

# 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[7], 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'[8] and allows the user to drag an input vector

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

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

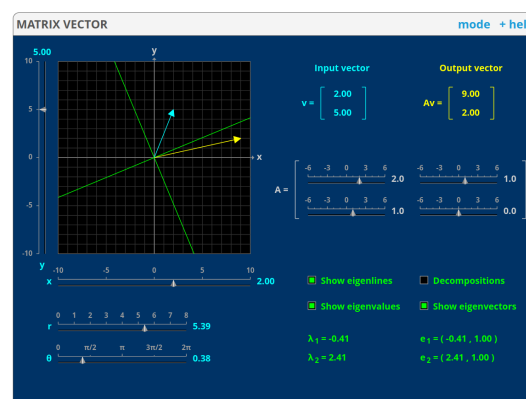


Figure 1.1: The MIT 'Matrix Vector' Mathlet

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

### 1.3.2 Linear Transformation Visualizer

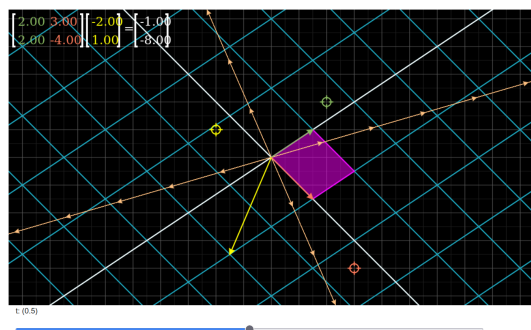


Figure 1.2: 'Linear Transformation Visualizer' halfway through an animation

Another web app that I found was one simply called 'Linear Transformation Visualizer' by Shad Sharma[22]. This one was similarly inspired by 3blue1brown's YouTube series. This app has the ability to render input and output vectors and eigenlines, but it can also render the determinant parallelogram; it allows the user to drag the basis vectors; and it has the option to snap vectors to the background grid, which is quite useful. It also implements a simple form of animation where the tips of the vectors move in straight lines from where they start to where they end, and the animation is controlled by dragging a slider labelled  $t$ . This isn't particularly intuitive.

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

### 1.3.3 Desmos app

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



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

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

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

### 1.3.4 Visualizing Linear Transformations



Figure 1.4: The GeoGebra applet rendering its default matrix

The last solution that I want to talk about is a GeoGebra applet simply titled 'Visualizing Linear Transformations'[10]. 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.

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<sup>1</sup>Python 3.8 or higher won't compile on any earlier versions of macOS[16]

<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[17]

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  $\mathbf{C}$  to  $\mathbf{TC}$ , and perhaps do sequential animation)
6. It must be able to display information about the currently rendered transformation (determinant, eigenlines, etc.)
7. It must be able to save and load sessions (defined matrices, display settings, etc.)
8. It must allow the user to define and transform arbitrary polygons

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

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

---

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

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

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

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

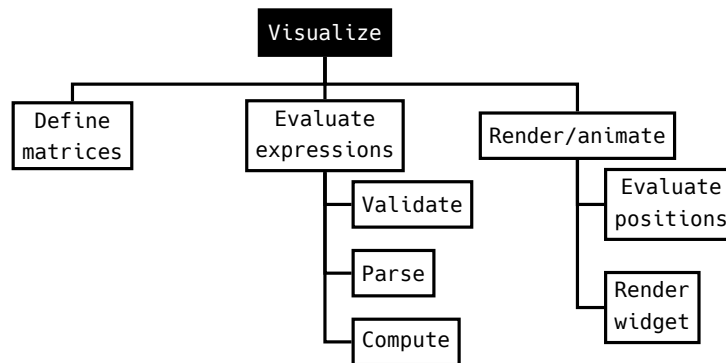
Transforming polygons is the lowest priority item on this list and will likely be implemented last, but it would definitely benefit learning. I wouldn't consider it necessary for success, but it would be very good to include, and it's certainly a feature that I want to have.

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

## 2 Design

### 2.1 Problem decomposition

I have decomposed the problem of visualization as follows:



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

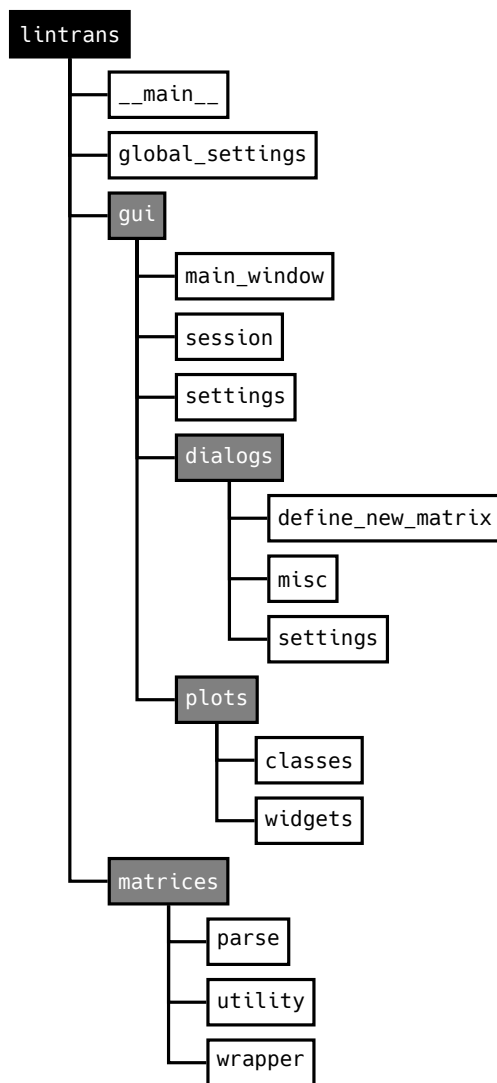
Evaluating expressions is another key part of the app and can be further broken down into validating, parsing, and computing the value. Validating an expression simply consists of checking that it adheres to a set of syntax rules for matrix expressions, and that it only contains matrices which have already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

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

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

### 2.2 Structure of the solution

I have decomposed my solution like so:



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

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

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

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

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

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

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

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

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

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

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

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

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

## 2.3 Algorithm design

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

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

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

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

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

```

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

```

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

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

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

```

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

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

```

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

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

## 2.4 Usability features

My main concern in terms of usability is colour. In the 3blue1brown videos on linear algebra, red and green are used for the basis vectors, but these colours are often hard to distinguish in most common forms of colour blindness. The most common form is deuteranopia[25], which makes red and green look incredibly similar. I will use blue and red for my basis vectors. These colours are easy to distinguish for people with deuteranopia and protanopia - the two most common forms of colour blindness. Tritanopia makes it harder to distinguish blue and yellow, but my colour scheme is still be accessible for people with tritanopia, as red and blue are very distinct in this form of colour blindness.

I will probably use green for the eigenvectors and eigenlines, which will be hard to distinguish from the red basis vector for people with red-green colour blindness, but I think that the basis vectors and eigenvectors/eigenlines will look physically different enough from each other that the colour shouldn't be too much of a problem. Additionally, I will use a tool called Color Oracle[11] to make sure that my app is accessible to people with different forms of colour blindness<sup>6</sup>.

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

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

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

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



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

## 2.5 Variables and validation

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

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

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

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

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

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

---

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

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

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

## 2.6 Iterative test data

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

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

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

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

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

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

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

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

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

which should parse to give:

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

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

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

## 2.7 Post-development test data

This section will be completed later.

## 2.8 Issues with testing

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

### 3 Development

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

#### 3.1 Matrices backend

##### 3.1.1 MatrixWrapper class

The first real part of development was creating the `MatrixWrapper` class. It needs a simple instance dictionary to be created in the constructor, and it needs a way of accessing the matrices. I decided to use Python's `__getitem__()` and `__setitem__()` special methods[15] to allow indexing into a `MatrixWrapper` object like `wrapper['M']`. This simplifies using the class.

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

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

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

```

44
45         self._matrices[name] = new_matrix

```

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

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

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

```

# 29ec1fedbf307e3b7ca731c4a381535fec899b0b
# tests/test_matrix_wrapper.py

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

```

```

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

```

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

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

### 3.1.2 Rudimentary parsing and evaluating

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

```

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

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

```

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

```

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

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

```

```

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

```

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

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

```

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

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

```

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

```

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

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

```

```

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

```

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

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



I then implemented several tests for this parsing.

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

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

```

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

```

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

expression and is equivalent to 'A+B'.

### 3.1.3 Simple matrix expression validation

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

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

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

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

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

```

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

12 class MatrixWrapper:
13 ...
99     def is_valid_expression(self, expression: str) -> bool:
100         """Check if the given expression is valid, using the context of the wrapper.
101
102         This method calls _parse.validate_matrix_expression(), but also ensures
103         that all the matrices in the expression are defined in the wrapper.
104
105         :param str expression: The expression to validate
106         :returns bool: Whether the expression is valid according the schema
107         """
108         # Get rid of the transposes to check all capital letters
109         expression = re.sub(r'\^T', 't', expression)
110         expression = re.sub(r'\^{T}', 't', expression)
111
112         # Make sure all the referenced matrices are defined
113         for matrix in {x for x in expression if re.match('[A-Z]', x)}:
114             if self[matrix] is None:
115                 return False
116
117         return _parse.validate_matrix_expression(expression)

```

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

```

# a0fb029f7da995803c24ee36e7e8078e5621f676
# tests/_parse/test_parse_and_validate_expression.py

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

```

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

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

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

### 3.1.4 Parsing matrix expressions

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

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

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

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

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

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

```

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

```

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

Compare the old version:

```

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

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

```

to the new version:

```

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

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

```

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

```

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

```

```

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

```

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

This method passes all the unit tests, as expected.

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

```

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

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

```

```

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

```

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

## 3.2 Initial GUI

### 3.2.1 First basic GUI

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

```

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

1  """The module to provide the main window as a QMainWindow object."""
2
3  import sys
4
5  from PyQt5 import QtCore, QtGui, QtWidgets
6  from PyQt5.QtWidgets import QApplication, QHBoxLayout, QMainWindow, QVBoxLayout
7
8  from lintrans.matrices import MatrixWrapper
9
10
11 class LintransMainWindow(QMainWindow):
12     """The class for the main window in the lintrans GUI."""
13
14     def __init__(self):
15         """Create the main window object, creating every widget in it."""
16         super().__init__()
17
18         self.matrix_wrapper = MatrixWrapper()
19
20         self.setWindowTitle('Linear Transformations')
21         self.setMinimumWidth(750)
22
23         # === Create widgets
24
25         # Left layout: the plot and input box
26
27         # NOTE: This QGraphicsView is only temporary
28         self.plot = QtWidgets.QGraphicsView(self)
29
30         self.text_input_expression = QtWidgets.QLineEdit(self)
31         self.text_input_expression.setPlaceholderText('Input matrix expression...')
32         self.text_input_expression.textChanged.connect(self.update_render_buttons)
33
34         # Right layout: all the buttons

```



```
35
36     # Misc buttons
37
38     self.button_create_polygon = QtWidgets.QPushButton(self)
39     self.button_create_polygon.setText('Create polygon')
40     # TODO: Implement create_polygon()
41     # self.button_create_polygon.clicked.connect(self.create_polygon)
42     self.button_create_polygon.setToolTip('Define a new polygon to view the transformation of')
43
44     self.button_change_display_settings = QtWidgets.QPushButton(self)
45     self.button_change_display_settings.setText('Change\ndisplay settings')
46     # TODO: Implement change_display_settings()
47     # self.button_change_display_settings.clicked.connect(self.change_display_settings)
48     self.button_change_display_settings.setToolTip('Change which things are rendered on the plot')
49
50     # Define new matrix buttons
51
52     self.label_define_new_matrix = QtWidgets.QLabel(self)
53     self.label_define_new_matrix.setText('Define a\nnew matrix')
54     self.label_define_new_matrix.setAlignment(QtCore.Qt.AlignCenter)
55
56     # TODO: Implement defining a new matrix visually, numerically, as a rotation, and as an expression
57
58     self.button_define_visually = QtWidgets.QPushButton(self)
59     self.button_define_visually.setText('Visually')
60     self.button_define_visually.setToolTip('Drag the basis vectors')
61
62     self.button_define_numerically = QtWidgets.QPushButton(self)
63     self.button_define_numerically.setText('Numerically')
64     self.button_define_numerically.setToolTip('Define a matrix just with numbers')
65
66     self.button_define_as_rotation = QtWidgets.QPushButton(self)
67     self.button_define_as_rotation.setText('As a rotation')
68     self.button_define_as_rotation.setToolTip('Define an angle to rotate by')
69
70     self.button_define_as_expression = QtWidgets.QPushButton(self)
71     self.button_define_as_expression.setText('As an expression')
72     self.button_define_as_expression.setToolTip('Define a matrix in terms of other matrices')
73
74     # Render buttons
75
76     self.button_render = QtWidgets.QPushButton(self)
77     self.button_render.setText('Render')
78     self.button_render.setEnabled(False)
79     self.button_render.clicked.connect(self.render_expression)
80     self.button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
81
82     self.button_render_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self)
83     self.button_render_shortcut.activated.connect(self.button_render.click)
84
85     self.button_animate = QtWidgets.QPushButton(self)
86     self.button_animate.setText('Animate')
87     self.button_animate.setEnabled(False)
88     self.button_animate.clicked.connect(self.animate_expression)
89     self.button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
90
91     self.button_animate_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Shift+Return'), self)
92     self.button_animate_shortcut.activated.connect(self.button_animate.click)
93
94     # === Arrange widgets
95
96     self.setContentsMargins(10, 10, 10, 10)
97
98     self.vlay_left = QVBoxLayout()
99     self.vlay_left.addWidget(self.plot)
100    self.vlay_left.addWidget(self.text_input_expression)
101
102    self.vlay_misc_buttons = QVBoxLayout()
103    self.vlay_misc_buttons.setSpacing(20)
104    self.vlay_misc_buttons.addWidget(self.button_create_polygon)
105    self.vlay_misc_buttons.addWidget(self.button_change_display_settings)
106
107    self.vlay_define_new_matrix = QVBoxLayout()
```

```

108     self.vlay_define_new_matrix.setSpacing(20)
109     self.vlay_define_new_matrix.addWidget(self.label_define_new_matrix)
110     self.vlay_define_new_matrix.addWidget(self.button_define_visually)
111     self.vlay_define_new_matrix.addWidget(self.button_define_numerically)
112     self.vlay_define_new_matrix.addWidget(self.button_define_as_rotation)
113     self.vlay_define_new_matrix.addWidget(self.button_define_as_expression)
114
115     self.vlay_render = QVBoxLayout()
116     self.vlay_render.setSpacing(20)
117     self.vlay_render.addWidget(self.button_animate)
118     self.vlay_render.addWidget(self.button_render)
119
120     self.vlay_right = QVBoxLayout()
121     self.vlay_right.setSpacing(50)
122     self.vlay_right.addLayout(self.vlay_misc_buttons)
123     self.vlay_right.addLayout(self.vlay_define_new_matrix)
124     self.vlay_right.addLayout(self.vlay_render)
125
126     self.hlay_all = QHBoxLayout()
127     self.hlay_all.setSpacing(15)
128     self.hlay_all.addLayout(self.vlay_left)
129     self.hlay_all.addLayout(self.vlay_right)
130
131     self.central_widget = QtWidgets.QWidget()
132     self.central_widget.setLayout(self.hlay_all)
133     self.setCentralWidget(self.central_widget)
134
135     def update_render_buttons(self) -> None:
136         """Enable or disable the render and animate buttons according to the validity of the matrix expression."""
137         valid = self.matrix_wrapper.is_valid_expression(self.text_input_expression.text())
138         self.button_render.setEnabled(valid)
139         self.button_animate.setEnabled(valid)
140
141     def render_expression(self) -> None:
142         """Render the expression in the input box, and then clear the box."""
143         # TODO: Render the expression
144         self.text_input_expression.setText('')
145
146     def animate_expression(self) -> None:
147         """Animate the expression in the input box, and then clear the box."""
148         # TODO: Animate the expression
149         self.text_input_expression.setText('')
150
151
152     def main() -> None:
153         """Run the GUI."""
154         app = QApplication(sys.argv)
155         window = LintransMainWindow()
156         window.show()
157         sys.exit(app.exec_())
158
159
160 if __name__ == '__main__':
161     main()

```

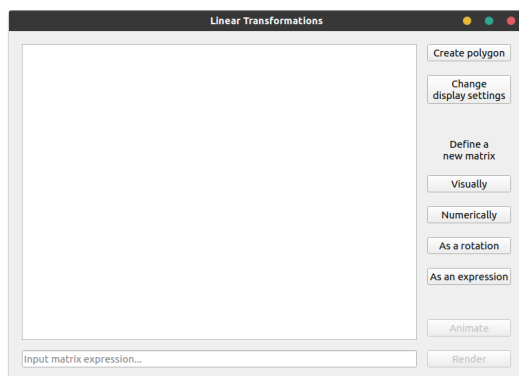


Figure 3.1: The first version of the GUI

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

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

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

### 3.2.2 Numerical definition dialog

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

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

1  """The module to provide dialogs for defining new matrices."""
2
3  from numpy import array
4  from PyQt5 import QtGui, QtWidgets
5  from PyQt5.QtWidgets import QDialog, QGridLayout, QHBoxLayout, QVBoxLayout
6
7  from lintrans.matrices import MatrixWrapper
8
9  ALPHABET_NO_I = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
10
11
12  def is_float(string: str) -> bool:
13      """Check if a string is a float."""
14      try:
15          float(string)
16          return True
17      except ValueError:
18          return False
19
20
21  class DefineNumericallyDialog(QDialog):
22      """The dialog class that allows the user to define a new matrix numerically."""
23
24      def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
25          """Create the dialog, but don't run it yet.
26
27          :param matrix_wrapper: The MatrixWrapper that this dialog will mutate
28          :type matrix_wrapper: MatrixWrapper
29          """
30          super().__init__(*args, **kwargs)
31
32          self.matrix_wrapper = matrix_wrapper
33          self.setWindowTitle('Define a matrix')
34
35          # === Create the widgets
36
37          self.button_confirm = QtWidgets.QPushButton(self)
38          self.button_confirm.setText('Confirm')
39          self.button_confirm.setEnabled(False)
40          self.button_confirm.clicked.connect(self.confirm_matrix)
41          self.button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
42
43          QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
44
45          self.button_cancel = QtWidgets.QPushButton(self)
46          self.button_cancel.setText('Cancel')
47          self.button_cancel.clicked.connect(self.close)
48          self.button_cancel.setToolTip('Cancel this definition<br><b>(Ctrl + Q)</b>')
49
50          QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Q'), self).activated.connect(self.button_cancel.click)
51
52          self.element_tl = QtWidgets.QLineEdit(self)
53          self.element_tl.textChanged.connect(self.update_confirm_button)
54
55          self.element_tr = QtWidgets.QLineEdit(self)
56          self.element_tr.textChanged.connect(self.update_confirm_button)
57
58          self.element_bl = QtWidgets.QLineEdit(self)
59          self.element_bl.textChanged.connect(self.update_confirm_button)
60
61          self.element_br = QtWidgets.QLineEdit(self)
62          self.element_br.textChanged.connect(self.update_confirm_button)
63
64          self.matrix_elements = (self.element_tl, self.element_tr, self.element_bl, self.element_br)
```

```
65
66     self.letter_combo_box = QtWidgets.QComboBox(self)
67
68     # Everything except I, because that's the identity
69     for letter in ALPHABET_NO_I:
70         self.letter_combo_box.addItem(letter)
71
72     self.letter_combo_box.activated.connect(self.load_matrix)
73
74     # === Arrange the widgets
75
76     self.setContentsMargins(10, 10, 10, 10)
77
78     self.grid_matrix = QGridLayout()
79     self.grid_matrix.setSpacing(20)
80     self.grid_matrix.addWidget(self.element_tl, 0, 0)
81     self.grid_matrix.addWidget(self.element_tr, 0, 1)
82     self.grid_matrix.addWidget(self.element_bl, 1, 0)
83     self.grid_matrix.addWidget(self.element_br, 1, 1)
84
85     self.hlay_buttons = QHBoxLayout()
86     self.hlay_buttons.setSpacing(20)
87     self.hlay_buttons.addWidget(self.button_cancel)
88     self.hlay_buttons.addWidget(self.button_confirm)
89
90     self.vlay_right = QVBoxLayout()
91     self.vlay_right.setSpacing(20)
92     self.vlay_right.addLayout(self.grid_matrix)
93     self.vlay_right.addLayout(self.hlay_buttons)
94
95     self.hlay_all = QHBoxLayout()
96     self.hlay_all.setSpacing(20)
97     self.hlay_all.addWidget(self.letter_combo_box)
98     self.hlay_all.addLayout(self.vlay_right)
99
100    self.setLayout(self.hlay_all)
101
102    # Finally, we load the default matrix A into the boxes
103    self.load_matrix(0)
104
105    def update_confirm_button(self) -> None:
106        """Enable the confirm button if there are numbers in every box."""
107        for elem in self.matrix_elements:
108            if elem.text() == '' or not is_float(elem.text()):
109                # If they're not all numbers, then we can't confirm it
110                self.button_confirm.setEnabled(False)
111                return
112
113        # If we didn't find anything invalid
114        self.button_confirm.setEnabled(True)
115
116    def load_matrix(self, index: int) -> None:
117        """If the selected matrix is defined, load it into the boxes."""
118        matrix = self.matrix_wrapper[ALPHABET_NO_I[index]]
119
120        if matrix is None:
121            for elem in self.matrix_elements:
122                elem.setText('')
123
124        else:
125            self.element_tl.setText(str(matrix[0][0]))
126            self.element_tr.setText(str(matrix[0][1]))
127            self.element_bl.setText(str(matrix[1][0]))
128            self.element_br.setText(str(matrix[1][1]))
129
130        self.update_confirm_button()
131
132    def confirm_matrix(self) -> None:
133        """Confirm the inputted matrix and assign it to the name."""
134        letter = self.letter_combo_box.currentText()
135        matrix = array([
136            [float(self.element_tl.text()), float(self.element_tr.text())],
137            [float(self.element_bl.text()), float(self.element_br.text())]
```

