))
475     self._draw_parallel_lines(painter, self.point_j, self.point_i)
476
477 def _draw_arrowhead_away_from_origin(self, painter: QPainter, point: Tuple[float, float]) -> None:
478     """Draw an arrowhead at ``point``, pointing away from the origin.
479
480     :param QPainter painter: The painter to draw the arrowhead with
481     :param point: The point to draw the arrowhead at, given in grid coords
482     :type point: Tuple[float, float]
483     """
484
485     # This algorithm was adapted from a C# algorithm found at
486     # http://csharphelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
487
488     # Get the x and y coords of the point, and then normalize them
489     # We have to normalize them, or else the size of the arrowhead will
490     # scale with the distance of the point from the origin
491     x, y = point
492     vector_length = np.sqrt(x * x + y * y)
493
494     if vector_length < 1e-12:
495         return
496
497     nx = x / vector_length
498     ny = y / vector_length
499
500     # We choose a length and find the steps in the x and y directions
501     length = min(
502         self._ARROWHEAD_LENGTH * self.DEFAULT_GRID_SPACING / self.grid_spacing,
503         vector_length
504     )
505     dx = length * (-nx - ny)
506     dy = length * (nx - ny)
507
508     # Then we just plot those lines
509     painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x + dx, y + dy))
510     painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x - dy, y + dx))
511
512 def _draw_position_vector(self, painter: QPainter, point: Tuple[float, float], colour: QColor) -> None:
513     """Draw a vector from the origin to the given point.
514
515     :param QPainter painter: The painter to draw the position vector with
516     :param point: The tip of the position vector in grid coords
517     :type point: Tuple[float, float]
518     :param QColor colour: The colour to draw the position vector in
519     """
520     painter.setPen(QPen(colour, self._WIDTH_VECTOR_LINE))
521     painter.drawLine(*self._canvas_origin, *self.canvas_coords(*point))
522     self._draw_arrowhead_away_from_origin(painter, point)

```

```

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_parallelgram(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
611     painter.fillPath(path, brush)
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         )
```

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

```

```

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', ''),
128                 ('', 'A', '2'),
129                 [(-15, 'B', 'T'), ('', 'T', '')]
130             ]
131         ),
132 
133     # Additions with multiplication
134     ('2.14A^{3} 4.5rot(14.5)^-1 + 8B^T - 3C^-1', [[('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1')], [
135         ('8', 'B', 'T'), [(-3, 'C', '-1')]]),
136     ('2.14A^{3} 4.5rot(14.5)^-1 + 8.5B^T 5.97C^{14} - 3.14D^{-1} 6.7E^{T}', [
137         [((2.14, 'A', '3'), ('4.5', 'rot(14.5)', '-1')), [('8.5', 'B', 'T'), ('5.97', 'C', '14')], [
138             ('-3.14', 'D', '-1'), ('6.7', 'E', 'T')]]),
139 
140     # Parenthesized expressions
141     ('(AB)^{-1}', [[(' ', 'AB', '-1')]]),
142     ('-3(A+B)^{2-C(B^TA)^{-1}}', [[(-3, 'A+B', '2')], [(-1, 'C', '')], ('', 'B^{T}A', '-1')]]),
143     ('2.3(3B^TA)^2', [[('2.3', '3B^{T}A', '2')]]),
144     ('-3.4(9D^{2}3F^{-1})T+C', [[(-3.4, '9D^{2}3F^{-1}', 'T')], [('', 'C', '')]]),
145     ('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}', [
146         '-1')]]]),
147 
148     # Anonymous matrices
149     ('[1 2; 3 4]', [[(' ', '[1 2;3 4]', '')]]),
150     ('A[-3 4; 16.2 87.93]', [[(' ', 'A', ''), ('', '[-3 4;16.2 87.93]', '')]]),
151     (
152         '3A^2(M-[ 1 2      ;      5 4 ]^T)^{-1}18([13.2      -6.4;      -11      0.2]+F)^{2+Z}', [
153             [
154                 ('3', 'A', '2'), ('', 'M+-1[1 2;5 4]^T', '-1'), ('18', '[13.2 -6.4;-11 0.2]+F', '2'),
155                 ('', 'Z', '')
156             ]
157         ),
158         ('[1 2; -3 -1]^{-1}', [[(' ', '[1 2;-3 -1]', '-1')]]),
159         ('[1 2; -3 -1][-5 6; 8.3 2]', [[(' ', '[1 2;-3 -1]', ''), ('', '[-5 6;8.3 2]', '')]]),
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         def test_parse_error() -> None:
187             """Test that parse_matrix_expression() raises a MatrixParseError."""
188             for expression in invalid_inputs:
189                 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\_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.5 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.6 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.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 conftest 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 to 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 == get_test_wrapper()
124
125
126 def test_matrix_powers(test_wrapper: MatrixWrapper) -> None:
127     """Test that matrices can be raised to integer powers."""
128     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
129         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
130         test_wrapper['G'] is not None
131
132     assert (test_wrapper.evaluate_expression('A^2') == la.matrix_power(test_wrapper['A'], 2)).all()
133     assert (test_wrapper.evaluate_expression('B^4') == la.matrix_power(test_wrapper['B'], 4)).all()
134     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()
```

```

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 - 4.9E^{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['E'], 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, 6], [8.3, 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 = 'ABCDEFGHIJKLMNPQRSTUVWXYZ'
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

```

```
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 + 30') ==
86             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
87             3 * test_wrapper.evaluate_expression('4B')) .all()
88
89     assert (test_wrapper.evaluate_expression('P^-1 - 3NO^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)) .all()
93
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()

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```
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('NOPOR') == {'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-40'
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'
```