```

138         ]
139
140         self.matrix_wrapper[letter] = matrix
141         self.close()

```

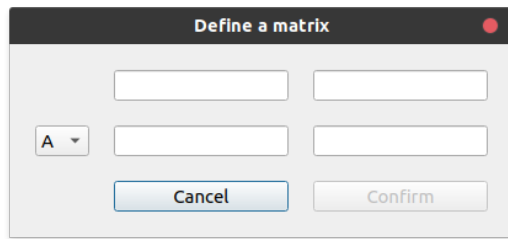


Figure 3.2: The first version of the numerical definition dialog

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

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

The `confirm_matrix()` method just updates the instance's matrix wrapper with the new matrix. We pass a reference to the `LintransMainWindow` instance's matrix wrapper when we open the dialog, so we're just updating the referenced object directly.

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

```

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

12 class LintransMainWindow(QMainWindow):
...
15     def __init__(self):
...
66         self.button_define_numerically.clicked.connect(
67             lambda: DefineNumericallyDialog(self.matrix_wrapper, self).exec()
68         )

```

### 3.2.3 More definition dialogs

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

```

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

22 class DefinedDialog(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_N0_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):
25     ...
26
27     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
28         ...
29
30         # === Arrange the widgets
31
32         self.setContentsMargins(10, 10, 10, 10)
33
34         self.horizontal_spacer = QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum)
35
36         self.hlay_buttons = QHBoxLayout()
37         self.hlay_buttons.setSpacing(20)
38         self.hlay_buttons.addItem(self.horizontal_spacer)
39         self.hlay_buttons.addWidget(self.button_cancel)
40         self.hlay_buttons.addWidget(self.button_confirm)
41
42         @property
43         def selected_letter(self) -> str:
44             """The letter currently selected in the combo box."""
45             return self.letter_combo_box.currentText()
46
47         @abc.abstractmethod
48         def update_confirm_button(self) -> None:
49             """Enable the confirm button if it should be enabled."""
50             ...
51
52         @abc.abstractmethod
53         def confirm_matrix(self) -> None:
54             """Confirm the inputted matrix and assign it.
55
56             This should mutate self.matrix_wrapper and then call self.accept().
57             """
58             ...

```

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.

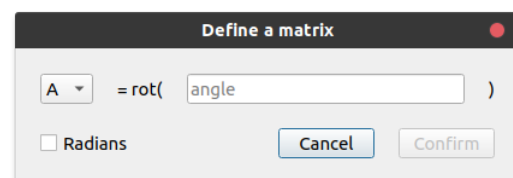


Figure 3.3: The first version of the rotation definition dialog

```

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

17 class LintransMainWindow(QMainWindow):
18     ...
19     def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
20         """Open a generic definition dialog to define a new matrix.
21
22         The class for the desired dialog is passed as an argument. We create an
23         instance of this class and the dialog is opened asynchronously and modally
24         (meaning it blocks interaction with the main window) with the proper method
25         connected to the ``dialog.finished`` slot.
26
27         .. note::
28             ``dialog_class`` must subclass :class:`lintrans.gui.dialogs.define_new_matrix.DefineDialog`.
29
30         :param dialog_class: The dialog class to instantiate
31         :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineDialog]
32         """
33         # We create a dialog with a deepcopy of the current matrix_wrapper
34         # This avoids the dialog mutating this one
35         dialog = dialog_class(deepcopy(self.matrix_wrapper), self)
36
37         # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
38         dialog.open()
39
40         # So we have to use the finished slot to call a method when the user accepts the dialog
41         # If the user rejects the dialog, this matrix_wrapper will be the same as the current one, because we copied
42         ↪ it
43         # So we don't care, we just assign the wrapper anyway
44         dialog.finished.connect(lambda: self._assign_matrix_wrapper(dialog.matrix_wrapper))
45
46     def _assign_matrix_wrapper(self, matrix_wrapper: MatrixWrapper) -> None:
47         """Assign a new value to self.matrix_wrapper.
48
49         This is a little utility function that only exists because a lambda
50         callback can't directly assign a value to a class attribute.
51
52         :param matrix_wrapper: The new value of the matrix wrapper to assign
53         :type matrix_wrapper: MatrixWrapper
54         """
55         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’[14], 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[13].

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

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

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

### 3.3.2 Creating the plots package

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

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

1  """This module provides the basic classes for plotting transformations."""
2
3  from __future__ import annotations
4
5  from PyQt5.QtCore import Qt
6  from PyQt5.QtGui import QColor, QPainter, QPaintEvent, QPen
7  from PyQt5.QtWidgets import QWidget
8
9
10 class TransformationPlotWidget(QWidget):
11     """An abstract superclass for plot widgets.
12
13     This class provides a background (untransformed) plane, and all the backend
14     details for a Qt application, but does not provide useful functionality. To
15     be useful, this class must be subclassed and behaviour must be implemented
16     by the subclass.
17
18     .. warning:: This class should never be directly instantiated, only subclassed.
19
20     .. note::
21         I would make this class have ``metaclass=abc.ABCMeta``, but I can't because it subclasses ``QWidget``,
22         and a every superclass of a class must have the same metaclass, and ``QWidget`` is not an abstract class.
23     """
24
25     def __init__(self, *args, **kwargs):
26         """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor (``QWidget``)."""
27         super().__init__(*args, **kwargs)
28
29         self.setAutoFillBackground(True)
30
31         # Set the background to white
32         palette = self.palette()
33         palette.setColor(self.backgroundRole(), Qt.white)
34         self.setPalette(palette)
35
36         # Set the grid colour to grey and the axes colour to black
37         self.grid_colour = QColor(128, 128, 128)
38         self.axes_colour = QColor(0, 0, 0)
39
40         self.grid_spacing: int = 50
41         self.line_width: float = 0.4
42
43     @property
44     def w(self) -> int:
45         """Return the width of the widget."""
46         return self.size().width()
47
48     @property
49     def h(self) -> int:
50         """Return the height of the widget."""
51         return self.size().height()
52
53     def paintEvent(self, e: QPaintEvent):
54         """Handle a ``QPaintEvent`` by drawing the widget."""
55         qp = QPainter()
56         qp.begin(self)
57         self.draw_widget(qp)
58         qp.end()
59
60     def draw_widget(self, qp: QPainter):
61         """Draw the grid and axes in the widget."""
62         qp.setRenderHint(QPainter.Antialiasing)
```

```

63         qp.setBrush(Qt.NoBrush)
64
65         # Draw the grid
66         qp.setPen(QPen(self.grid_colour, self.line_width))
67
68         # We draw the background grid, centered in the middle
69         # We deliberately exclude the axes - these are drawn separately
70         for x in range(self.w // 2 + self.grid_spacing, self.w, self.grid_spacing):
71             qp.drawLine(x, 0, x, self.h)
72             qp.drawLine(self.w - x, 0, self.w - x, self.h)
73
74         for y in range(self.h // 2 + self.grid_spacing, self.h, self.grid_spacing):
75             qp.drawLine(0, y, self.w, y)
76             qp.drawLine(0, self.h - y, self.w, self.h - y)
77
78         # Now draw the axes
79         qp.setPen(QPen(self.axes_colour, self.line_width))
80         qp.drawLine(self.w // 2, 0, self.w // 2, self.h)
81         qp.drawLine(0, self.h // 2, self.w, self.h // 2)
82
83
84 class ViewTransformationWidget(TransformationPlotWidget):
85     """This class is used to visualise matrices as transformations."""
86
87     def __init__(self, *args, **kwargs):
88         """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor."""
89         super().__init__(*args, **kwargs)

```

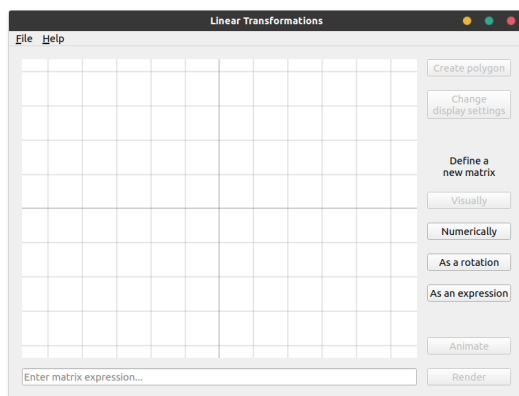


Figure 3.4: The GUI with background axes

The meat of this class is the `draw_widget()` method. Right now, this method only draws the background axes. My next step is to implement basis vector attributes and draw them in `draw_widget()`. After changing the `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):
13     ...
14
15     @property
16     def origin(self) -> tuple[int, int]:
17         """Return the canvas coords of the origin."""
18         return self.width() // 2, self.height() // 2
19
20     def trans_x(self, x: float) -> int:

```

```

51         """Transform an x coordinate from grid coords to canvas coords."""
52         return int(self.origin[0] + x * self.grid_spacing)
53
54     def trans_y(self, y: float) -> int:
55         """Transform a y coordinate from grid coords to canvas coords."""
56         return int(self.origin[1] - y * self.grid_spacing)
57
58     def trans_coords(self, x: float, y: float) -> tuple[int, int]:
59         """Transform a coordinate in grid coords to canvas coords."""
60         return self.trans_x(x), self.trans_y(y)

```

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

```

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

```

```

92 class ViewTransformationWidget(TransformationPlotWidget):
93     """This class is used to visualise matrices as transformations."""
94
95     def __init__(self, *args, **kwargs):
96         """Create the widget, passing ``*args`` and ``**kwargs`` to the superclass constructor."""
97         super().__init__(*args, **kwargs)
98
99         self.point_i: tuple[float, float] = (1., 0.)
100        self.point_j: tuple[float, float] = (0., 1.)
101
102        self.colour_i = QColor(37, 244, 15)
103        self.colour_j = QColor(8, 8, 216)
104
105        self.width_vector_line = 1
106        self.width_transformed_grid = 0.6
107
108        def transform_by_matrix(self, matrix: MatrixType) -> None:
109            """Transform the plane by the given matrix."""
110            self.point_i = (matrix[0][0], matrix[1][0])
111            self.point_j = (matrix[0][1], matrix[1][1])
112            self.update()

```

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

```

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

```

```

92 class ViewTransformationWidget(TransformationPlotWidget):
93     ...
122     def draw_transformed_grid(self, painter: QPainter) -> None:
123         """Draw the transformed version of the grid, given by the unit vectors."""
124         # Draw the unit vectors
125         painter.setPen(QPen(self.colour_i, self.width_vector_line))
126         painter.drawLine(*self.origin, *self.trans_coords(*self.point_i))
127         painter.setPen(QPen(self.colour_j, self.width_vector_line))
128         painter.drawLine(*self.origin, *self.trans_coords(*self.point_j))

```

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

```

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

```

```

19 class LintransMainWindow(QMainWindow):
20     ...
229     def render_expression(self) -> None:
230         """Render the expression in the input box, and then clear the box."""

```

```

231     self.plot.transform_by_matrix(
232         self.matrix_wrapper.evaluate_expression(
233             self.lineedit_expression_box.text()
234         )
235     )

```

Testing this new code shows that it works well.

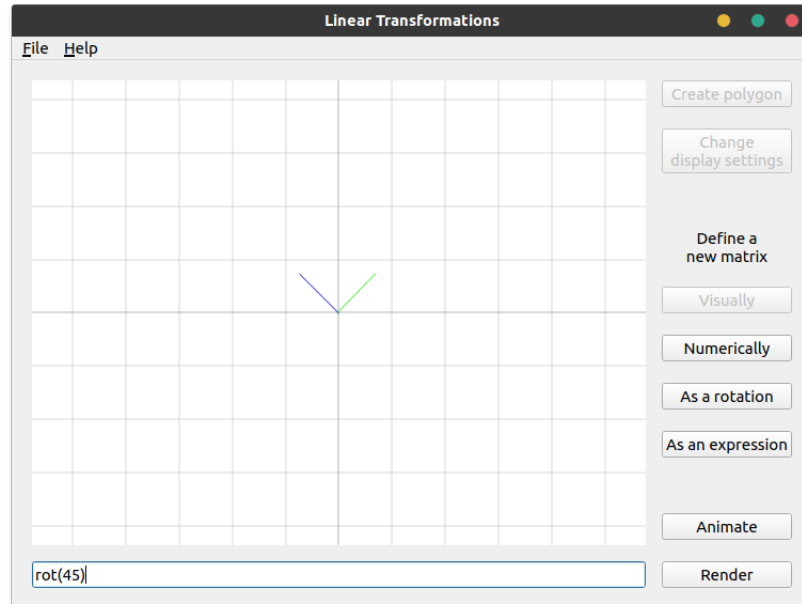


Figure 3.5: Basis vectors drawn for a  $45^\circ$  rotation

### 3.3.4 Drawing the transformed grid

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

```

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

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

```

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

```

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

96 class ViewTransformationWidget(TransformationPlotWidget):
...
126     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
        None:
127         """Draw a set of grid lines parallel to ``vector`` intersecting ``point``."""
128         max_x, max_y = self.grid_corner()
129         vector_x, vector_y = vector

```

```

130     point_x, point_y = point
131
132     if vector_x == 0:
133         painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
134
135         for i in range(int(max_x / point_x)):
136             painter.drawLine(
137                 self.trans_x((i + 1) * point_x),
138                 0,
139                 self.trans_x((i + 1) * point_x),
140                 self.height()
141             )
142             painter.drawLine(
143                 self.trans_x(-1 * (i + 1) * point_x),
144                 0,
145                 self.trans_x(-1 * (i + 1) * point_x),
146                 self.height()
147             )
148
149     elif vector_y == 0:
150         painter.drawLine(0, self.trans_y(0), self.width(), self.trans_y(0))
151
152         for i in range(int(max_y / point_y)):
153             painter.drawLine(
154                 0,
155                 self.trans_y((i + 1) * point_y),
156                 self.width(),
157                 self.trans_y((i + 1) * point_y)
158             )
159             painter.drawLine(
160                 0,
161                 self.trans_y(-1 * (i + 1) * point_y),
162                 self.width(),
163                 self.trans_y(-1 * (i + 1) * point_y)
164             )

```

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

```

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

```

```

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

```

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

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

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

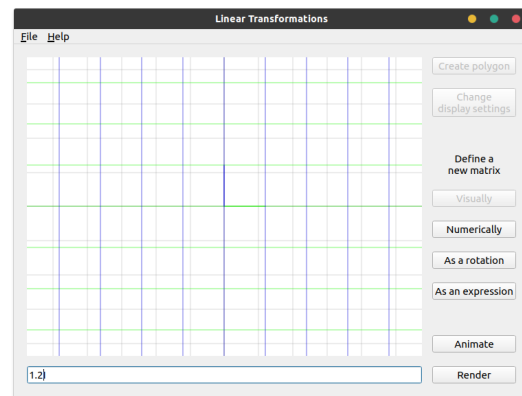


Figure 3.6: Parallel lines being drawn for matrix 1.2I

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

```
96 class ViewTransformationWidget(TransformationPlotWidget):
97     ...
126     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
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                 )
```

```

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
191         # Count up how many multiples of  $c$  we can have without wasting time rendering lines off screen
192         multiples_of_c: int = 0
193         ii: int = 1
194         while True:
195             y1 = m * max_x + ii * c
196             y2 = -1 * m * max_x + ii * c
197
198             if y1 < max_y or y2 < max_y:
199                 multiples_of_c += 1
200                 ii += 1
201
202             else:
203                 break
204
205         # Once we know how many lines we can draw, we just draw them all
206         for i in range(1, multiples_of_c + 1):
207             painter.drawLine(
208                 *self.trans_coords(
209                     -1 * max_x,
210                     m * -1 * max_x + i * c
211                 ),
212                 *self.trans_coords(
213                     max_x,
214                     m * max_x + i * c
215                 )
216             )
217             painter.drawLine(
218                 *self.trans_coords(
219                     -1 * max_x,
220                     m * -1 * max_x - i * c
221                 ),
222                 *self.trans_coords(
223                     max_x,
224                     m * max_x - i * c
225                 )
226             )

```

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.

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



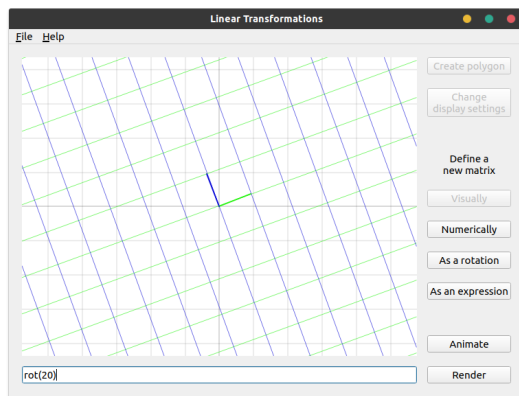


Figure 3.7: An example of a 20° rotation

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

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

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

### 3.3.5 Implementing animation

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

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

20 class LintransMainWindow(QMainWindow):
21     ...
238     def animate_expression(self) -> None:
239         """Animate the expression in the input box, and then clear the box."""
240         self.button_render.setEnabled(False)
241         self.button_animate.setEnabled(False)
242
243         matrix = self.matrix_wrapper.evaluate_expression(self.lineEdit_expression_box.text())
244         matrix_move = matrix - self.matrix_wrapper['I']
245         steps: int = 100
246
247         for i in range(0, steps + 1):
248             self.plot.visualize_matrix_transformation(
249                 self.matrix_wrapper['I'] + (i / steps) * matrix_move
250             )
251
252             self.update()
253             self.repaint()
254
255             time.sleep(0.01)
256
257         self.button_render.setEnabled(False)
258         self.button_animate.setEnabled(False)
```

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

### 3.3.6 Preserving determinants

Ignoring the obvious flaw with not being able to render transformations with a more than 90° rotation, the animations don't respect determinants. When rotating 90°, the determinant changes during the animation, even though we're going from a determinant 1 matrix (the identity) to another determinant

1 matrix. This is because we're just moving each vector to its new position in a straight line. I want to animate in a way that smoothly transitions the determinant.

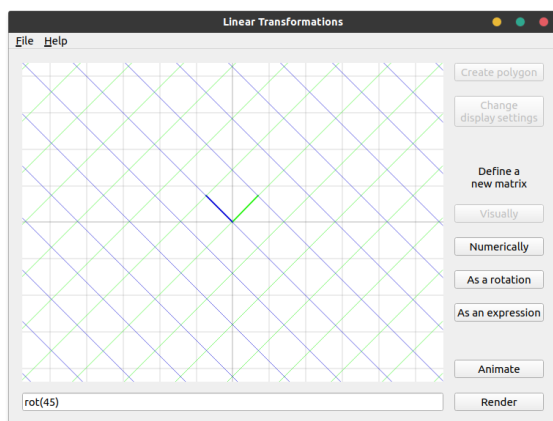


Figure 3.8: What we would expect halfway through a 90° rotation

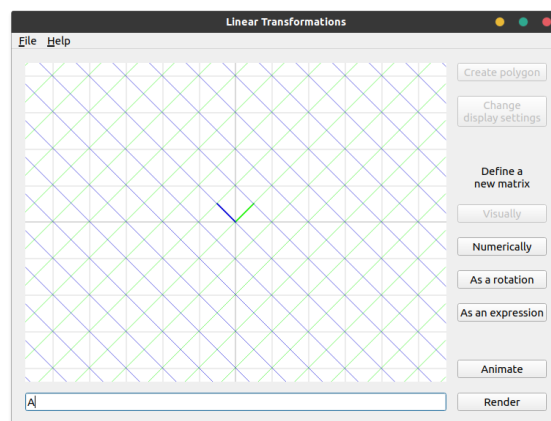


Figure 3.9: What we actually get halfway through a 90° rotation

In order to smoothly animate the determinant, I had to do some maths. I first defined the matrix  $\mathbf{A}$  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  $\mathbf{A}$  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  $\mathbf{A}$  by  $\frac{1}{\det(\mathbf{A})}$  but that didn't work, so I googled it. I found a post[12] on ResearchGate about the topic, and thanks to a very helpful comment from Jeffrey L Stuart, I learned that for a  $2 \times 2$  matrix  $\mathbf{A}$  and a scalar  $c$ ,  $\det(c\mathbf{A}) = c^2 \det(\mathbf{A})$ .

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

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

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

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

22 class LintransMainWindow(QMainWindow):
23     ...
240     def animate_expression(self) -> None:
241         ...
245         # Get the target matrix and it's determinant
246         matrix_target = self.matrix_wrapper.evaluate_expression(self.linedit_expression_box.text())
247         det_target = linalg.det(matrix_target)
248
249         identity = self.matrix_wrapper['I']
250         steps: int = 100
251
252         for i in range(0, steps + 1):
253             # This proportion is how far we are through the loop
254             proportion = i / steps
255
256             # matrix_a is the identity plus some part of the target, scaled by the proportion
```

```

257     # If we just used matrix_a, then things would animate, but the determinants would be weird
258     matrix_a = identity + proportion * (matrix_target - identity)
259
260     # So to fix the determinant problem, we get the determinant of matrix_a and use it to normalise
261     det_a = linalg.det(matrix_a)
262
263     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
264     # We want B = cA such that det(B) = 1, so then we can scale it with the animation
265     # So we get c^2 det(A) = 1 => c = sqrt(1 / abs(det(A)))
266     # Then we scale A down to get a determinant of 1, and call that matrix_b
267     if det_a == 0:
268         c = 0
269     else:
270         c = np.sqrt(1 / abs(det_a))
271
272     matrix_b = c * matrix_a
273
274     # matrix_c is the final matrix that we transform by
275     # It's B, but we scale it up over time to have the target determinant
276
277     # We want some C = dB such that det(C) is some target determinant T
278     # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
279     # But we defined B to have det 1, so we can ignore it there
280
281     # We're also subtracting 1 and multiplying by the proportion and then adding one
282     # This just scales the determinant along with the animation
283     scalar = 1 + proportion * (np.sqrt(abs(det_target)) - 1)
284
285     matrix_c = scalar * matrix_b
286
287     self.plot.visualize_matrix_transformation(matrix_c)
288
289     self.repaint()
290     time.sleep(0.01)

```

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

## 3.4 Improving the GUI

### 3.4.1 Fixing rendering

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

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

```

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

118 class VectorGridPlot(BackgroundPlot):
119     ...
120
121     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
122         ↪ None:
123         ...
124         else: # If the line is not horizontal or vertical, then we can use y = mx + c
125             m = vector_y / vector_x
126             c = point_y - m * point_x
127
128             # For c = 0
129             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):
119     ...
120
121     def draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
122         """Draw a pair of oblique lines, using the equation  $y = mx + c$ .
123
124         This method just calls :meth:`draw_oblique_line` with ``c`` and ``-c``,
125         and returns True if either call returned True.
126
127         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
128         :param float m: The gradient of the lines to draw
129         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
130         :returns bool: Whether we were able to draw any lines on the canvas
131         """
132         return any([
133             self.draw_oblique_line(painter, m, c),
134             self.draw_oblique_line(painter, m, -c)
135         ])
136
137     def draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
138         """Draw an oblique line, using the equation  $y = mx + c$ .
139
140         We only draw the part of the line that fits within the canvas, returning True if
141         we were able to draw a line within the boundaries, and False if we couldn't draw a line
142
143         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
144         :param float m: The gradient of the line to draw
145         :param float c: The y-intercept of the line to draw
146         :returns bool: Whether we were able to draw a line on the canvas
147         """
148         max_x, max_y = self.grid_corner()
149
150         # These variable names are shortened for convenience
151         # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
152         myi = (max_y - c) / m
153         mmyi = (-max_y - c) / m
154         mxi = max_x * m + c
155         mmxi = -max_x * m + c
156
157         # The inner list here is a list of coords, or None
158         # If an intersection fits within the bounds, then we keep its coord,
159         # else it is None, and then gets discarded from the points list
160         # By the end, points is a list of two coords, or an empty list
161         points: list[tuple[float, float]] = [
162             x for x in [
163                 (myi, max_y) if -max_x < myi < max_x else None,
164                 (mmyi, -max_y) if -max_x < mmyi < max_x else None,
165                 (max_x, mxi) if -max_y < mxi < max_y else None,
166                 (-max_x, mmxi) if -max_y < mmxi < max_y else None
167             ] if x is not None
168         ]
169
170     ]

```

```

272
273     # If no intersections fit on the canvas
274     if len(points) < 2:
275         return False
276
277     # If we can, then draw the line
278     else:
279         painter.drawLine(
280             *self.trans_coords(*points[0]),
281             *self.trans_coords(*points[1])
282         )
283         return True

```

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

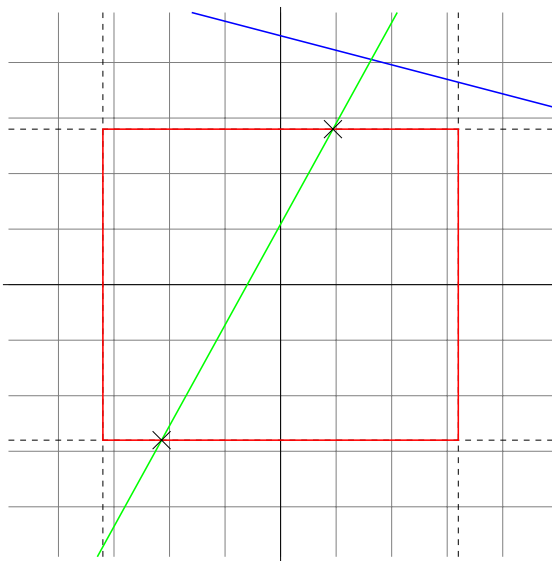


Figure 3.10: Two example lines and the viewport box

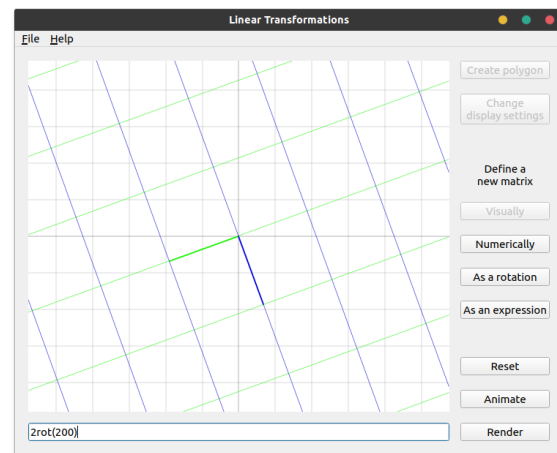


Figure 3.11: A demonstration of the new oblique lines system.

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  $my_i$ ,  $mmy_i$ ,  $mx_i$ , and  $mmx_i$  variables represent. The value of  $my_i$  is the  $x$  value where the line intersects the maximum  $y$  line, for example.

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

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

### 3.4.2 Adding vector arrowheads

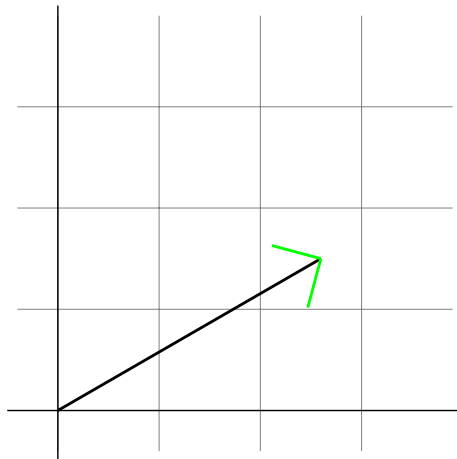


Figure 3.12: An example of a vector with the arrowheads highlighted in green

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° 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° lines in the top right quadrant, but none of my possible solutions worked for any arbitrary point.

So I started googling and found a very nice algorithm on [csharpshelper.com](http://csharpshelper.com)[23], which I adapted for Python.

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

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

As the comments suggest, we get the  $x$  and  $y$  components of the normalised vector, and then do some magic with a chosen length and get some distance values, and then draw those lines. I don't

really understand how this code works, but I'm happy that it does. All we have to do is call `draw_vector_arrowheads()` from `paintEvent()`.

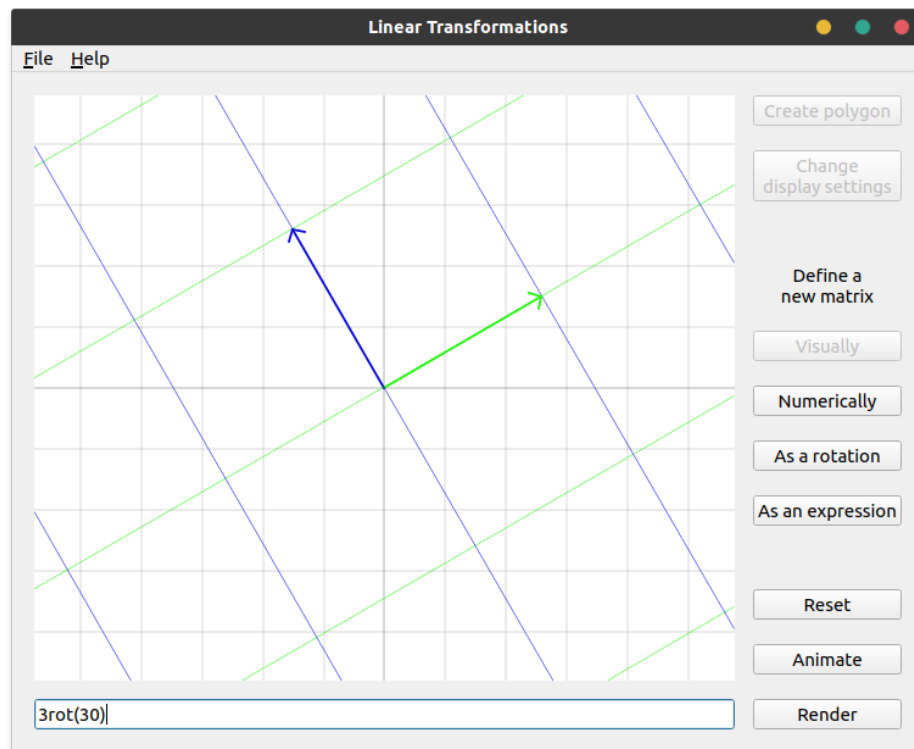


Figure 3.13: An example of the  $i$  and  $j$  vectors with arrowheads

### 3.4.3 Implementing zoom

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

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

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

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

To actually allow for zooming, I had to implement the `wheelEvent()` method in `BackgroundPlot` to listen for mouse wheel events. After reading through the docs for the `QWheelEvent` class[18], I learned how to handle this event.

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

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

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

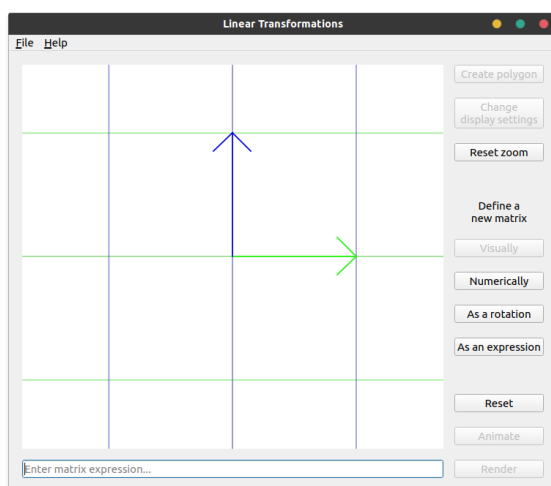


Figure 3.14: The GUI zoomed in a bit

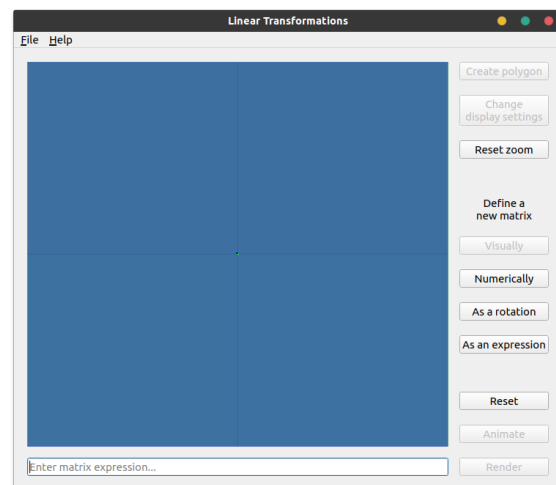


Figure 3.15: The GUI zoomed out as far as possible

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

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

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

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

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



```

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

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

```

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

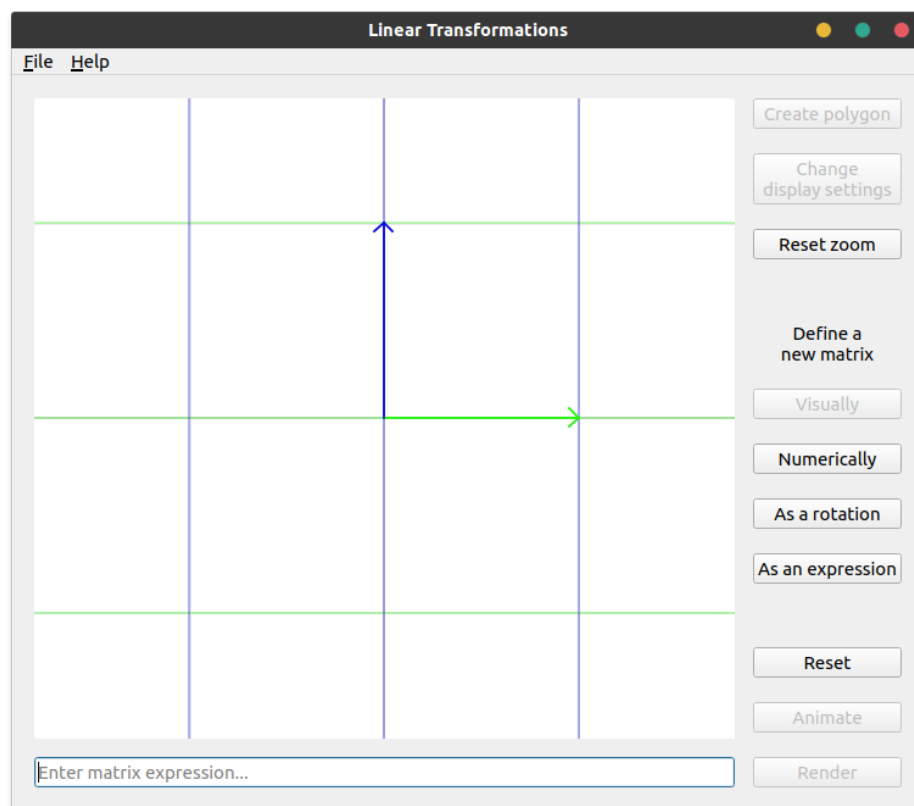


Figure 3.16: The arrowheads adjusted for zoom level

### 3.4.4 Animation blocks zooming

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

I did some googling and found a helpful post on StackOverflow[9] 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[24], 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[20, 21] 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.sleep()` allows for asynchronous processing and therefore non-blocking animation.

### 3.4.5 Rank 1 transformations

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

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

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

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

132 class VectorGridPlot(BackgroundPlot):
133     ...
164     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
165         ↪ None:
166         ...
177         # If the determinant is 0
178         if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
179             rank = np.linalg.matrix_rank(
180                 np.array([
181                     [vector_x, point_x],
182                     [vector_y, point_y]
183                 ])
184             )
185
186         # If the matrix is rank 1, then we can draw the column space line
187         if rank == 1:
188             self.draw_oblique_line(painter, vector_y / vector_x, 0)
189
190         # If the rank is 0, then we don't draw any lines
191         else:
192             return
```

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

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

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

```

...
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()`.

```

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

```

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

```

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

```

### 3.4.7 Creating the DefineVisuallyDialog

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

```

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

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

```

```

177         """
178
179     def show_matrix(self, index: int) -> None:
180         """Show the selected matrix on the plot. If the matrix is None, show the identity."""
181         matrix = self.matrix_wrapper[ALPHABET_NO_I[index]]
182
183         if matrix is None:
184             matrix = self.matrix_wrapper['I']
185
186         self.plot.visualize_matrix_transformation(matrix)
187         self.plot.update()
188
189     def confirm_matrix(self) -> None:

```

This DefineVisuallyDialog class just implements the normal methods needed for a DefineDialog and has a plot attribute to handle drawing graphics and handling mouse movement. After creating the DefineVisuallyWidget as a skeleton and doing some more research in the Qt5 docs[19], 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         # We get the maximum grid coords and convert them into canvas coords
94         return (x - self.canvas_origin[0]) / self.grid_spacing, (-y + self.canvas_origin[1]) / self.grid_spacing

```

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

```

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

```

```

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

```

```

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

```

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

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

### 3.4.8 Fixing a division by zero bug

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

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

```

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

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

```

### 3.4.9 Implementing transitional animation

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

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

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

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

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

In code, that looks like this:

```

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

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

```

```

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

```



```

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

```

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

### 3.4.10 Allowing for sequential animation with commas

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

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

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

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

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

```

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

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

```

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

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

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

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

```

## 3.5 Adding display settings

### 3.5.1 Creating the dataclass

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

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

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

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

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

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

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

26  class LintransMainWindow(QMainWindow):
27      ...
28      def animate_expression(self) -> None:
29          """Animate from the current matrix to the matrix in the expression box."""
30          self.button_render.setEnabled(False)
31          self.button_animate.setEnabled(False)
32
33          matrix_start: MatrixType = np.array([
34              [self.plot.point_i[0], self.plot.point_j[0]],
35              [self.plot.point_i[1], self.plot.point_j[1]]
36          ])
37
38          text = self.lineedit_expression_box.text()
39
40          # If there's commas in the expression, then we want to animate each part at a time
41          if ',' in text:
42              current_matrix = matrix_start
43
44              # For each expression in the list, right multiply it by the current matrix,
45              # and animate from the current matrix to that new matrix
46              for expr in text.split(',')[:-1]:
47                  new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
48
49                  self.animate_between_matrices(current_matrix, new_matrix)
50                  current_matrix = new_matrix
51
52          # 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()

```

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

```

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

26 class LintransMainWindow(QMainWindow):
...
333     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
↪     None:
334         """Animate from the start matrix to the target matrix."""
335         det_target = linalg.det(matrix_target)
336         det_start = linalg.det(matrix_start)
337
338         for i in range(0, steps + 1):
339             # This proportion is how far we are through the loop
340             proportion = i / steps
341
342             # matrix_a is the start matrix plus some part of the target, scaled by the proportion
343             # If we just used matrix_a, then things would animate, but the determinants would be weird
344             matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
345
346             if self.display_settings.animate_determinant and det_target != 0:
347                 # To fix the determinant problem, we get the determinant of matrix_a and use it to normalise
348                 det_a = linalg.det(matrix_a)
349
350                 # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
351                 # We want B = cA such that det(B) = det(S), where S is the start matrix,
352                 # so then we can scale it with the animation, so we get
353                 # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
354                 # Then we scale A to get the determinant we want, and call that matrix_b
355                 if det_a == 0:
356                     c = 0
357                 else:
358                     c = np.sqrt(abs(det_start / det_a))
359
360                 matrix_b = c * matrix_a
361                 det_b = linalg.det(matrix_b)
362
363                 # matrix_to_render is the final matrix that we then render for this frame
364                 # It's B, but we scale it over time to have the target determinant
365
366                 # We want some C = dB such that det(C) is some target determinant T
367                 # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
368
369                 # We're also subtracting 1 and multiplying by the proportion and then adding one
370                 # This just scales the determinant along with the animation
371                 scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
372                 matrix_to_render = scalar * matrix_b

```

```

373
374         else:
375             matrix_to_render = matrix_a
376
377         if self.is_matrix_too_big(matrix_to_render):
378             self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
379             return
380
381         self.plot.visualize_matrix_transformation(matrix_to_render)
382
383         # We schedule the plot to be updated, tell the event loop to
384         # process events, and asynchronously sleep for 10ms
385         # This allows for other events to be processed while animating, like zooming in and out
386         self.plot.update()
387         QApplication.processEvents()
388         QThread.sleep(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
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

```

<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.

```
31     self.button_cancel = QtWidgets.QPushButton(self)
32     self.button_cancel.setText('Cancel')
33     self.button_cancel.clicked.connect(self.reject)
34     self.button_cancel.setToolTip('Revert these settings<br><b>(Escape)</b>')
35
36     # === Arrange the widgets
37
38     self.setContentsMargins(10, 10, 10, 10)
39
40     self.hlay_buttons = QHBoxLayout()
41     self.hlay_buttons.setSpacing(20)
42     self.hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
43     self.hlay_buttons.addWidget(self.button_cancel)
44     self.hlay_buttons.addWidget(self.button_confirm)
45
46     self.vlay_options = QVBoxLayout()
47     self.vlay_options.setSpacing(20)
48
49     self.vlay_all = QVBoxLayout()
50     self.vlay_all.setSpacing(20)
51     self.vlay_all.addLayout(self.vlay_options)
52     self.vlay_all.addLayout(self.hlay_buttons)
53
54     self.setLayout(self.vlay_all)
55
56     @abc.abstractmethod
57     def load_settings(self) -> None:
58         """Load the current settings into the widgets."""
59
60     @abc.abstractmethod
61     def confirm_settings(self) -> None:
62         """Confirm the settings chosen in the dialog."""
63
64
65     class DisplaySettingsDialog(SettingsDialog):
66         """The dialog to allow the user to edit the display settings."""
67
68         def __init__(self, display_settings: DisplaySettings, *args, **kwargs):
69             """Create the widgets and layout of the dialog.
70
71             :param DisplaySettings display_settings: The :class:`lintrans.gui.settings.DisplaySettings` object to mutate
72             """
73             super().__init__(*args, **kwargs)
74
75             self.display_settings = display_settings
76             self.setWindowTitle('Change display settings')
77
78             # === Create the widgets
79
80             font_label = self.font()
81             font_label.setUnderline(True)
82             font_label.setPointSize(int(font_label.pointSize() * 1.2))
83
84             self.label_animations = QtWidgets.QLabel(self)
85             self.label_animations.setText('Animations')
86             self.label_animations.setAlignment(Qt.AlignCenter)
87             self.label_animations.setFont(font_label)
88
89             self.checkbox_animate_determinant = QCheckBox(self)
90             self.checkbox_animate_determinant.setText('Animate determinant')
91             self.checkbox_animate_determinant.setToolTip('Smoothly animate the determinant during animation')
92
93             self.checkbox_applicative_animation = QCheckBox(self)
94             self.checkbox_applicative_animation.setText('Applicative animation')
95             self.checkbox_applicative_animation.setToolTip(
96                 'Animate the new transformation applied to the current one,\n'
97                 'rather than just that transformation on its own'
98             )
99
100             self.label_animation_pause_length = QtWidgets.QLabel(self)
101             self.label_animation_pause_length.setText('Animation pause length (ms)')
102             self.label_animation_pause_length.setToolTip(
103                 'How many milliseconds to pause for in comma-separated animations'
```

```

104         )
105
106         self.lineEdit_animation_pause_length = QtWidgets.QLineEdit(self)
107         self.lineEdit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
108
109         # === Arrange the widgets
110
111         self.hlay_animation_pause_length = QHBoxLayout()
112         self.hlay_animation_pause_length.addWidget(self.label_animation_pause_length)
113         self.hlay_animation_pause_length.addWidget(self.lineEdit_animation_pause_length)
114
115         self.vlay_options.addWidget(self.label_animations)
116         self.vlay_options.addWidget(self.checkbox_animate_determinant)
117         self.vlay_options.addWidget(self.checkbox_applicative_animation)
118         self.vlay_options.addLayout(self.hlay_animation_pause_length)
119
120         # Finally, we load the current settings
121         self.load_settings()
122
123     def load_settings(self) -> None:
124         """Load the current display settings into the widgets."""
125         self.checkbox_animate_determinant.setChecked(self.display_settings.animate_determinant)
126         self.checkbox_applicative_animation.setChecked(self.display_settings.applicative_animation)
127         self.lineEdit_animation_pause_length.setText(str(self.display_settings.animation_pause_length))
128
129     def confirm_settings(self) -> None:
130         """Build a :class:`lintrans.gui.settings.DisplaySettings` object and assign it."""
131         self.display_settings.animate_determinant = self.checkbox_animate_determinant.isChecked()
132         self.display_settings.applicative_animation = self.checkbox_applicative_animation.isChecked()
133         self.display_settings.animation_pause_length = int(self.lineEdit_animation_pause_length.text())
134
135         self.accept()

```

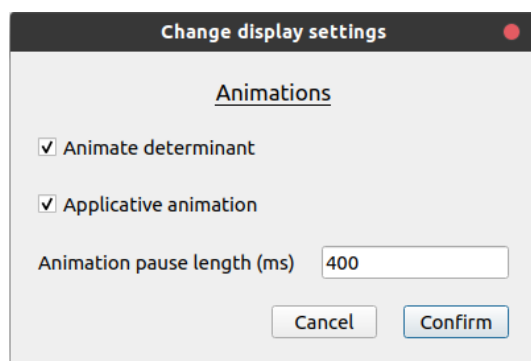
I then just had to enable the button in the main GUI and implement the method to open the new dialog. I have to use a lambda to capture the local dialog variable, but a separate method to actually assign its display settings, since Python doesn't allow assignments in lambda expressions.

```

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

27 class LintransMainWindow(QMainWindow):
...
436     def dialog_change_display_settings(self) -> None:
437         """Open the dialog to change the display settings."""
438         dialog = DisplaySettingsDialog(self.display_settings, self)
439         dialog.open()
440         dialog.finished.connect(lambda: self._assign_display_settings(dialog.display_settings))
441
442     def _assign_display_settings(self, display_settings: DisplaySettings) -> None:
443         """Assign a new value to `self.display_settings`."""
444         self.display_settings = display_settings

```



The dialog.finished signal on line 429 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.

Figure 3.17: The display settings dialog

### 3.5.3 Fixing a bug with transitional animation

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

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

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

27 class LintransMainWindow(QMainWindow):
...
285     def animate_expression(self) -> None:
...
315     else:
...
328         # If we want a transitional animation and we're animating the same matrix, then restart the animation
329         # We use this check rather than equality because of small floating point errors
330         elif (matrix_start - matrix_target < 1e-12).all():
331             matrix_start = self.matrix_wrapper['I']
332
333         # We pause here for 200 ms to make the animation look a bit nicer
334         self.plot.visualize_matrix_transformation(matrix_start)
335         self.plot.update()
336         QApplication.processEvents()
337         QThread.sleep(200)
338
```

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

27 class LintransMainWindow(QMainWindow):
...
288     def animate_expression(self) -> None:
...
318     else:
...
333         elif (abs(matrix_start - matrix_target) < 1e-12).all():

```

### 3.5.4 Adding the determinant parallelogram

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

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

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

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

```



```

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

140 class VectorGridPlot(BackgroundPlot):
141     ...
385     def draw_determinant_parallelagram(self, painter: QPainter) -> None:
386         """Draw the parallelogram of the determinant of the matrix."""
387         path = QPainterPath()
388         path.moveTo(*self.canvas_origin)
389         path.lineTo(*self.canvas_coords(*self.point_i))
390         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
391         path.lineTo(*self.canvas_coords(*self.point_j))
392
393         brush = QBrush(QColor(16, 235, 253, alpha=128), Qt.SolidPattern)
394         painter.fillPath(path, brush)

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

13 class VisualizeTransformationWidget(VectorGridPlot):
14     ...
42     def paintEvent(self, event: QPaintEvent) -> None:
43         """Handle a ``QPaintEvent`` by drawing the background grid and the transformed grid.
44
45         The transformed grid is defined by the basis vectors i and j, which can
46         be controlled with the :meth:`visualize_matrix_transformation` method.
47         """
48         painter = QPainter()
49         painter.begin(self)
50
51         painter.setRenderHint(QPainter.Antialiasing)
52         painter.setBrush(Qt.NoBrush)
53
54         self.draw_background(painter)
55         self.draw_transformed_grid(painter)
56         self.draw_vector_arrowheads(painter)
57
58         if self.display_settings.draw_determinant_parallelagram:
59             self.draw_determinant_parallelagram(painter)
60
61         painter.end()
62         event.accept()

```

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

```

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

140 class VectorGridPlot(BackgroundPlot):
141     ...
385     def draw_determinant_parallelagram(self, painter: QPainter) -> None:
386         """Draw the parallelogram of the determinant of the matrix."""
387         det = np.linalg.det(np.array([
388             [self.point_i[0], self.point_j[0]],
389             [self.point_i[1], self.point_j[1]]
390         ]))
391
392         if det == 0:
393             return
394
395         path = QPainterPath()
396         path.moveTo(*self.canvas_origin)
397         path.lineTo(*self.canvas_coords(*self.point_i))
398         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
399         path.lineTo(*self.canvas_coords(*self.point_j))
400
401         color = (16, 235, 253) if det > 0 else (253, 34, 16)
402         brush = QBrush(QColor(*color, alpha=128), Qt.SolidPattern)

```

403  
404

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

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

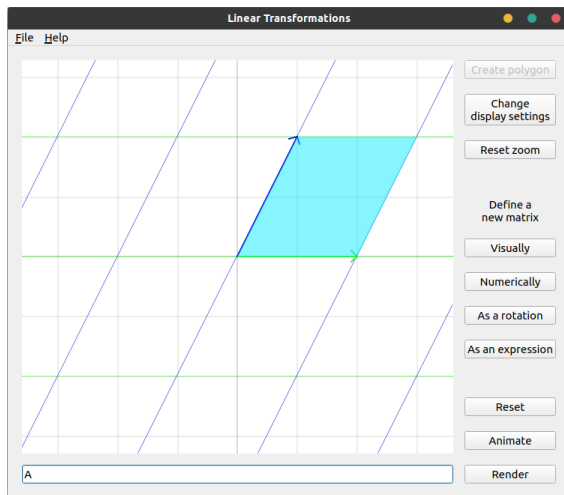


Figure 3.18: The blue parallelogram

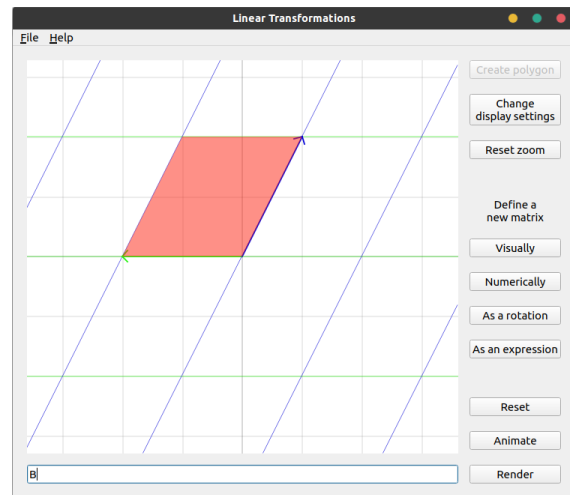


Figure 3.19: The red parallelogram

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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

```

```
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 = ['save', 'crash_reports']
128
129         os.makedirs(self._directory, exist_ok=True)
130         for sub_directory in sub_directories:
131             os.makedirs(os.path.join(self._directory, sub_directory), exist_ok=True)
132
133         self._executable_path: Optional[str] = None
134
135         self._settings_file = os.path.join(self._directory, 'settings.dat')
136         self._display_settings_file = os.path.join(self._directory, 'display_settings.dat')
137
138         try:
139             self._data = GlobalSettingsData.load_from_file(self._settings_file)[1]
```

```
140     except KeyError:
141         self._data = GlobalSettingsData()
142         self._data.save_to_file(self._settings_file)
143
144     def get_executable_path(self) -> str:
145         """Return the path to the binary executable, or an empty string if lintrans is not installed standalone.
146
147         This method will call :attr:`sys.executable` to see if it's lintrans. If it is, then we cache the path for
148         future use and return it. Otherwise, it's a Python interpreter, so we return an empty string instead.
149         """
150         if self._executable_path is None:
151             executable_path = sys.executable
152             if os.path.isfile(executable_path):
153                 version_output = subprocess.run(
154                     [executable_path, '--version'],
155                     stdout=subprocess.PIPE,
156                     shell=(os.name == 'nt')
157                 ).stdout.decode()
158
159                 if 'lintrans' in version_output:
160                     self._executable_path = executable_path
161             else:
162                 self._executable_path = ''
163
164         return self._executable_path or ''
165
166     def get_save_directory(self) -> str:
167         """Return the default directory for save files."""
168         return os.path.join(self._directory, 'saves')
169
170     def get_crash_reports_directory(self) -> str:
171         """Return the default directory for crash reports."""
172         return os.path.join(self._directory, 'crash_reports')
173
174     def get_settings_file(self) -> str:
175         """Return the full path of the settings file."""
176         return self._settings_file
177
178     def save_display_settings(self, settings: lintrans.gui.settings.DisplaySettings) -> None:
179         """Save the given display settings to the default file."""
180         settings.save_to_file(self._display_settings_file)
181
182     def get_display_settings(self) -> lintrans.gui.settings.DisplaySettings:
183         """Get the display settings from the default file, using the defaults for anything that's not available."""
184         return lintrans.gui.settings.DisplaySettings.load_from_file(self._display_settings_file)[1]
185
186     def get_update_download_filename(self) -> str:
187         """Return a name for a temporary file next to the executable.
188
189         This method is used when downloading a new version of lintrans into a temporary file.
190         This is needed to allow :func:`os.rename` instead of :func:`shutil.move`. The first
191         requires the src and dest to be on the same partition, but also allows us to replace
192         the running executable.
193         """
194         return str(Path(self.get_executable_path()).parent / 'lintrans-update-temp.dat')
195
196     def get_update_replace_bat_filename(self) -> str:
197         """Return the full path of the ``replace.bat`` file needed to update on Windows.
198
199         See :meth:`get_update_download_filename`.
200         """
201         return str(Path(self.get_executable_path()).parent / 'replace.bat')
202
203     def get_data(self) -> GlobalSettingsData:
204         """Return a copy of the internal global settings data."""
205         return copy(self._data)
206
207     def set_data(self, data: GlobalSettingsData) -> None:
208         """Set the internal global settings data and save it to a file."""
209         self._data = data
210         self._data.save_to_file(self._settings_file)
211
212     def set_update_type(self, type_: UpdateType) -> None:
```

```

213         """Set the internal data update type."""
214         data = self.get_data()
215         data.update_type = type_
216         self.set_data(data)

```

## A.2 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/'
119
120     if os.name == 'posix':
121         url += f'v{latest_version}/lintrans-Linux-{latest_version}'
122
123     elif os.name == 'nt':
124         url += f'v{latest_version}/lintrans-Windows-{latest_version}.exe'
125
126     else:
127         return
128
129     temp_file = GlobalSettings().get_update_download_filename()
130
131     # If the temp file already exists, then another instance of lintrans (probably
132     # in a background thread) is currently updating, so we don't want to interfere
133     if os.path.isfile(temp_file):
134         return
135
136     with open(temp_file, 'wb') as f:

```



```

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

```

### A.3 crash\_reporting.py

```

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

```

```

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

```

```

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

```

```

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

```

```

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

```

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

```

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

```

```

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

```

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

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This is the top-level ``lintrans`` package, which contains all the subpackages of the project."""
8
9  from . import (crash_reporting, global_settings, gui, matrices, typing_,
10                updating)
11
12  __version__ = '0.4.1-alpha'
13
14  __all__ = ['crash_reporting', 'global_settings', 'gui', 'matrices', 'typing_', 'updating', '__version__']

```

## A.6 gui/main\_window.py

```

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

```

```

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

```

```
85     """This class provides a main window for the GUI using the Qt framework.
86
87     This class should not be used directly, instead call :func:`main` to create the GUI.
88     """
89
90     def __init__(self):
91         """Create the main window object, and create and arrange every widget in it.
92
93         This doesn't show the window, it just constructs it. Use :func:`main` to show the GUI.
94         """
95         super().__init__()
96
97         self._matrix_wrapper = MatrixWrapper()
98
99         self._expression_history: List[str] = []
100        self._expression_history_index: Optional[int] = None
101
102        self.setWindowTitle(['*'] * lintrans)
103        self.setMinimumSize(800, 650)
104
105        path = Path(__file__).parent.absolute() / 'assets' / 'icon.jpg'
106        self.setWindowIcon(QIcon(str(path)))
107
108        self._animating: bool = False
109        self._animating_sequence: bool = False
110        self._reset_during_animation: bool = False
111
112        self._save_filename: Optional[str] = None
113
114        # Set up thread and worker to check for updates
115
116        self._thread_updates = QThread()
117        self._worker_updates = _UpdateChecker()
118        self._worker_updates.moveToThread(self._thread_updates)
119
120        self._thread_updates.started.connect(self._worker_updates.check_for_updates_and_emit)
121        self._worker_updates.signal_prompt_update.connect(self._prompt_update)
122        self._worker_updates.finished.connect(self._thread_updates.quit)
123        self._worker_updates.finished.connect(self._worker_updates.deleteLater)
124        self._thread_updates.finished.connect(self._thread_updates.deleteLater)
125
126        # === Create menubar
127
128        menubar = QtWidgets.QMenuBar(self)
129
130        menu_file = QMenu(menubar)
131        menu_file.setTitle('&File')
132
133        menu_help = QMenu(menubar)
134        menu_help.setTitle('&Help')
135
136        action_global_settings = QAction(self)
137        action_global_settings.setText('Settings')
138        action_global_settings.setShortcut('Ctrl+Alt+S')
139        action_global_settings.triggered.connect(self._dialog_change_global_settings)
140
141        action_reset_session = QAction(self)
142        action_reset_session.setText('Reset session')
143        action_reset_session.triggered.connect(self._reset_session)
144
145        action_open = QAction(self)
146        action_open.setText('&Open')
147        action_open.setShortcut('Ctrl+O')
148        action_open.triggered.connect(self._ask_for_session_file)
149
150        action_save = QAction(self)
151        action_save.setText('&Save')
152        action_save.setShortcut('Ctrl+S')
153        action_save.triggered.connect(self._save_session)
154
155        action_save_as = QAction(self)
156        action_save_as.setText('Save as...')
157        action_save_as.setShortcut('Ctrl+Shift+S')
```



```
158         action_save_as.triggered.connect(self._save_session_as)
159
160         action_quit = QAction(self)
161         action_quit.setText('&Quit')
162         action_quit.triggered.connect(self.close)
163
164         # If this is an old release, use the docs for this release. Else, use the latest docs
165         # We use the latest because most use cases for non-stable releases will be in development and testing
166         docs_link = 'https://lintrans.readthedocs.io/en/'
167
168         if re.match(r'^\d+\.\d+\.\d+$', lintrans.__version__):
169             docs_link += 'v' + lintrans.__version__
170         else:
171             docs_link += 'latest'
172
173         action_tutorial = QAction(self)
174         action_tutorial.setText('&Tutorial')
175         action_tutorial.setShortcut('F1')
176         action_tutorial.triggered.connect(
177             lambda: webbrowser.open_new_tab(docs_link + '/tutorial/index.html')
178         )
179
180         action_docs = QAction(self)
181         action_docs.setText('&Docs')
182         action_docs.triggered.connect(
183             lambda: webbrowser.open_new_tab(docs_link + '/backend/lintrans.html')
184         )
185
186         menu_feedback = QMenu(menu_help)
187         menu_feedback.setTitle('Give feedback')
188
189         action_bug_report = QAction(self)
190         action_bug_report.setText('Report a bug')
191         action_bug_report.triggered.connect(
192             lambda: webbrowser.open_new_tab('https://forms.gle/Q82cLTtgPLcV4xQD6')
193         )
194
195         action_suggest_feature = QAction(self)
196         action_suggest_feature.setText('Suggest a new feature')
197         action_suggest_feature.triggered.connect(
198             lambda: webbrowser.open_new_tab('https://forms.gle/mVWbHiMBw9Zq5Ze37')
199         )
200
201         menu_feedback.addAction(action_bug_report)
202         menu_feedback.addAction(action_suggest_feature)
203
204         action_about = QAction(self)
205         action_about.setText('&About')
206         action_about.triggered.connect(lambda: AboutDialog(self).open())
207
208         menu_file.addAction(action_global_settings)
209         menu_file.addSeparator()
210         menu_file.addAction(action_reset_session)
211         menu_file.addAction(action_open)
212         menu_file.addSeparator()
213         menu_file.addAction(action_save)
214         menu_file.addAction(action_save_as)
215         menu_file.addSeparator()
216         menu_file.addAction(action_quit)
217
218         menu_help.addAction(action_tutorial)
219         menu_help.addAction(action_docs)
220         menu_help.addSeparator()
221         menu_help.addMenu(menu_feedback)
222         menu_help.addSeparator()
223         menu_help.addAction(action_about)
224
225         menubar.addAction(menu_file.menuAction())
226         menubar.addAction(menu_help.menuAction())
227
228         self.setMenuBar(menubar)
229
230         # === Create widgets
```

```

231
232     # Left layout: the plot and input box
233
234     self._plot = MainViewportWidget(
235         self,
236         display_settings=GlobalSettings().get_display_settings(),
237         polygon_points=[]
238     )
239
240     self._lineedit_expression_box = QtWidgets.QLineEdit(self)
241     self._lineedit_expression_box.setPlaceholderText('Enter matrix expression...')
242     self._lineedit_expression_box.setValidator(MatrixExpressionValidator(self))
243     self._lineedit_expression_box.textChanged.connect(self._update_render_buttons)
244
245     # Right layout: all the buttons
246
247     # Misc buttons
248
249     button_define_polygon = QPushButton(self)
250     button_define_polygon.setText('Define polygon')
251     button_define_polygon.clicked.connect(self._dialog_define_polygon)
252     button_define_polygon.setToolTip('Define a polygon to view its transformation<br><b>(Ctrl + P)</b>')
253     QShortcut(QKeySequence('Ctrl+P'), self).activated.connect(button_define_polygon.click)
254
255     self._button_change_display_settings = QPushButton(self)
256     self._button_change_display_settings.setText('Change\ndisplay settings')
257     self._button_change_display_settings.clicked.connect(self._dialog_change_display_settings)
258     self._button_change_display_settings.setToolTip(
259         "Change which things are rendered and how they're rendered<br><b>(Ctrl + D)</b>"
260     )
261     QShortcut(QKeySequence('Ctrl+D'), self).activated.connect(self._button_change_display_settings.click)
262
263     button_reset_zoom = QPushButton(self)
264     button_reset_zoom.setText('Reset zoom')
265     button_reset_zoom.clicked.connect(self._reset_zoom)
266     button_reset_zoom.setToolTip('Reset the zoom level back to normal<br><b>(Ctrl + Shift + R)</b>')
267     QShortcut(QKeySequence('Ctrl+Shift+R'), self).activated.connect(button_reset_zoom.click)
268
269     # Define new matrix buttons and their groupbox
270
271     self._button_define_visually = QPushButton(self)
272     self._button_define_visually.setText('Visually')
273     self._button_define_visually.setToolTip('Drag the basis vectors<br><b>(Alt + 1)</b>')
274     self._button_define_visually.clicked.connect(lambda: self._dialog_define_matrix(DefineVisuallyDialog))
275     QShortcut(QKeySequence('Alt+1'), self).activated.connect(self._button_define_visually.click)
276
277     self._button_define_numerically = QPushButton(self)
278     self._button_define_numerically.setText('Numerically')
279     self._button_define_numerically.setToolTip('Define a matrix just with numbers<br><b>(Alt + 2)</b>')
280     self._button_define_numerically.clicked.connect(lambda: self._dialog_define_matrix(DefineNumericallyDialog))
281     QShortcut(QKeySequence('Alt+2'), self).activated.connect(self._button_define_numerically.click)
282
283     self._button_define_as_expression = QPushButton(self)
284     self._button_define_as_expression.setText('As an expression')
285     self._button_define_as_expression.setToolTip('Define a matrix in terms of other matrices<br><b>(Alt +  
↩ 3)</b>')
286     self._button_define_as_expression.clicked.connect(
287         lambda: self._dialog_define_matrix(DefineAsExpressionDialog)
288     )
289     QShortcut(QKeySequence('Alt+3'), self).activated.connect(self._button_define_as_expression.click)
290
291     vlay_define_new_matrix = QVBoxLayout()
292     vlay_define_new_matrix.setSpacing(20)
293     vlay_define_new_matrix.addWidget(self._button_define_visually)
294     vlay_define_new_matrix.addWidget(self._button_define_numerically)
295     vlay_define_new_matrix.addWidget(self._button_define_as_expression)
296
297     groupbox_define_new_matrix = QtWidgets.QGroupBox('Define a new matrix', self)
298     groupbox_define_new_matrix.setLayout(vlay_define_new_matrix)
299
300     # Info panel button
301
302     self._button_info_panel = QPushButton(self)

```

```

303     self._button_info_panel.setText('Show defined matrices')
304     self._button_info_panel.clicked.connect(self._open_info_panel)
305     self._button_info_panel.setToolTip(
306         'Open an info panel with all matrices that have been defined in this session<br><b>(Ctrl + M)</b>'
307     )
308     QShortcut(QKeySequence('Ctrl+M'), self).activated.connect(self._button_info_panel.click)
309
310     # Render buttons
311
312     button_reset = QPushButton(self)
313     button_reset.setText('Reset')
314     button_reset.clicked.connect(self._reset_transformation)
315     button_reset.setToolTip('Reset the visualized transformation back to the identity<br><b>(Ctrl + R)</b>')
316     QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(button_reset.click)
317
318     self._button_render = QPushButton(self)
319     self._button_render.setText('Render')
320     self._button_render.setEnabled(False)
321     self._button_render.clicked.connect(self._render_expression)
322     self._button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
323     QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_render.click)
324
325     self._button_animate = QPushButton(self)
326     self._button_animate.setText('Animate')
327     self._button_animate.setEnabled(False)
328     self._button_animate.clicked.connect(self._animate_expression)
329     self._button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
330     QShortcut(QKeySequence('Ctrl+Shift+Return'), self).activated.connect(self._button_animate.click)
331
332     # === Arrange widgets
333
334     vlay_left = QVBoxLayout()
335     vlay_left.addWidget(self._plot)
336     vlay_left.addWidget(self._lineedit_expression_box)
337
338     vlay_misc_buttons = QVBoxLayout()
339     vlay_misc_buttons.setSpacing(20)
340     vlay_misc_buttons.addWidget(button_define_polygon)
341     vlay_misc_buttons.addWidget(self._button_change_display_settings)
342     vlay_misc_buttons.addWidget(button_reset_zoom)
343
344     vlay_info_buttons = QVBoxLayout()
345     vlay_info_buttons.setSpacing(20)
346     vlay_info_buttons.addWidget(self._button_info_panel)
347
348     vlay_render = QVBoxLayout()
349     vlay_render.setSpacing(20)
350     vlay_render.addWidget(button_reset)
351     vlay_render.addWidget(self._button_animate)
352     vlay_render.addWidget(self._button_render)
353
354     vlay_right = QVBoxLayout()
355     vlay_right.setSpacing(50)
356     vlay_right.addLayout(vlay_misc_buttons)
357     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
358     vlay_right.addWidget(groupbox_define_new_matrix)
359     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
360     vlay_right.addLayout(vlay_info_buttons)
361     vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
362     vlay_right.addLayout(vlay_render)
363
364     hlay_all = QHBoxLayout()
365     hlay_all.setSpacing(15)
366     hlay_all.addLayout(vlay_left)
367     hlay_all.addLayout(vlay_right)
368
369     central_widget = QWidget()
370     central_widget.setLayout(hlay_all)
371     central_widget.setContentsMargins(10, 10, 10, 10)
372
373     self.setCentralWidget(central_widget)
374
375     def closeEvent(self, event: QCloseEvent) -> None:

```

```
376 """Handle a :class:`QCloseEvent` by confirming if the user wants to save, and cancelling animation."""
377 if not self.isWindowModified():
378     self._animating = False
379     self._animating_sequence = False
380     GlobalSettings().save_display_settings(self._plot.display_settings)
381     event.accept()
382     return
383
384 if self._save_filename is not None:
385     text = f"If you don't save, then changes made to {self._save_filename} will be lost."
386 else:
387     text = "If you don't save, then changes made will be lost."
388
389 dialog = QMessageBox(self)
390 dialog.setIcon(QMessageBox.Question)
391 dialog.setWindowTitle('Save changes?')
392 dialog.setText(text)
393 dialog.setStandardButtons(QMessageBox.Save | QMessageBox.Discard | QMessageBox.Cancel)
394 dialog.setDefaultButton(QMessageBox.Save)
395
396 pressed_button = dialog.exec()
397
398 if pressed_button == QMessageBox.Save:
399     self._save_session()
400
401 if pressed_button in (QMessageBox.Save, QMessageBox.Discard):
402     self._animating = False
403     self._animating_sequence = False
404     GlobalSettings().save_display_settings(self._plot.display_settings)
405     event.accept()
406 else:
407     event.ignore()
408
409 def keyPressEvent(self, event: QKeyEvent) -> None:
410     """Handle a :class:`QKeyEvent` by scrolling through expression history."""
411     key = event.key()
412
413     # Load previous expression
414     if key == Qt.Key_Up:
415         if self._expression_history_index is None:
416             if len(self._expression_history) == 0:
417                 event.ignore()
418                 return
419
420             # If the index is none and we've got a history, set the index to -1
421             self._expression_history_index = -1
422
423             # If the index is in range of the list (the index is always negative), then decrement it
424             elif self._expression_history_index > -len(self._expression_history):
425                 self._expression_history_index -= 1
426
427             self._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                 except LinAlgError:
552                     self._show_error_message('Singular matrix', 'Cannot take inverse of singular matrix.')
553                     return
554
555                 self._animate_between_matrices(current_matrix, new_matrix)
556                 current_matrix = new_matrix
557
558                 # Here we just redraw and allow for other events to be handled while we pause
559                 self._plot.update()
560                 QApplication.processEvents()
561                 QThread.sleep(self._plot.display_settings.animation_pause_length)
562
563             self._animating_sequence = False
564
565         # If there's no commas, then just animate directly from the start to the target
566         else:
567             # Get the target matrix and its determinant
568             try:
569                 matrix_target = self._matrix_wrapper.evaluate_expression(text)
570
571             except LinAlgError:
572                 self._show_error_message('Singular matrix', 'Cannot take inverse of singular matrix.')
573                 return
574
575             # The concept of applicative animation is explained in /gui/settings.py
576             if self._plot.display_settings.applicative_animation:
577                 matrix_target = matrix_target @ matrix_start
578
579             # If we want a transitional animation and we're animating the same matrix, then restart the animation
580             # We use this check rather than equality because of small floating point errors
581             elif (abs(matrix_start - matrix_target) < 1e-12).all():
582                 matrix_start = self._matrix_wrapper['I']
583
584             # We pause here for 200 ms to make the animation look a bit nicer
585             self._plot.plot_matrix(matrix_start)
586             self._plot.update()
587             QApplication.processEvents()
588             QThread.sleep(200)
589
590             self._animate_between_matrices(matrix_start, matrix_target)
591
592         self._update_render_buttons()
593
594     def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:

```

```

595         """Get the matrix to render for this frame of the animation.
596
597         This method will smoothen the determinant if that setting is enabled and if the determinant is positive.
598         It also animates rotation-like matrices using a logarithmic spiral to rotate around and scale continuously.
599         Essentially, it just makes things look good when animating.
600
601         :param MatrixType start: The starting matrix
602         :param MatrixType target: The target matrix
603         :param float proportion: How far we are through the loop
604         """
605         det_target = linalg.det(target)
606         det_start = linalg.det(start)
607
608         # This is the matrix that we're applying to get from start to target
609         # We want to check if it's rotation-like
610         if linalg.det(start) == 0:
611             matrix_application = None
612         else:
613             matrix_application = target @ linalg.inv(start)
614
615         # For a matrix to represent a rotation, it must have a positive determinant,
616         # its vectors must be perpendicular, the same length, and at right angles
617         # The checks for 'abs(value) < 1e-10' are to account for floating point error
618         if matrix_application is not None \
619             and self._plot.display_settings.smoothen_determinant \
620             and linalg.det(matrix_application) > 0 \
621             and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 1e-10 \
622             and abs(np.hypot(*matrix_application.T[0]) - np.hypot(*matrix_application.T[1])) < 1e-10:
623             rotation_vector: VectorType = matrix_application.T[0] # Take the i column
624             radius, angle = polar_coords(*rotation_vector)
625
626             # We want the angle to be in [-pi, pi), so we have to subtract 2pi from it if it's too big
627             if angle > np.pi:
628                 angle -= 2 * np.pi
629
630             i: VectorType = start.T[0]
631             j: VectorType = start.T[1]
632
633             # Scale the coords with a list comprehension
634             # It's a bit janky, but rotate_coords() will always return a 2-tuple,
635             # so new_i and new_j will always be lists of length 2
636             scale = (radius - 1) * proportion + 1
637             new_i = [scale * c for c in rotate_coord(i[0], i[1], angle * proportion)]
638             new_j = [scale * c for c in rotate_coord(j[0], j[1], angle * proportion)]
639
640             return np.array(
641                 [
642                     [new_i[0], new_j[0]],
643                     [new_i[1], new_j[1]]
644                 ]
645             )
646
647         # matrix_a is the start matrix plus some part of the target, scaled by the proportion
648         # If we just used matrix_a, then things would animate, but the determinants would be weird
649         matrix_a = start + proportion * (target - start)
650
651         if not self._plot.display_settings.smoothen_determinant or det_start * det_target <= 0:
652             return matrix_a
653
654         # To fix the determinant problem, we get the determinant of matrix_a and use it to normalize
655         det_a = linalg.det(matrix_a)
656
657         # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
658         # We want B = cA such that det(B) = det(S), where S is the start matrix,
659         # so then we can scale it with the animation, so we get
660         # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
661         # Then we scale A to get the determinant we want, and call that matrix_b
662         if det_a == 0:
663             c = 0
664         else:
665             c = np.sqrt(abs(det_start / det_a))
666
667         matrix_b = c * matrix_a

```

```

668         det_b = linalg.det(matrix_b)
669
670         # We want to return B, but we have to scale it over time to have the target determinant
671
672         # We want some C = dB such that det(C) is some target determinant T
673         # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
674
675         # We're also subtracting 1 and multiplying by the proportion and then adding one
676         # This just scales the determinant along with the animation
677
678         # That is all of course, if we can do that
679         # We'll crash if we try to do this with det(B) == 0
680         if det_b == 0:
681             return matrix_a
682
683         scalar: float = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
684         return scalar * matrix_b
685
686     def _animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType) -> None:
687         """Animate from the start matrix to the target matrix."""
688         self._animating = True
689
690         # Making steps depend on animation_time ensures a smooth animation without
691         # massive overheads for small animation times
692         steps = self._plot.display_settings.animation_time // 10
693
694         for i in range(0, steps + 1):
695             if not self._animating:
696                 break
697
698             matrix_to_render = self._get_animation_frame(matrix_start, matrix_target, i / steps)
699
700             if self._is_matrix_too_big(matrix_to_render):
701                 self._animating = False
702                 self._animating_sequence = False
703                 return
704
705             self._plot.plot_matrix(matrix_to_render)
706
707             # We schedule the plot to be updated, tell the event loop to
708             # process events, and asynchronously sleep for 10ms
709             # This allows for other events to be processed while animating, like zooming in and out
710             self._plot.update()
711             QApplication.processEvents()
712             QThread.sleep(self._plot.display_settings.animation_time // steps)
713
714             if not self._reset_during_animation:
715                 self._plot.plot_matrix(matrix_target)
716             else:
717                 self._plot.plot_matrix(self._matrix_wrapper['I'])
718
719             self._plot.update()
720
721             self._animating = False
722             self._reset_during_animation = False
723
724     @pyqtSlot()
725     def _open_info_panel(self) -> None:
726         """Open the info panel and register a callback to undefine matrices."""
727         dialog = InfoPanelDialog(self._matrix_wrapper, self)
728         dialog.open()
729         dialog.finished.connect(self._assign_matrix_wrapper)
730
731     @pyqtSlot(DefineMatrixDialog)
732     def _dialog_define_matrix(self, dialog_class: Type[DefineMatrixDialog]) -> None:
733         """Open a generic definition dialog to define a new matrix.
734
735         The class for the desired dialog is passed as an argument. We create an
736         instance of this class and the dialog is opened asynchronously and modally
737         (meaning it blocks interaction with the main window) with the proper method
738         connected to the :meth:`QDialog.accepted` signal.
739

```



```

740     .. note:: ``dialog_class`` must subclass
↪ :class:`~lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog`.
741
742     :param dialog_class: The dialog class to instantiate
743     :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineMatrixDialog]
744     """
745     # We create a dialog with a deepcopy of the current matrix_wrapper
746     # This avoids the dialog mutating this one
747     dialog: DefineMatrixDialog
748
749     if dialog_class == DefineVisuallyDialog:
750         dialog = DefineVisuallyDialog(
751             self,
752             matrix_wrapper=deepcopy(self._matrix_wrapper),
753             display_settings=self._plot.display_settings,
754             polygon_points=self._plot.polygon_points,
755             input_vector=self._plot.point_input_vector
756         )
757     else:
758         dialog = dialog_class(self, matrix_wrapper=deepcopy(self._matrix_wrapper))
759
760     # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
761     dialog.open()
762
763     # So we have to use the accepted signal to call a method when the user accepts the dialog
764     dialog.accepted.connect(self._assign_matrix_wrapper)
765
766 @pyqtSlot()
767 def _assign_matrix_wrapper(self) -> None:
768     """Assign a new value to ``self._matrix_wrapper`` and give the expression box focus."""
769     self._matrix_wrapper = self.sender().matrix_wrapper
770     self._lineEdit_expression_box.setFocus()
771     self._update_render_buttons()
772
773     self.setWindowModified(True)
774     self._update_window_title()
775
776 @pyqtSlot()
777 def _dialog_change_global_settings(self) -> None:
778     """Open the dialog to change the global settings."""
779     dialog = GlobalSettingsDialog(self)
780     dialog.open()
781     dialog.accepted.connect(self._plot.update)
782
783 @pyqtSlot()
784 def _dialog_change_display_settings(self) -> None:
785     """Open the dialog to change the display settings."""
786     dialog = DisplaySettingsDialog(self, display_settings=self._plot.display_settings)
787     dialog.open()
788     dialog.accepted.connect(self._assign_display_settings)
789
790 @pyqtSlot()
791 def _assign_display_settings(self) -> None:
792     """Assign a new value to ``self._plot.display_settings`` and give the expression box focus."""
793     self._plot.display_settings = self.sender().display_settings
794     self._plot.update()
795     self._lineEdit_expression_box.setFocus()
796     self._update_render_buttons()
797
798 @pyqtSlot()
799 def _dialog_define_polygon(self) -> None:
800     """Open the dialog to define a polygon."""
801     dialog = DefinePolygonDialog(self, polygon_points=self._plot.polygon_points)
802     dialog.open()
803     dialog.accepted.connect(self._assign_polygon_points)
804
805 @pyqtSlot()
806 def _assign_polygon_points(self) -> None:
807     """Assign a new value to ``self._plot.polygon_points`` and give the expression box focus."""
808     self._plot.polygon_points = self.sender().polygon_points
809     self._plot.update()
810     self._lineEdit_expression_box.setFocus()
811     self._update_render_buttons()

```

```

812
813     self.setWindowModified(True)
814     self._update_window_title()
815
816 def _show_error_message(self, title: str, text: str, info: str | None = None, *, warning: bool = False) -> None:
817     """Show an error message in a dialog box.
818
819     :param str title: The window title of the dialog box
820     :param str text: The simple error message
821     :param info: The more informative error message
822     :type info: Optional[str]
823     """
824     dialog = QMessageBox(self)
825     dialog.setWindowTitle(title)
826     dialog.setText(text)
827
828     if warning:
829         dialog.setIcon(QMessageBox.Warning)
830     else:
831         dialog.setIcon(QMessageBox.Critical)
832
833     if info is not None:
834         dialog.setInformativeText(info)
835
836     dialog.open()
837
838     # This is `finished` rather than `accepted` because we want to update the buttons no matter what
839     dialog.finished.connect(self._update_render_buttons)
840
841 def _is_matrix_too_big(self, matrix: MatrixType) -> bool:
842     """Check if the given matrix will actually fit on the grid.
843
844     We're checking against a 1000x1000 grid here, which is far less than the actual space we have available.
845     But even when fully zoomed out 1080p monitor, the grid is only roughly 170x90, so 1000x1000 is plenty.
846
847     :param MatrixType matrix: The matrix to check
848     :returns bool: Whether the matrix is too big to fit on the canvas
849     """
850     for x, y in matrix.T:
851         if not (-1000 <= x <= 1000 and -1000 <= y <= 1000):
852             self._show_error_message(
853                 'Matrix too big',
854                 "This matrix doesn't fit on the grid.",
855                 'This grid is only 1000x1000, and this matrix\n'
856                 f'[{int(matrix[0][0])} {int(matrix[0][1])}; {int(matrix[1][0])} {int(matrix[1][1])}]\n'
857                 " doesn't fit."
858             )
859             return True
860
861     return False
862
863 def _update_window_title(self) -> None:
864     """Update the window title to reflect whether the session has changed since it was last saved."""
865     if self._save_filename:
866         title = os.path.split(self._save_filename)[-1] + ' [*] - lintrans'
867     else:
868         title = ' [*] lintrans'
869
870     self.setWindowTitle(title)
871
872 def _reset_session(self) -> None:
873     """Ask the user if they want to reset the current session.
874
875     Resetting the session means setting the matrix wrapper to a new instance, and rendering I.
876     """
877     dialog = QMessageBox(self)
878     dialog.setIcon(QMessageBox.Question)
879     dialog.setWindowTitle('Reset the session?')
880     dialog.setText('Are you sure you want to reset the current session?')
881     dialog.setStandardButtons(QMessageBox.Yes | QMessageBox.No)
882     dialog.setDefaultButton(QMessageBox.No)
883
884     if dialog.exec() == QMessageBox.Yes:

```

```

885         self._matrix_wrapper = MatrixWrapper()
886         self._plot.polygon_points = []
887         self._plot.display_settings = GlobalSettings().get_display_settings()
888
889         self._reset_transformation()
890         self._expression_history = []
891         self._expression_history_index = None
892         self._lineedit_expression_box.setText('')
893         self._lineedit_expression_box.setFocus()
894         self._update_render_buttons()
895
896         self._save_filename = None
897         self.setWindowModified(False)
898         self._update_window_title()
899
900     def open_session_file(self, filename: str) -> None:
901         """Open the given session file.
902
903         If the selected file is not a valid lintrans session file, we just show an error message,
904         but if it's valid, we load it and set it as the default filename for saving.
905         """
906         try:
907             session, version, extra_attrs = Session.load_from_file(filename)
908
909             # load_from_file() can raise errors if the contents is not a valid pickled Python object,
910             # or if the pickled Python object is of the wrong type
911             except (AttributeError, EOFError, FileNotFoundError, ValueError, UnpicklingError):
912                 self._show_error_message(
913                     'Invalid file contents',
914                     'This is not a valid lintrans session file.',
915                     'Not all .lt files are lintrans session files. This file was probably created by an unrelated '
916                     'program.'
917                 )
918             return
919
920         missing_parts = False
921
922         if session.matrix_wrapper is not None:
923             self._matrix_wrapper = session.matrix_wrapper
924         else:
925             self._matrix_wrapper = MatrixWrapper() # type: ignore[unreachable]
926             missing_parts = True
927
928         if session.polygon_points is not None:
929             self._plot.polygon_points = session.polygon_points
930         else:
931             self._plot.polygon_points = [] # type: ignore[unreachable]
932             missing_parts = True
933
934         if session.display_settings is not None:
935             self._plot.display_settings = session.display_settings
936         else:
937             self._plot.display_settings = DisplaySettings() # type: ignore[unreachable]
938             missing_parts = True
939
940         if session.input_vector is not None:
941             self._plot.point_input_vector = session.input_vector
942         else:
943             self._plot.point_input_vector = (1, 1) # type: ignore[unreachable]
944             missing_parts = True
945
946         if missing_parts:
947             if version != lintrans.__version__:
948                 info = f"This may be a version conflict. This file was saved with lintrans v{version} " \
949                     f"but you're running lintrans v{lintrans.__version__}."
950             else:
951                 info = None
952
953             self._show_error_message(
954                 'Session file missing parts',
955                 'This session file is missing certain elements. It may not work correctly.',
956                 info,
957                 warning=True

```

```

958         )
959     elif extra_attrs:
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 has extra parts',
968             'This session file has more parts than expected. It will work correctly, '
969             'but you might be missing some features.',
970             info,
971             warning=True
972         )
973
974     self._reset_transformation()
975     self._expression_history = []
976     self._expression_history_index = None
977     self._linedit_expression_box.setText('')
978     self._linedit_expression_box.setFocus()
979     self._update_render_buttons()
980
981     # Set this as the default filename if we could read it properly
982     self._save_filename = filename
983     self.setWindowModified(False)
984     self._update_window_title()
985
986 @pyqtSlot()
987 def _ask_for_session_file(self) -> None:
988     """Ask the user to select a session file, and then open it and load the session."""
989     dialog = QFileDialog(
990         self,
991         'Open a session',
992         GlobalSettings().get_save_directory(),
993         'lintrans sessions (*.lt)'
994     )
995     dialog.setAcceptMode(QFileDialog.AcceptOpen)
996     dialog.setFileMode(QFileDialog.ExistingFile)
997     dialog.setViewMode(QFileDialog.List)
998
999     if dialog.exec():
1000         self.open_session_file(dialog.selectedFiles()[0])
1001
1002 @pyqtSlot()
1003 def _save_session(self) -> None:
1004     """Save the session to the given file.
1005
1006     If ``self._save_filename`` is ``None``, then call :meth:`_save_session_as` and return.
1007     """
1008     if self._save_filename is None:
1009         self._save_session_as()
1010         return
1011
1012     Session(
1013         matrix_wrapper=self._matrix_wrapper,
1014         polygon_points=self._plot.polygon_points,
1015         display_settings=self._plot.display_settings,
1016         input_vector=self._plot.point_input_vector,
1017     ).save_to_file(self._save_filename)
1018
1019     self.setWindowModified(False)
1020     self._update_window_title()
1021
1022 @pyqtSlot()
1023 def _save_session_as(self) -> None:
1024     """Ask the user for a file to save the session to, and then call :meth:`_save_session`.
1025
1026     .. note::
1027         If the user doesn't select a file to save the session to, then the session
1028         just doesn't get saved, and :meth:`_save_session` is never called.
1029     """
1030     dialog = FileSelectDialog(

```

```

1031         self,
1032         'Save this session',
1033         GlobalSettings().get_save_directory(),
1034         'lintrans sessions (*.lt)'
1035     )
1036     dialog.setAcceptMode(QFileDialog.AcceptSave)
1037     dialog.setFileMode(QFileDialog.AnyFile)
1038     dialog.setViewMode(QFileDialog.List)
1039     dialog.setDefaultSuffix('.lt')
1040
1041     if dialog.exec():
1042         filename = dialog.selectedFiles()[0]
1043         self._save_filename = filename
1044         self._save_session()
1045
1046     @pyqtSlot(str)
1047     def _prompt_update(self, version: str) -> None:
1048         """Open a modal dialog to prompt the user to update lintrans."""
1049         dialog = PromptUpdateDialog(self, new_version=version)
1050         dialog.open()
1051
1052     def check_for_updates_and_prompt(self) -> None:
1053         """Update lintrans depending on the user's choice of update type.
1054
1055         If they chose 'prompt', then this method will open a prompt dialog (after checking
1056         if a new version actually exists). See :meth:`_prompt_update`.
1057         """
1058         self._thread_updates.start()
1059
1060
1061     def main(filename: Optional[str]) -> NoReturn:
1062         """Run the GUI by creating and showing an instance of :class:`LintransMainWindow`.
1063
1064         :param Optional[str] filename: A session file to optionally open at startup
1065         """
1066         app = QApplication([])
1067         app.setApplicationName('lintrans')
1068         app.setApplicationVersion(lintrans.__version__)
1069
1070         qapp().setStyle(QStyleFactory.create('fusion'))
1071
1072         window = LintransMainWindow()
1073         window.show()
1074         window.check_for_updates_and_prompt()
1075
1076         if filename:
1077             window.open_session_file(filename)
1078
1079         sys.exit(app.exec_())

```

## A.7 gui/session.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides the :class:`Session` class, which provides a way to save and load sessions."""
8
9  from __future__ import annotations
10
11  import os
12  import pathlib
13  import pickle
14  from collections import defaultdict
15  from typing import Any, DefaultDict, List, Tuple
16
17  import lintrans
18  from lintrans.gui.settings import DisplaySettings

```

```

19 from lintrans.matrices import MatrixWrapper
20
21
22 def _return_none() -> None:
23     """Return None.
24
25     This function only exists to make the defaultdict in :class:`Session` pickle-able.
26     """
27     return None
28
29
30 class Session:
31     """Hold information about a session and provide methods to save and load that data."""
32
33     __slots__ = ('matrix_wrapper', 'polygon_points', 'display_settings', 'input_vector')
34     matrix_wrapper: MatrixWrapper
35     polygon_points: List[Tuple[float, float]]
36     display_settings: DisplaySettings
37     input_vector: Tuple[float, float]
38
39     def __init__(
40         self,
41         *,
42         matrix_wrapper: MatrixWrapper,
43         polygon_points: List[Tuple[float, float]],
44         display_settings: DisplaySettings,
45         input_vector: Tuple[float, float],
46     ) -> None:
47         """Create a :class:`Session` object with the given data."""
48         self.matrix_wrapper = matrix_wrapper
49         self.polygon_points = polygon_points
50         self.display_settings = display_settings
51         self.input_vector = input_vector
52
53     def save_to_file(self, filename: str) -> None:
54         """Save the session state to a file, creating parent directories as needed."""
55         parent_dir = pathlib.Path(os.path.expanduser(filename)).parent.absolute()
56
57         if not os.path.isdir(parent_dir):
58             os.makedirs(parent_dir)
59
60         data_dict: DefaultDict[str, Any] = defaultdict(_return_none, lintrans=lintrans.__version__)
61         for attr in self.__slots__:
62             data_dict[attr] = getattr(self, attr)
63
64         with open(filename, 'wb') as f:
65             pickle.dump(data_dict, f, protocol=4)
66
67     @classmethod
68     def load_from_file(cls, filename: str) -> Tuple[Session, str, bool]:
69         """Return the session state that was previously saved to ``filename`` along with some extra information.
70
71         The tuple we return has the :class:`Session` object (with some possibly None arguments),
72         the lintrans version that the file was saved under, and whether the file had any extra
73         attributes that this version doesn't support.
74
75         :raises AttributeError: For specific older versions of :class:`Session` before it used ``__slots__``
76         :raises EOFError: If the file doesn't contain a pickled Python object
77         :raises FileNotFoundError: If the file doesn't exist
78         :raises ValueError: If the file contains a pickled object of the wrong type
79         """
80         with open(filename, 'rb') as f:
81             data_dict = pickle.load(f)
82
83         if not isinstance(data_dict, defaultdict):
84             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be defaultdict)')
85
86         session = cls(
87             matrix_wrapper=data_dict['matrix_wrapper'],
88             polygon_points=data_dict['polygon_points'],
89             display_settings=data_dict['display_settings'],
90             input_vector=data_dict['input_vector'],
91         )

```

```

92
93     # Check if the file has more attributes than we expect
94     # If it does, it's probably from a higher version of lintrans
95     extra_attrs = len(
96         set(data_dict.keys()).difference(
97             set(['lintrans', *cls.__slots__])
98         )
99     ) != 0
100
101     return session, data_dict['lintrans'], extra_attrs

```

## A.8 gui/utility.py

```

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

```

## A.9 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.10 gui/settings.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module contains the :class:`DisplaySettings` class, which holds configuration for display."""
8
9  from __future__ import annotations
10
11  import os
12  import pathlib
13  import pickle
14  from dataclasses import dataclass
15  from typing import Tuple
16
17  import lintrans
18
19
20  @dataclass(slots=True)
21  class DisplaySettings:
22      """This class simply holds some attributes to configure display."""
23
24      # === Basic stuff
25
26      draw_background_grid: bool = True
27      """This controls whether we want to draw the background grid.
28
29      The background axes will always be drawn. This makes it easy to identify the center of the space.
30      """
31
32      draw_transformed_grid: bool = True
33      """This controls whether we want to draw the transformed grid. Vectors are handled separately."""
34
35      draw_basis_vectors: bool = True
36      """This controls whether we want to draw the transformed basis vectors."""
37
38      label_basis_vectors: bool = False
39      """This controls whether we want to label the `i` and `j` basis vectors."""
40
41      # === Animations
42
43      smoothen_determinant: bool = True
44      """This controls whether we want the determinant to change smoothly during the animation.
45
46      .. note::
47          Even if this is ``True``, it will be ignored if we're animating from a positive det matrix to
48          a negative det matrix, or vice versa, because if we try to smoothly animate that determinant,
49          things blow up and the app often crashes.
50      """
51
52      applicative_animation: bool = True
53      """There are two types of simple animation, transitional and applicative.
54
55      Let ``C`` be the matrix representing the currently displayed transformation, and let ``T`` be the target matrix.
56      Transitional animation means that we animate directly from ``C`` from ``T``,
57      and applicative animation means that we animate from ``C`` to ``TC``, so we apply ``T`` to ``C``.
58      """
59
60      animation_time: int = 1200

```



```

61     """This is the number of milliseconds that an animation takes."""
62
63     animation_pause_length: int = 400
64     """This is the number of milliseconds that we wait between animations when using comma syntax."""
65
66     # === Matrix info
67
68     draw_determinant_parallelogram: bool = False
69     """This controls whether or not we should shade the parallelogram representing the determinant of the matrix."""
70
71     show_determinant_value: bool = True
72     """This controls whether we should write the text value of the determinant inside the parallelogram.
73
74     The text only gets draw if :attr:`draw_determinant_parallelogram` is also True.
75     """
76
77     draw_eigenvectors: bool = False
78     """This controls whether we should draw the eigenvectors of the transformation."""
79
80     draw_eigenlines: bool = False
81     """This controls whether we should draw the eigenlines of the transformation."""
82
83     # === Polygon
84
85     draw_untransformed_polygon: bool = True
86     """This controls whether we should draw the untransformed version of the user-defined polygon."""
87
88     draw_transformed_polygon: bool = True
89     """This controls whether we should draw the transformed version of the user-defined polygon."""
90
91     # === Input/output vectors
92
93     draw_input_vector: bool = True
94     """This controls whether we should draw the input vector in the main viewport."""
95
96     draw_output_vector: bool = True
97     """This controls whether we should draw the output vector in the main viewport."""
98
99     def save_to_file(self, filename: str) -> None:
100         """Save the display settings to a file, creating parent directories as needed."""
101         parent_dir = pathlib.Path(os.path.expanduser(filename)).parent.absolute()
102
103         if not os.path.isdir(parent_dir):
104             os.makedirs(parent_dir)
105
106         data: Tuple[str, DisplaySettings] = (lintrans.__version__, self)
107
108         with open(filename, 'wb') as f:
109             pickle.dump(data, f, protocol=4)
110
111     @classmethod
112     def load_from_file(cls, filename: str) -> Tuple[str, DisplaySettings]:
113         """Return the display settings that were previously saved to ``filename`` along with some extra information.
114
115         The tuple we return has the version of lintrans that was used to save the file, and the data itself.
116
117         :raises EOFError: If the file doesn't contain a pickled Python object
118         :raises FileNotFoundError: If the file doesn't exist
119         :raises ValueError: If the file contains a pickled object of the wrong type
120         """
121         if not os.path.isfile(filename):
122             return lintrans.__version__, cls()
123
124         with open(filename, 'rb') as f:
125             file_data = pickle.load(f)
126
127         if not isinstance(file_data, tuple):
128             raise ValueError(f'File {filename} contains pickled object of the wrong type (must be tuple)')
129
130         # Create a default object and overwrite the fields that we have
131         data = cls()
132         for attr in file_data[1].__slots__:
133             # Try to get the attribute from the old data, but don't worry if we can't,

```

```

134         # because that means it's from an older version, so we can use the default
135         # values from `cls()`
136         try:
137             setattr(data, attr, getattr(file_data[1], attr))
138         except AttributeError:
139             pass
140
141     return file_data[0], data

```

## A.11 gui/\_\_init\_\_.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This package supplies the main GUI and associated dialogs for visualization."""
8
9  from . import dialogs, plots, session, settings, utility, validate
10 from .main_window import main
11
12 __all__ = ['dialogs', 'main', 'plots', 'session', 'settings', 'utility', 'validate']

```

## A.12 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 = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
31
32
33 def get_first_undefined_matrix(wrapper: MatrixWrapper) -> str:
34     """Return the letter of the first undefined matrix in the given wrapper, or ``A`` if all matrices are
35     ↪ defined."""
36     defined_matrices = [x for x, _ in wrapper.get_defined_matrices()]
37     for letter in _ALPHABET_NO_I:
38         if letter not in defined_matrices:
39             return letter
40
41     return 'A'

```

```

42
43 class DefineMatrixDialog(FixedSizeDialog):
44     """An abstract superclass for definitions dialogs.
45
46     .. warning:: This class should never be directly instantiated, only subclassed.
47     """
48
49     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
50         """Create the widgets and layout of the dialog.
51
52         .. note:: ``*args`` and ``**kwargs`` are passed to the super constructor (:class:`QDialog`).
53
54         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
55         """
56         super().__init__(*args, **kwargs)
57
58         self.matrix_wrapper = matrix_wrapper
59         self.setWindowTitle('Define a matrix')
60
61         # === Create the widgets
62
63         self._button_confirm = QPushButton(self)
64         self._button_confirm.setText('Confirm')
65         self._button_confirm.setEnabled(False)
66         self._button_confirm.clicked.connect(self._confirm_matrix)
67         self._button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
68         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_confirm.click)
69
70         button_cancel = QPushButton(self)
71         button_cancel.setText('Cancel')
72         button_cancel.clicked.connect(self.reject)
73         button_cancel.setToolTip('Cancel this definition<br><b>(Escape)</b>')
74
75         label_equals = QLabel(self)
76         label_equals.setText('=')
77
78         self._combobox_letter = QtWidgets.QComboBox(self)
79
80         for letter in _ALPHABET_NO_I:
81             self._combobox_letter.addItem(letter)
82
83         self._combobox_letter.activated.connect(self._load_matrix)
84         self._combobox_letter.setCurrentText(get_first_undefined_matrix(self.matrix_wrapper))
85
86         # === Arrange the widgets
87
88         self.setContentsMargins(10, 10, 10, 10)
89
90         self._hlay_buttons = QHBoxLayout()
91         self._hlay_buttons.setSpacing(20)
92         self._hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
93         self._hlay_buttons.addWidget(button_cancel)
94         self._hlay_buttons.addWidget(self._button_confirm)
95
96         self._hlay_definition = QHBoxLayout()
97         self._hlay_definition.setSpacing(20)
98         self._hlay_definition.addWidget(self._combobox_letter)
99         self._hlay_definition.addWidget(label_equals)
100
101         # All subclasses have to manually add the hlay layouts to _vlay_all
102         # This is because the subclasses add their own widgets and if we add
103         # the layout here, then these new widgets won't be included
104         self._vlay_all = QVBoxLayout()
105         self._vlay_all.setSpacing(20)
106
107         self.setLayout(self._vlay_all)
108
109     @property
110     def _selected_letter(self) -> str:
111         """Return the letter currently selected in the combo box."""
112         return str(self._combobox_letter.currentText())
113
114     @abc.abstractmethod

```

```

115     @pyqtSlot()
116     def _update_confirm_button(self) -> None:
117         """Enable the confirm button if it should be enabled, else, disable it."""
118
119     @pyqtSlot(int)
120     def _load_matrix(self, index: int) -> None:
121         """Load the selected matrix into the dialog.
122
123         This method is optionally able to be overridden. If it is not overridden,
124         then no matrix is loaded when selecting a name.
125
126         We have this method in the superclass so that we can define it as the slot
127         for the :meth:`QComboBox.activated` signal in this constructor, rather than
128         having to define that in the constructor of every subclass.
129         """
130
131     @abc.abstractmethod
132     @pyqtSlot()
133     def _confirm_matrix(self) -> None:
134         """Confirm the inputted matrix and assign it.
135
136         .. note:: When subclassing, this method should mutate ``self.matrix_wrapper`` and then call
137         ↩ ``self.accept()``.
138         """
139
140 class DefineVisuallyDialog(DefineMatrixDialog):
141     """The dialog class that allows the user to define a matrix visually."""
142
143     def __init__(
144         self,
145         *args,
146         matrix_wrapper: MatrixWrapper,
147         display_settings: DisplaySettings,
148         polygon_points: List[Tuple[float, float]],
149         input_vector: Tuple[float, float],
150         **kwargs
151     ):
152         """Create the widgets and layout of the dialog.
153
154         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
155         """
156         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
157
158         self.setMinimumSize(700, 550)
159
160         # === Create the widgets
161
162         self._plot = DefineMatrixVisuallyWidget(
163             self,
164             display_settings=display_settings,
165             polygon_points=polygon_points,
166             input_vector=input_vector
167         )
168
169         # === Arrange the widgets
170
171         self._hlay_definition.addWidget(self._plot)
172         self._hlay_definition.setStretchFactor(self._plot, 1)
173
174         self._vlay_all.addLayout(self._hlay_definition)
175         self._vlay_all.addLayout(self._hlay_buttons)
176
177         # We load the default matrix A into the plot
178         self._load_matrix(0)
179
180         # We also enable the confirm button, because any visually defined matrix is valid
181         self._button_confirm.setEnabled(True)
182
183     @pyqtSlot()
184     def _update_confirm_button(self) -> None:
185         """Enable the confirm button.
186

```

```

187     .. note::
188         The confirm button is always enabled in this dialog and this method is never actually used,
189         so it's got an empty body. It's only here because we need to implement the abstract method.
190     """
191
192     @pyqtSlot(int)
193     def _load_matrix(self, index: int) -> None:
194         """Show the selected matrix on the plot. If the matrix is None, show the identity."""
195         matrix = self.matrix_wrapper[self._selected_letter]
196
197         if matrix is None:
198             self._plot.plot_matrix(eye(2))
199         else:
200             self._plot.plot_matrix(matrix)
201
202         self._plot.update()
203
204     @pyqtSlot()
205     def _confirm_matrix(self) -> None:
206         """Confirm the matrix that's been defined visually."""
207         matrix: MatrixType = array([
208             [self._plot.point_i[0], self._plot.point_j[0]],
209             [self._plot.point_i[1], self._plot.point_j[1]]
210         ])
211
212         self.matrix_wrapper[self._selected_letter] = matrix
213         self.accept()
214
215
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(0)
277
278     self._element_tl.setFocus()
279
280 @pyqtSlot()
281 def _update_confirm_button(self) -> None:
282     """Enable the confirm button if there are valid floats in every box."""
283     for elem in self._matrix_elements:
284         if not is_valid_float(elem.text()):
285             # If they're not all numbers, then we can't confirm it
286             self._button_confirm.setEnabled(False)
287             return
288
289     # If we didn't find anything invalid
290     self._button_confirm.setEnabled(True)
291
292 @pyqtSlot(int)
293 def _load_matrix(self, index: int) -> None:
294     """If the selected matrix is defined, load its values into the boxes."""
295     matrix = self.matrix_wrapper[self._selected_letter]
296
297     if matrix is None:
298         for elem in self._matrix_elements:
299             elem.setText('')
300
301     else:
302         self._element_tl.setText(round_float(matrix[0][0]))
303         self._element_tr.setText(round_float(matrix[0][1]))
304         self._element_bl.setText(round_float(matrix[1][0]))
305         self._element_br.setText(round_float(matrix[1][1]))
306
307     self._update_confirm_button()
308
309 @pyqtSlot()
310 def _confirm_matrix(self) -> None:
311     """Confirm the matrix in the boxes and assign it to the name in the combo box."""
312     matrix: MatrixType = array([
313         [float(self._element_tl.text()), float(self._element_tr.text())],
314         [float(self._element_bl.text()), float(self._element_br.text())]
315     ])
316
317     self.matrix_wrapper[self._selected_letter] = matrix
318     self.accept()
319
320
321 class DefineAsExpressionDialog(DefineMatrixDialog):
322     """The dialog class that allows the user to define a matrix as an expression of other matrices."""
323
324     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
325         """Create the widgets and layout of the dialog.
326
327         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
328         """
329         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
330
331         self.setMinimumWidth(450)
332

```

```

333         # === Create the widgets
334
335         self._lineEdit_expression_box = QLineEdit(self)
336         self._lineEdit_expression_box.setPlaceholderText('Enter matrix expression...')
337         self._lineEdit_expression_box.textChanged.connect(self._update_confirm_button)
338         self._lineEdit_expression_box.setValidator(MatrixExpressionValidator())
339
340         # === Arrange the widgets
341
342         self._hlay_definition.addWidget(self._lineEdit_expression_box)
343
344         self._vlay_all.addLayout(self._hlay_definition)
345         self._vlay_all.addLayout(self._hlay_buttons)
346
347         # Load the matrix if it's defined as an expression
348         self._load_matrix(0)
349
350         self._lineEdit_expression_box.setFocus()
351
352     @pyqtSlot()
353     def _update_confirm_button(self) -> None:
354         """Enable the confirm button if the matrix expression is valid in the wrapper."""
355         text = self._lineEdit_expression_box.text()
356         valid_expression = self.matrix_wrapper.is_valid_expression(text)
357
358         self._button_confirm.setEnabled(
359             valid_expression
360             and self._selected_letter not in text
361             and self._selected_letter not in self.matrix_wrapper.get_expression_dependencies(text)
362         )
363
364     @pyqtSlot(int)
365     def _load_matrix(self, index: int) -> None:
366         """If the selected matrix is defined an expression, load that expression into the box."""
367         if (expr := self.matrix_wrapper.get_expression(self._selected_letter)) is not None:
368             self._lineEdit_expression_box.setText(expr)
369         else:
370             self._lineEdit_expression_box.setText('')
371
372     @pyqtSlot()
373     def _confirm_matrix(self) -> None:
374         """Evaluate the matrix expression and assign its value to the name in the combo box."""
375         self.matrix_wrapper[self._selected_letter] = self._lineEdit_expression_box.text()
376         self.accept()

```

## A.13 gui/dialogs/settings.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides dialogs to edit settings within the app."""
8
9  from __future__ import annotations
10
11  import abc
12  from typing import Dict
13
14  from PyQt5 import QtWidgets
15  from PyQt5.QtCore import Qt
16  from PyQt5.QtGui import (QDoubleValidator, QIntValidator, QKeyEvent,
17                           QKeySequence)
18  from PyQt5.QtWidgets import (QCheckBox, QGroupBox, QHBoxLayout, QLabel,
19                              QLayout, QLineEdit, QRadioButton, QShortcut,
20                              QSizePolicy, QSpacerItem, QVBoxLayout)
21
22  from lintrans.global_settings import (GlobalSettings, GlobalSettingsData,
23                                       UpdateType)

```

```

24 from lintrans.gui.dialogs.misc import FixedSizeDialog
25 from lintrans.gui.settings import DisplaySettings
26
27
28 class SettingsDialog(FixedSizeDialog):
29     """An abstract superclass for other simple dialogs."""
30
31     def __init__(self, *args, resettable: bool, **kwargs):
32         """Create the widgets and layout of the dialog, passing ``*args`` and ``**kwargs`` to super."""
33         super().__init__(*args, **kwargs)
34
35         # === Create the widgets
36
37         self._button_confirm = QtWidgets.QPushButton(self)
38         self._button_confirm.setText('Confirm')
39         self._button_confirm.clicked.connect(self._confirm_settings)
40         self._button_confirm.setToolTip('Confirm these new settings<br><b>(Ctrl + Enter)</b>')
41         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self._button_confirm.click)
42
43         self._button_cancel = QtWidgets.QPushButton(self)
44         self._button_cancel.setText('Cancel')
45         self._button_cancel.clicked.connect(self.reject)
46         self._button_cancel.setToolTip('Revert these settings<br><b>(Escape)</b>')
47
48         if resettable:
49             self._button_reset = QtWidgets.QPushButton(self)
50             self._button_reset.setText('Reset to defaults')
51             self._button_reset.clicked.connect(self._reset_settings)
52             self._button_reset.setToolTip('Reset these settings to their defaults<br><b>(Ctrl + R)</b>')
53             QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(self._button_reset.click)
54
55         # === Arrange the widgets
56
57         self.setContentsMargins(10, 10, 10, 10)
58
59         self._hlay_buttons = QHBoxLayout()
60         self._hlay_buttons.setSpacing(20)
61
62         if resettable:
63             self._hlay_buttons.addWidget(self._button_reset)
64
65         self._hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
66         self._hlay_buttons.addWidget(self._button_cancel)
67         self._hlay_buttons.addWidget(self._button_confirm)
68
69     def _setup_layout(self, options_layout: QLayout) -> None:
70         """Set the layout of the settings widget.
71
72         .. note:: This method must be called at the end of :meth:``__init__``
73            in subclasses to setup the layout properly.
74         """
75         vlay_all = QVBoxLayout()
76         vlay_all.setSpacing(20)
77         vlay_all.addLayout(options_layout)
78         vlay_all.addLayout(self._hlay_buttons)
79
80         self.setLayout(vlay_all)
81
82     @abc.abstractmethod
83     def _load_settings(self) -> None:
84         """Load the current settings into the widgets."""
85
86     @abc.abstractmethod
87     def _confirm_settings(self) -> None:
88         """Confirm the settings chosen in the dialog."""
89
90     def _reset_settings(self) -> None:
91         """Reset the settings.
92
93         .. note:: This method is empty but not abstract because not all subclasses will need to implement it.
94         """
95
96

```



```

97 class DisplaySettingsDialog(SettingsDialog):
98     """The dialog to allow the user to edit the display settings."""
99
100     def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
101         """Create the widgets and layout of the dialog.
102
103         :param DisplaySettings display_settings: The :class:`~lintrans.gui.settings.DisplaySettings` object to
104         ↪ mutate
105         """
106         super().__init__(*args, resettable=True, **kwargs)
107
108         self.display_settings = display_settings
109         self.setWindowTitle('Change display settings')
110
111         self._dict_checkboxes: Dict[str, QCheckBox] = {}
112
113         # === Create the widgets
114
115         # Basic stuff
116
117         self._checkbox_draw_background_grid = QCheckBox(self)
118         self._checkbox_draw_background_grid.setText('Draw &background grid')
119         self._checkbox_draw_background_grid.setToolTip(
120             'Draw the background grid (axes are always drawn)'
121         )
122         self._dict_checkboxes['b'] = self._checkbox_draw_background_grid
123
124         self._checkbox_draw_transformed_grid = QCheckBox(self)
125         self._checkbox_draw_transformed_grid.setText('Draw t&ransformed grid')
126         self._checkbox_draw_transformed_grid.setToolTip(
127             'Draw the transformed grid (vectors are handled separately)'
128         )
129         self._dict_checkboxes['r'] = self._checkbox_draw_transformed_grid
130
131         self._checkbox_draw_basis_vectors = QCheckBox(self)
132         self._checkbox_draw_basis_vectors.setText('Draw basis &vectors')
133         self._checkbox_draw_basis_vectors.setToolTip(
134             'Draw the transformed basis vectors'
135         )
136         self._checkbox_draw_basis_vectors.clicked.connect(self._update_gui)
137         self._dict_checkboxes['v'] = self._checkbox_draw_basis_vectors
138
139         self._checkbox_label_basis_vectors = QCheckBox(self)
140         self._checkbox_label_basis_vectors.setText('Label the bas&is vectors')
141         self._checkbox_label_basis_vectors.setToolTip(
142             'Label the transformed i and j basis vectors'
143         )
144         self._dict_checkboxes['i'] = self._checkbox_label_basis_vectors
145
146         # Animations
147
148         self._checkbox_smooththen_determinant = QCheckBox(self)
149         self._checkbox_smooththen_determinant.setText('&Smoothen determinant')
150         self._checkbox_smooththen_determinant.setToolTip(
151             'Smoothly animate the determinant transition during animation (if possible)'
152         )
153         self._dict_checkboxes['s'] = self._checkbox_smooththen_determinant
154
155         self._checkbox_applicative_animation = QCheckBox(self)
156         self._checkbox_applicative_animation.setText('&Applicative animation')
157         self._checkbox_applicative_animation.setToolTip(
158             'Animate the new transformation applied to the current one,\n'
159             'rather than just that transformation on its own'
160         )
161         self._dict_checkboxes['a'] = self._checkbox_applicative_animation
162
163         label_animation_time = QLabel(self)
164         label_animation_time.setText('Total animation length (ms)')
165         label_animation_time.setToolTip(
166             'How long it takes for an animation to complete'
167         )
168
169         self._lineedit_animation_time = QLineEdit(self)

```

```

169     self._lineEdit_animation_time.setValidator(QIntValidator(1, 9999, self))
170     self._lineEdit_animation_time.textChanged.connect(self._update_gui)
171
172     label_animation_pause_length = QLabel(self)
173     label_animation_pause_length.setText('Animation pause length (ms)')
174     label_animation_pause_length.setToolTip(
175         'How many milliseconds to pause for in comma-separated animations'
176     )
177
178     self._lineEdit_animation_pause_length = QLineEdit(self)
179     self._lineEdit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
180
181     # Matrix info
182
183     self._checkbox_draw_determinant_parallelogram = QCheckBox(self)
184     self._checkbox_draw_determinant_parallelogram.setText('Draw &determinant parallelogram')
185     self._checkbox_draw_determinant_parallelogram.setToolTip(
186         'Shade the parallelogram representing the determinant of the matrix'
187     )
188     self._checkbox_draw_determinant_parallelogram.clicked.connect(self._update_gui)
189     self._dict_checkboxes['d'] = self._checkbox_draw_determinant_parallelogram
190
191     self._checkbox_show_determinant_value = QCheckBox(self)
192     self._checkbox_show_determinant_value.setText('Show 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_smooththen_determinant)
259     vlay_groupbox_animations.addWidget(self._checkbox_applicative_animation)
260     vlay_groupbox_animations.addLayout(hlay_animation_time)
261     vlay_groupbox_animations.addLayout(hlay_animation_pause_length)
262
263     groupbox_animations = QGroupBox('Animations', self)
264     groupbox_animations.setLayout(vlay_groupbox_animations)
265
266     # Matrix info
267
268     vlay_groupbox_matrix_info = QVBoxLayout()
269     vlay_groupbox_matrix_info.setSpacing(20)
270     vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_determinant_parallelogram)
271     vlay_groupbox_matrix_info.addWidget(self._checkbox_show_determinant_value)
272     vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_eigenvectors)
273     vlay_groupbox_matrix_info.addWidget(self._checkbox_draw_eigenlines)
274
275     groupbox_matrix_info = QGroupBox('Matrix info', self)
276     groupbox_matrix_info.setLayout(vlay_groupbox_matrix_info)
277
278     # Polygon
279
280     vlay_groupbox_polygon = QVBoxLayout()
281     vlay_groupbox_polygon.setSpacing(20)
282     vlay_groupbox_polygon.addWidget(self._checkbox_draw_untransformed_polygon)
283     vlay_groupbox_polygon.addWidget(self._checkbox_draw_transformed_polygon)
284
285     groupbox_polygon = QGroupBox('Polygon', self)
286     groupbox_polygon.setLayout(vlay_groupbox_polygon)
287
288     # Input/output vectors
289
290     vlay_groupbox_io_vectors = QVBoxLayout()
291     vlay_groupbox_io_vectors.setSpacing(20)
292     vlay_groupbox_io_vectors.addWidget(self._checkbox_draw_input_vector)
293     vlay_groupbox_io_vectors.addWidget(self._checkbox_draw_output_vector)
294
295     groupbox_io_vectors = QGroupBox('Input/output vectors', self)
296     groupbox_io_vectors.setLayout(vlay_groupbox_io_vectors)
297
298     # Now arrange the groupboxes
299     vlay_left = QVBoxLayout()
300     vlay_left.setSpacing(20)
301     vlay_left.addWidget(groupbox_basic_stuff)
302     vlay_left.addWidget(groupbox_animations)
303
304     vlay_right = QVBoxLayout()
305     vlay_right.setSpacing(20)
306     vlay_right.addWidget(groupbox_matrix_info)
307     vlay_right.addWidget(groupbox_polygon)
308     vlay_right.addWidget(groupbox_io_vectors)
309
310     options_layout = QHBoxLayout()
311     options_layout.setSpacing(20)
312     options_layout.addLayout(vlay_left)
313     options_layout.addLayout(vlay_right)
314
```

```

315         self._setup_layout(options_layout)
316
317         # Finally, we load the current settings and update the GUI
318         self._load_settings()
319         self._update_gui()
320
321     def _load_settings(self) -> None:
322         """Load the current display settings into the widgets."""
323         # Basic stuff
324         self._checkboxbox_draw_background_grid.setChecked(self.display_settings.draw_background_grid)
325         self._checkboxbox_draw_transformed_grid.setChecked(self.display_settings.draw_transformed_grid)
326         self._checkboxbox_draw_basis_vectors.setChecked(self.display_settings.draw_basis_vectors)
327         self._checkboxbox_label_basis_vectors.setChecked(self.display_settings.label_basis_vectors)
328
329         # Animations
330         self._checkboxbox_smooththen_determinant.setChecked(self.display_settings.smoothen_determinant)
331         self._checkboxbox_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._checkboxbox_draw_determinant_parallelogram.setChecked(
337             self.display_settings.draw_determinant_parallelogram)
338         self._checkboxbox_show_determinant_value.setChecked(self.display_settings.show_determinant_value)
339         self._checkboxbox_draw_eigenvectors.setChecked(self.display_settings.draw_eigenvectors)
340         self._checkboxbox_draw_eigenlines.setChecked(self.display_settings.draw_eigenlines)
341
342         # Polygon
343         self._checkboxbox_draw_untransformed_polygon.setChecked(self.display_settings.draw_untransformed_polygon)
344         self._checkboxbox_draw_transformed_polygon.setChecked(self.display_settings.draw_transformed_polygon)
345
346         # Input/output vectors
347         self._checkboxbox_draw_input_vector.setChecked(self.display_settings.draw_input_vector)
348         self._checkboxbox_draw_output_vector.setChecked(self.display_settings.draw_output_vector)
349
350     def _confirm_settings(self) -> None:
351         """Build a :class:`~lintrans.gui.settings.DisplaySettings` object and assign it."""
352         # Basic stuff
353         self.display_settings.draw_background_grid = self._checkboxbox_draw_background_grid.isChecked()
354         self.display_settings.draw_transformed_grid = self._checkboxbox_draw_transformed_grid.isChecked()
355         self.display_settings.draw_basis_vectors = self._checkboxbox_draw_basis_vectors.isChecked()
356         self.display_settings.label_basis_vectors = self._checkboxbox_label_basis_vectors.isChecked()
357
358         # Animations
359         self.display_settings.smoothen_determinant = self._checkboxbox_smooththen_determinant.isChecked()
360         self.display_settings.applicative_animation = self._checkboxbox_applicative_animation.isChecked()
361         self.display_settings.animation_time = int(self._lineedit_animation_time.text())
362         self.display_settings.animation_pause_length = int(self._lineedit_animation_pause_length.text())
363
364         # Matrix info
365         self.display_settings.draw_determinant_parallelogram =
366             self._checkboxbox_draw_determinant_parallelogram.isChecked()
367         self.display_settings.show_determinant_value = self._checkboxbox_show_determinant_value.isChecked()
368         self.display_settings.draw_eigenvectors = self._checkboxbox_draw_eigenvectors.isChecked()
369         self.display_settings.draw_eigenlines = self._checkboxbox_draw_eigenlines.isChecked()
370
371         # Polygon
372         self.display_settings.draw_untransformed_polygon = self._checkboxbox_draw_untransformed_polygon.isChecked()
373         self.display_settings.draw_transformed_polygon = self._checkboxbox_draw_transformed_polygon.isChecked()
374
375         # Input/output vectors
376         self.display_settings.draw_input_vector = self._checkboxbox_draw_input_vector.isChecked()
377         self.display_settings.draw_output_vector = self._checkboxbox_draw_output_vector.isChecked()
378
379         self.accept()
380
381     def _reset_settings(self) -> None:
382         """Reset the display settings to their defaults."""
383         self.display_settings = DisplaySettings()
384         self._load_settings()
385         self._update_gui()
386
387     def _update_gui(self) -> None:

```

```

386         """Update the GUI according to other widgets in the GUI.
387
388         For example, this method updates which checkboxes are enabled based on the values of other checkboxes.
389         """
390         self._checkbox_show_determinant_value.setEnabled(self._checkbox_draw_determinant_parallelogram.isChecked())
391         self._checkbox_label_basis_vectors.setEnabled(self._checkbox_draw_basis_vectors.isChecked())
392
393         try:
394             self._button_confirm.setEnabled(int(self._lineEdit_animation_time.text()) >= 10)
395         except ValueError:
396             self._button_confirm.setEnabled(False)
397
398     def keyPressEvent(self, event: QKeyEvent) -> None:
399         """Handle a :class:`QKeyEvent` by manually activating toggling checkboxes.
400
401         Qt handles these shortcuts automatically and allows the user to do ``Alt + Key``
402         to activate a simple shortcut defined with ``&``. However, I like to be able to
403         just hit ``Key`` and have the shortcut activate.
404         """
405         letter = event.text().lower()
406         key = event.key()
407
408         if letter in self._dict_checkboxes:
409             self._dict_checkboxes[letter].animateClick()
410
411         # Return or keypad enter
412         elif key == Qt.Key_Return or key == Qt.Key_Enter:
413             self._button_confirm.click()
414
415         # Escape
416         elif key == Qt.Key_Escape:
417             self._button_cancel.click()
418
419         else:
420             event.ignore()
421             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 distacne (in grid units) that a draggable point '
465             'must be from an integer coordinate to snap to it'
466         )
467
468         self._lineedit_snap_dist = QLineEdit(self)
469         self._lineedit_snap_dist.setValidator(QDoubleValidator(0.0, 0.99, 2, self))
470         self._lineedit_snap_dist.setText(str(self._data.snap_dist))
471         self._lineedit_snap_dist.textChanged.connect(self._update_gui)
472
473         # === Arrange the widgets
474
475         vlay_update_type = QVBoxLayout()
476         vlay_update_type.addWidget(self._radio_button_auto)
477         vlay_update_type.addWidget(self._radio_button_prompt)
478         vlay_update_type.addWidget(self._radio_button_never)
479         groupbox_update_types.setLayout(vlay_update_type)
480
481         hlay_cursor_epsilon = QHBoxLayout()
482         hlay_cursor_epsilon.addWidget(label_cursor_epsilon)
483         hlay_cursor_epsilon.addWidget(self._lineedit_cursor_epsilon)
484
485         hlay_snap_dist = QHBoxLayout()
486         hlay_snap_dist.addWidget(label_snap_dist)
487         hlay_snap_dist.addWidget(self._lineedit_snap_dist)
488
489         vlay_dist = QVBoxLayout()
490         vlay_dist.setSpacing(20)
491         vlay_dist.addLayout(hlay_cursor_epsilon)
492         vlay_dist.addWidget(self._checkbox_snap_to_int_coords)
493         vlay_dist.addLayout(hlay_snap_dist)
494
495         groupbox_dist = QGroupBox('Distances', self)
496         groupbox_dist.setLayout(vlay_dist)
497
498         options_layout = QVBoxLayout()
499         options_layout.setSpacing(20)
500         options_layout.addWidget(groupbox_update_types)
501         options_layout.addWidget(groupbox_dist)
502
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._lineedit_snap_dist.setEnabled(self._checkbox_snap_to_int_coords.isChecked())
520         self._button_confirm.setEnabled(cursor_epsilon and snap_dist)
521
522     def _load_settings(self) -> None:
523         """Load the current display settings into the widgets."""
524         if self._data.update_type == UpdateType.auto:
525             self._radio_button_auto.setChecked(True)
526         elif self._data.update_type == UpdateType.prompt:
527             self._radio_button_prompt.setChecked(True)
528         elif self._data.update_type == UpdateType.never:
529             self._radio_button_never.setChecked(True)
530
531         self._lineedit_cursor_epsilon.setText(str(self._data.cursor_epsilon))

```

```

532         self._checkbox_snap_to_int_coords.setChecked(self._data.snap_to_int_coords)
533         self._lineedit_snap_dist.setText(str(self._data.snap_dist))
534
535     def _confirm_settings(self) -> None:
536         """Set the global settings."""
537         if self._radio_button_auto.isChecked():
538             self._data.update_type = UpdateType.auto
539         elif self._radio_button_prompt.isChecked():
540             self._data.update_type = UpdateType.prompt
541         elif self._radio_button_never.isChecked():
542             self._data.update_type = UpdateType.never
543
544         self._data.cursor_epsilon = int(self._lineedit_cursor_epsilon.text())
545         self._data.snap_to_int_coords = self._checkbox_snap_to_int_coords.isChecked()
546         self._data.snap_dist = float(self._lineedit_snap_dist.text())
547
548         GlobalSettings().set_data(self._data)
549
550         self.accept()
551
552     def _reset_settings(self) -> None:
553         """Reset the internal data values to their defaults."""
554         self._data = GlobalSettingsData()
555         self._load_settings()
556         self._update_gui()

```

## A.14 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 :c++: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
64             label_title = QLabel(self)
65             label_title.setText(f'lintrans (version {lintrans.__version__})')
66             label_title.setAlignment(Qt.AlignCenter)
67
68             font_title = label_title.font()
69             font_title.setPointSize(font_title.pointSize() * 2)
70             label_title.setFont(font_title)
71
72             label_version_info = QLabel(self)
73             label_version_info.setText(
74                 f'With Python version {platform.python_version()}\n'
75                 f'Qt version {QT_VERSION_STR} and PyQt5 version {PYQT_VERSION_STR}\n'
76                 f'Running on {platform.platform()}'
77             )
78             label_version_info.setAlignment(Qt.AlignCenter)
79
80             label_info = QLabel(self)
81             label_info.setText(
82                 'lintrans is a program designed to help visualise<br>'
83                 '2D linear transformations represented with matrices.<br>'
84                 'It's designed for teachers and students and all feedback<br>'
85                 'is greatly appreciated. Go to <em>Help</em> &gt; <em>Give feedback</em><br>'
86                 'to report a bug or suggest a new feature, or you can<br>email me directly at '
87                 '<a href="mailto:dyson.dyson@icloud.com" style="color: black;">dyson.dyson@icloud.com</a>.'
88             )
89             label_info.setAlignment(Qt.AlignCenter)
90             label_info.setTextFormat(Qt.RichText)
91             label_info.setOpenExternalLinks(True)
92
93             label_copyright = QLabel(self)
94             label_copyright.setText(
95                 'This program is free software.<br>Copyright 2021-2022 D. Dyson (DoctorDalek1963).<br>'
96                 'This program is licensed under GPLv3, which can be found '
97                 '<a href="https://www.gnu.org/licenses/gpl-3.0.html" style="color: black;">here</a>.'
98             )
99             label_copyright.setAlignment(Qt.AlignCenter)
100             label_copyright.setTextFormat(Qt.RichText)
101             label_copyright.setOpenExternalLinks(True)
102
103             # === Arrange the widgets
104
105             self.setContentsMargins(10, 10, 10, 10)
106
107             vlay = QVBoxLayout()
108             vlay.setSpacing(20)
109             vlay.addWidget(label_title)
110             vlay.addWidget(label_version_info)
111             vlay.addWidget(label_info)
112             vlay.addWidget(label_copyright)
113
114             self.setLayout(vlay)

```



```

115
116 class InfoPanelDialog(FixedSizeDialog):
117     """A simple dialog class to display an info panel that shows all currently defined matrices."""
118
119     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
120         """Create the dialog box with all the widgets needed to show the information."""
121         super().__init__(*args, **kwargs)
122         self.matrix_wrapper = matrix_wrapper
123
124         self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
125             name: value
126             for name, value in self.matrix_wrapper.get_defined_matrices()
127         }
128
129         self.setWindowTitle('Defined matrices')
130         self.setContentsMargins(10, 10, 10, 10)
131
132         self._stacked_layout = QStackedLayout(self)
133         self.setLayout(self._stacked_layout)
134
135         self._draw_ui()
136
137     def _draw_ui(self) -> None:
138         grid_layout = QGridLayout()
139         grid_layout.setSpacing(20)
140
141         for i, (name, value) in enumerate(self._matrices.items()):
142             if value is None:
143                 continue
144
145             grid_layout.addWidget(
146                 self._get_full_matrix_widget(name, value),
147                 i % 4,
148                 i // 4,
149                 Qt.AlignCenter
150             )
151
152             container = QWidget(self)
153             container.setLayout(grid_layout)
154             self._stacked_layout.setCurrentIndex(self._stacked_layout.addWidget(container))
155
156     def _undefine_matrix(self, name: str) -> None:
157         """Undefine the given matrix and redraw the dialog."""
158         for x in self.matrix_wrapper.undefine_matrix(name):
159             self._matrices[x] = None
160
161         self._draw_ui()
162
163     def _get_full_matrix_widget(self, name: str, value: Union[MatrixType, str]) -> QWidget:
164         """Return a :class:`QWidget` containing the whole matrix widget composition.
165
166         Each defined matrix will get a widget group. Each group will be a label for the name,
167         a label for '=', and a container widget to either show the matrix numerically, or to
168         show the expression that it's defined as.
169
170         See :meth:`_get_matrix_data_widget`.
171         """
172         bold_font = self.font()
173         bold_font.setBold(True)
174
175         label_name = QLabel(self)
176         label_name.setText(name)
177         label_name.setFont(bold_font)
178
179         widget_matrix = self._get_matrix_data_widget(value)
180
181         hlay = QHBoxLayout()
182         hlay.setSpacing(10)
183         hlay.addWidget(label_name)
184         hlay.addWidget(QLabel('=', self))
185         hlay.addWidget(widget_matrix)
186
187         vlay = QVBoxLayout()

```

```

188         vlay.setSpacing(10)
189         vlay.addLayout(hlay)
190
191         if name != 'I':
192             button_undefine = QPushButton(self)
193             button_undefine.setText('Undefine')
194             button_undefine.clicked.connect(lambda: self._undefine_matrix(name))
195
196         vlay.addWidget(button_undefine)
197
198         groupbox = QGroupBox(self)
199         groupbox.setContentsMargins(10, 10, 10, 10)
200         groupbox.setLayout(vlay)
201
202         lay = QVBoxLayout()
203         lay.setSpacing(0)
204         lay.addWidget(groupbox)
205
206         container = QWidget(self)
207         container.setLayout(lay)
208
209         return container
210
211     def _get_matrix_data_widget(self, matrix: Union[MatrixType, str]) -> QWidget:
212         """Return a :class:`QWidget` containing the value of the matrix.
213
214         If the matrix is defined as an expression, it will be a simple :class:`QLabel`.
215         If the matrix is defined as a matrix, it will be a :class:`QWidget` container
216         with multiple :class:`QLabel` objects in it.
217         """
218         if isinstance(matrix, str):
219             label = QLabel(self)
220             label.setText(matrix)
221             return label
222
223         elif is_matrix_type(matrix):
224             # tl = top left, br = bottom right, etc.
225             label_tl = QLabel(self)
226             label_tl.setText(round_float(matrix[0][0]))
227
228             label_tr = QLabel(self)
229             label_tr.setText(round_float(matrix[0][1]))
230
231             label_bl = QLabel(self)
232             label_bl.setText(round_float(matrix[1][0]))
233
234             label_br = QLabel(self)
235             label_br.setText(round_float(matrix[1][1]))
236
237             # The parens need to be bigger than the numbers, but increasing the font size also
238             # makes the font thicker, so we have to reduce the font weight by the same factor
239             font_parens = self.font()
240             font_parens.setPointSize(int(font_parens.pointSize() * 2.5))
241             font_parens.setWeight(int(font_parens.weight() / 2.5))
242
243             label_paren_left = QLabel(self)
244             label_paren_left.setText('(')
245             label_paren_left.setFont(font_parens)
246
247             label_paren_right = QLabel(self)
248             label_paren_right.setText(')')
249             label_paren_right.setFont(font_parens)
250
251             container = QWidget(self)
252             grid_layout = QGridLayout()
253
254             grid_layout.addWidget(label_paren_left, 0, 0, -1, 1)
255             grid_layout.addWidget(label_tl, 0, 1)
256             grid_layout.addWidget(label_tr, 0, 2)
257             grid_layout.addWidget(label_bl, 1, 1)
258             grid_layout.addWidget(label_br, 1, 2)
259             grid_layout.addWidget(label_paren_right, 0, 3, -1, 1)
260

```

```
261         container.setLayout(grid_layout)
262
263         return container
264
265         raise ValueError('Matrix was not MatrixType or str')
266
267
268 class FileSelectDialog(QFileDialog):
269     """A subclass of :class:`QFileDialog` that fixes an issue with the default suffix on UNIX platforms."""
270
271     def selectedFiles(self) -> List[str]:
272         """Return a list of strings containing the absolute paths of the selected files in the dialog.
273
274         There is an issue on UNIX platforms where a hidden directory will be recognised as a suffix.
275         For example, ``/home/dyson/.lintrans/saves/test`` should have ``.lt`` appended, but
276         ``.lintrans/saves/test`` gets recognised as the suffix, so the default suffix is not added.
277
278         To fix this, we just look at the basename and see if it needs a suffix added. We do this for
279         every name in the list, but there should be just one name, since this class is only intended
280         to be used for saving files. We still return the full list of filenames.
281         """
282         selected_files: List[str] = []
283
284         for filename in super().selectedFiles():
285             # path will be the full path of the file, without the extension
286             # This method understands hidden directories on UNIX platforms
287             path, ext = os.path.splitext(filename)
288
289             if ext == '':
290                 ext = '.' + self.defaultSuffix()
291
292             selected_files.append(''.join((path, ext)))
293
294         return selected_files
295
296
297 class DefinePolygonDialog(FixedSizeDialog):
298     """This dialog class allows the use to define a polygon with :class:`DefinePolygonWidget`."""
299
300     def __init__(self, *args, polygon_points: List[Tuple[float, float]], **kwargs) -> None:
301         """Create the dialog with the :class:`DefinePolygonWidget` widget."""
302         super().__init__(*args, **kwargs)
303
304         self.setWindowTitle('Define a polygon')
305         self.setMinimumSize(700, 550)
306
307         self.polygon_points = polygon_points
308
309         # === Create the widgets
310
311         self._polygon_widget = DefinePolygonWidget(polygon_points=polygon_points)
312
313         button_confirm = QPushButton(self)
314         button_confirm.setText('Confirm')
315         button_confirm.clicked.connect(self._confirm_polygon)
316         button_confirm.setToolTip('Confirm this polygon<br><b>(Ctrl + Enter)</b>')
317         QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(button_confirm.click)
318
319         button_cancel = QPushButton(self)
320         button_cancel.setText('Cancel')
321         button_cancel.clicked.connect(self.reject)
322         button_cancel.setToolTip('Discard this polygon<br><b>(Escape)</b>')
323
324         button_reset = QPushButton(self)
325         button_reset.setText('Reset polygon')
326         button_reset.clicked.connect(self._polygon_widget.reset_polygon)
327         button_reset.setToolTip('Remove all points of the polygon<br><b>(Ctrl + R)</b>')
328         QShortcut(QKeySequence('Ctrl+R'), self).activated.connect(button_reset.click)
329
330         # === Arrange the widgets
331
332         self.setContentsMargins(10, 10, 10, 10)
333
```

```

334         hlay_buttons = QHBoxLayout()
335         hlay_buttons.setSpacing(20)
336         hlay_buttons.addWidget(button_reset)
337         hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
338         hlay_buttons.addWidget(button_cancel)
339         hlay_buttons.addWidget(button_confirm)
340
341         vlay = QVBoxLayout()
342         vlay.setSpacing(20)
343         vlay.addWidget(self._polygon_widget)
344         vlay.addLayout(hlay_buttons)
345
346         self.setLayout(vlay)
347
348     @pyqtSlot()
349     def _confirm_polygon(self) -> None:
350         """Confirm the polygon that the user has defined."""
351         self.polygon_points = self._polygon_widget.points
352         self.accept()
353
354
355 class PromptUpdateDialog(FixedSizeDialog):
356     """A simple dialog to ask the user if they want to upgrade their lintrans installation."""
357
358     def __init__(self, *args, new_version: str, **kwargs) -> None:
359         """Create the dialog with all its widgets."""
360         super().__init__(*args, **kwargs)
361
362         if new_version.startswith('v'):
363             new_version = new_version[1:]
364
365         self.setWindowTitle('Update available')
366
367         # === Create the widgets
368
369         label_info = QLabel(self)
370         label_info.setText(
371             'A new version of lintrans is available!\n'
372             f'({lintrans.__version__} -> {new_version})\n\n'
373             'Would you like to update now?'
374         )
375         label_info.setAlignment(Qt.AlignCenter)
376
377         label_explanation = QLabel(self)
378         label_explanation.setText(
379             'The update will run silently in the background, so you can keep using lintrans uninterrupted.\n'
380             'You can change your choice at any time in File > Settings.'
381         )
382         label_explanation.setAlignment(Qt.AlignCenter)
383
384         font = label_explanation.font()
385         font.setPointSize(int(0.9 * font.pointSize()))
386         font.setItalic(True)
387         label_explanation.setFont(font)
388
389         groupbox_radio_buttons = QGroupBox(self)
390
391         self._radio_button_auto = QRadioButton('Always update automatically', groupbox_radio_buttons)
392         self._radio_button_prompt = QRadioButton('Always ask to update', groupbox_radio_buttons)
393         self._radio_button_never = QRadioButton('Never update', groupbox_radio_buttons)
394
395         # If this prompt is even appearing, then the update type must be 'prompt'
396         self._radio_button_prompt.setChecked(True)
397
398         button_remind_me_later = QPushButton('Remind me later', self)
399         button_remind_me_later.clicked.connect(lambda: self._save_choice_and_update(False))
400         button_remind_me_later.setShortcut(Qt.Key_Escape)
401         button_remind_me_later.setFocus()
402
403         button_update_now = QPushButton('Update now', self)
404         button_update_now.clicked.connect(lambda: self._save_choice_and_update(True))
405
406         # === Arrange the widgets

```

```

407
408         self.setContentsMargins(10, 10, 10, 10)
409
410         hlay_buttons = QHBoxLayout()
411         hlay_buttons.setSpacing(20)
412         hlay_buttons.addWidget(button_remind_me_later)
413         hlay_buttons.addWidget(button_update_now)
414
415         vlay = QVBoxLayout()
416         vlay.setSpacing(20)
417         vlay.addWidget(label_info)
418
419         vlay_radio_buttons = QVBoxLayout()
420         vlay_radio_buttons.setSpacing(10)
421         vlay_radio_buttons.addWidget(self._radio_button_auto)
422         vlay_radio_buttons.addWidget(self._radio_button_prompt)
423         vlay_radio_buttons.addWidget(self._radio_button_never)
424
425         groupbox_radio_buttons.setLayout(vlay_radio_buttons)
426
427         vlay.addWidget(groupbox_radio_buttons)
428         vlay.addWidget(label_explanation)
429         vlay.addLayout(hlay_buttons)
430
431         self.setLayout(vlay)
432
433     def _save_choice_and_update(self, update_now: bool) -> None:
434         """Save the user's choice of how to update and optionally trigger an update now."""
435         gs = GlobalSettings()
436         if self._radio_button_auto.isChecked():
437             gs.set_update_type(UpdateType.auto)
438
439         elif self._radio_button_prompt.isChecked():
440             gs.set_update_type(UpdateType.prompt)
441
442         elif self._radio_button_never.isChecked():
443             gs.set_update_type(UpdateType.never)
444
445         if update_now:
446             # We don't need to check because we'll only get here if we know a new version is available
447             update_lintrans_in_background(check=False)
448             self.accept()
449         else:
450             self.reject()

```

## A.15 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.16 gui/plots/widgets.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides the actual widgets that can be used to visualize transformations in the GUI."""
8
9  from __future__ import annotations
10
11  import operator
12  from abc import abstractmethod
13  from copy import copy
14  from math import dist
15  from typing import List, Optional, Tuple
16
17  from PyQt5.QtCore import QPointF, Qt, pyqtSlot
18  from PyQt5.QtGui import QBrush, QColor, QMouseEvent, QPainter, QPaintEvent,
19      QPen, QPolygonF
20
21  from lintrans.global_settings import GlobalSettings
22  from lintrans.gui.settings import DisplaySettings
23  from lintrans.typing_ import MatrixType
24
25  from .classes import InteractivePlot, VisualizeTransformationPlot
26
27
28  class VisualizeTransformationWidget(VisualizeTransformationPlot):
29      """This widget is used in the main window to visualize transformations.
30
31      It handles all the rendering itself, and the only method that the user needs to care about
32      is :meth:`plot_matrix`, which allows you to visualize the given matrix transformation.
33      """
34
35      _COLOUR_OUTPUT_VECTOR = QColor('#f7c216')
36
37      def __init__(self, *args, display_settings: DisplaySettings, polygon_points: List[Tuple[float, float]],
38          ↪ **kwargs):
39          """Create the widget and assign its display settings, passing ``*args`` and ``**kwargs`` to super."""
40          super().__init__(*args, **kwargs)
41
42          self.display_settings = display_settings
43          self.polygon_points = polygon_points
44
45      def plot_matrix(self, matrix: MatrixType) -> None:
46          """Plot the given matrix on the grid by setting the basis vectors.
47
48          .. warning:: This method does not call :meth:`QWidget.update()`. This must be done by the caller.
49
50          :param MatrixType matrix: The matrix to plot
51          """
52          self.point_i = (matrix[0][0], matrix[1][0])
53          self.point_j = (matrix[0][1], matrix[1][1])
54
55      def _draw_scene(self, painter: QPainter) -> None:
56          """Draw the default scene of the transformation.
57
58          This method exists to make it easier to split the main viewport from visual definitions while
59          not using multiple :class:`QPainter` objects from a single :meth:`paintEvent` call in a subclass.
60          """
61          painter.setRenderHint(QPainter.Antialiasing)
62          painter.setBrush(Qt.NoBrush)
63
64          self._draw_background(painter, self.display_settings.draw_background_grid)
65
66          if self.display_settings.draw_eigenlines:
67              self._draw_eigenlines(painter)
68
69          if self.display_settings.draw_eigenvectors:
70              self._draw_eigenvectors(painter)

```

```

70
71     if self.display_settings.draw_determinant_parallelogram:
72         self._draw_determinant_parallelogram(painter)
73
74     if self.display_settings.show_determinant_value:
75         self._draw_determinant_text(painter)
76
77     if self.display_settings.draw_transformed_grid:
78         self._draw_transformed_grid(painter)
79
80     if self.display_settings.draw_basis_vectors:
81         self._draw_basis_vectors(painter)
82
83     if self.display_settings.label_basis_vectors:
84         self._draw_basis_vector_labels(painter)
85
86     if self.display_settings.draw_untransformed_polygon:
87         self._draw_untransformed_polygon(painter)
88
89     if self.display_settings.draw_transformed_polygon:
90         self._draw_transformed_polygon(painter)
91
92     @abstractmethod
93     def paintEvent(self, event: QPaintEvent) -> None:
94         """Paint the scene of the transformation."""
95
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         """

```



```

216 def __init__(
217     self,
218     *args,
219     display_settings: DisplaySettings,
220     polygon_points: List[Tuple[float, float]],
221     input_vector: Tuple[float, float],
222     **kwargs
223 ) -> None:
224     """Create the widget and enable mouse tracking. ``*args`` and ``**kwargs`` are passed to ``super()``."""
225     super().__init__(*args, display_settings=display_settings, polygon_points=polygon_points, **kwargs)
226
227     self._input_vector = input_vector
228     self._dragged_point: Tuple[float, float] | None = None
229
230 def _draw_input_vector(self, painter: QPainter) -> None:
231     """Draw the input vector."""
232     color = QColor('#000000')
233     color.setAlpha(0x88)
234     pen = QPen(color, self._WIDTH_VECTOR_LINE)
235     painter.setPen(pen)
236
237     x, y = self.canvas_coords(*self._input_vector)
238     painter.drawLine(*self._canvas_origin, x, y)
239
240     painter.setBrush(self._BRUSH_SOLID_WHITE)
241     cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
242
243     painter.setPen(Qt.NoPen)
244     painter.drawPie(
245         x - cursor_epsilon,
246         y - cursor_epsilon,
247         2 * cursor_epsilon,
248         2 * cursor_epsilon,
249         0,
250         16 * 360
251     )
252
253     painter.setPen(pen)
254     painter.drawArc(
255         x - cursor_epsilon,
256         y - cursor_epsilon,
257         2 * cursor_epsilon,
258         2 * cursor_epsilon,
259         0,
260         16 * 360
261     )
262
263 def _draw_output_vector(self, painter: QPainter) -> None:
264     """Draw the output vector."""
265     color = copy(self._COLOUR_OUTPUT_VECTOR)
266     color.setAlpha(0x88)
267     painter.setPen(QPen(color, self._WIDTH_VECTOR_LINE))
268     painter.setBrush(QBrush(self._COLOUR_OUTPUT_VECTOR, Qt.SolidPattern))
269
270     x, y = self.canvas_coords(*(self._matrix @ self._input_vector))
271     cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
272
273     painter.drawLine(*self._canvas_origin, x, y)
274     painter.drawPie(
275         x - cursor_epsilon,
276         y - cursor_epsilon,
277         2 * cursor_epsilon,
278         2 * cursor_epsilon,
279         0,
280         16 * 360
281     )
282
283 def paintEvent(self, event: QPaintEvent) -> None:
284     """Paint the scene by just calling :meth:`_draw_scene`."""
285     painter = QPainter()
286     painter.begin(self)
287
288     self._draw_scene(painter)

```

```

289
290         if self.display_settings.draw_output_vector:
291             self._draw_output_vector(painter)
292
293         if self.display_settings.draw_input_vector:
294             self._draw_input_vector(painter)
295
296     painter.end()
297     event.accept()
298
299     def mousePressEvent(self, event: QMouseEvent) -> None:
300         """Set the dragged point if the cursor is within the cursor epsilon.
301
302         See :attr:`lintrans.global_settings.GlobalSettingsData.cursor_epsilon`.
303         """
304         cursor_pos = (event.x(), event.y())
305
306         if event.button() != Qt.LeftButton:
307             event.ignore()
308             return
309
310         for point in (self.point_i, self.point_j):
311             if self._is_within_epsilon(cursor_pos, point):
312                 self._dragged_point = point[0], point[1]
313
314         event.accept()
315
316     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
317         """Handle the mouse click being released by unsetting the dragged point."""
318         if event.button() == Qt.LeftButton:
319             self._dragged_point = None
320             event.accept()
321         else:
322             event.ignore()
323
324     def mouseMoveEvent(self, event: QMouseEvent) -> None:
325         """Handle the mouse moving on the canvas."""
326         if self._dragged_point is None:
327             event.ignore()
328             return
329
330         x, y = self._round_to_int_coord(self._grid_coords(event.x(), event.y()))
331
332         if self._dragged_point == self.point_i:
333             self.point_i = x, y
334
335         elif self._dragged_point == self.point_j:
336             self.point_j = x, y
337
338         self._dragged_point = x, y
339
340         self.update()
341         event.accept()
342
343
344     class DefinePolygonWidget(InteractivePlot):
345         """This widget allows the user to define a polygon by clicking and dragging points on the canvas."""
346
347         def __init__(self, *args, polygon_points: List[Tuple[float, float]], **kwargs):
348             """Create the widget with a list of points and a dragged point index."""
349             super().__init__(*args, **kwargs)
350
351             self._dragged_point_index: Optional[int] = None
352             self.points = polygon_points.copy()
353
354         @pyqtSlot()
355         def reset_polygon(self) -> None:
356             """Reset the polygon and update the widget."""
357             self.points = []
358             self.update()
359
360         def mousePressEvent(self, event: QMouseEvent) -> None:

```

```

361         """Handle the mouse being clicked by adding a point or setting the dragged point index to an existing
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:])) + \
398                 [(distances_to_point[-1], distances_to_point[0])]
399
400             # mypy doesn't like the use of sum for some reason. Just ignore it
401             point_triangle_lengths = map(sum, dist_to_point_pairs) # type: ignore[arg-type]
402
403             # The normalized distance is the sum of the distances to the ends of the line segment
404             # (point_triangle_lengths) divided by the length of the segment
405             normalized_distances = list(map(operator.truediv, point_triangle_lengths, segment_lengths))
406
407             # Get the best distance and insert this new point just after the point with that index
408             # This will put it in the middle of the closest line segment
409             best_distance = min(normalized_distances)
410             index = 1 + normalized_distances.index(best_distance)
411
412             self.points.insert(index, new_point)
413             self._dragged_point_index = index
414
415         elif event.button() == Qt.RightButton:
416             for i, point in enumerate(self.points):
417                 if self._is_within_epsilon(canvas_pos, point):
418                     self.points.pop(i)
419                     break
420
421         self.update()
422         event.accept()
423
424     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
425         """Handle the mouse click being released by unsetting the dragged point index."""
426         if event.button() == Qt.LeftButton:
427             self._dragged_point_index = None
428             event.accept()
429         else:
430             event.ignore()
431
432     def mouseMoveEvent(self, event: QMouseEvent) -> None:
433         """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.17 gui/plots/classes.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4  # This program is licensed under GNU GPLv3, available here:
5  # <https://www.gnu.org/licenses/gpl-3.0.html>
6
7  """This module provides superclasses for plotting transformations."""
8
9  from __future__ import annotations
10
11  from abc import abstractmethod
12  from math import ceil, dist, floor
13  from typing import Iterable, List, Optional, Tuple
14
15  import numpy as np
16  from PyQt5.QtCore import QPoint, QPointF, QRectF, Qt
17  from PyQt5.QtGui import (QBrush, QColor, QFont, QMouseEvent, QPainter,
18                          QPainterPath, QPaintEvent, QPen, QPolygonF,
19                          QWheelEvent)
20  from PyQt5.QtWidgets import QWidget
21
22  from lintrans.global_settings import GlobalSettings
23  from lintrans.typing_ import MatrixType, VectorType
24
25
26  class BackgroundPlot(QWidget):
27      """This class provides a background for plotting, as well as setup for a Qt widget.
28
29      This class provides a background (untransformed) plane, and all the backend details
30      for a Qt application, but does not provide useful functionality. To be useful,
31      this class must be subclassed and behaviour must be implemented by the subclass.
32      """
33
34      DEFAULT_GRID_SPACING: int = 85
35      """This is the starting spacing between grid lines (in pixels)."""
36
37      _MINIMUM_GRID_SPACING: int = 5
38      """This is the minimum spacing between grid lines (in pixels)."""
39
40      _COLOUR_BACKGROUND_GRID: QColor = QColor('#808080')
41      """This is the colour of the background grid lines."""
42
43      _COLOUR_BACKGROUND_AXES: QColor = QColor('#000000')
44      """This is the colour of the background axes."""
45
46      _WIDTH_BACKGROUND_GRID: float = 0.3
47      """This is the width of the background grid lines, as a multiple of the :class:`QPainter` line width."""
48
49      _PEN_POLYGON: QPen = QPen(QColor('#000000'), 1.5)
50      """This is the pen used to draw the normal polygon."""
51
52      _BRUSH_SOLID_WHITE: QBrush = QBrush(QColor('#FFFFFF'), Qt.SolidPattern)
53      """This brush is just solid white. Used to draw the insides of circles."""
54
55      def __init__(self, *args, **kwargs):
56          """Create the widget and setup backend stuff for rendering.
57
58          .. note:: ``*args`` and ``**kwargs`` are passed the superclass constructor (:class:`QWidget`).
59          """
60          super().__init__(*args, **kwargs)
61
62          self.setAutoFillBackground(True)
63
64          # Set the background to white
65          palette = self.palette()
66          palette.setColor(self.backgroundRole(), Qt.white)
67          self.setPalette(palette)
68
69          self.grid_spacing = self.DEFAULT_GRID_SPACING
70

```

```

71     @property
72     def _canvas_origin(self) -> Tuple[int, int]:
73         """Return the canvas coords of the grid origin.
74
75         The return value is intended to be unpacked and passed to a :meth:`QPainter.drawLine:iiii` call.
76
77         See :meth:`_canvas_coords`.
78
79         :returns: The canvas coordinates of the grid origin
80         :rtype: Tuple[int, int]
81         """
82         return self.width() // 2, self.height() // 2
83
84     def _canvas_x(self, x: float) -> int:
85         """Convert an x coordinate from grid coords to canvas coords."""
86         return int(self._canvas_origin[0] + x * self.grid_spacing)
87
88     def _canvas_y(self, y: float) -> int:
89         """Convert a y coordinate from grid coords to canvas coords."""
90         return int(self._canvas_origin[1] - y * self.grid_spacing)
91
92     def canvas_coords(self, x: float, y: float) -> Tuple[int, int]:
93         """Convert a coordinate from grid coords to canvas coords.
94
95         This method is intended to be used like
96
97         .. code::
98
99             painter.drawLine(*self.canvas_coords(x1, y1), *self.canvas_coords(x2, y2))
100
101         or like
102
103         .. code::
104
105             painter.drawLine(*self._canvas_origin, *self.canvas_coords(x, y))
106
107         See :attr:`_canvas_origin`.
108
109         :param float x: The x component of the grid coordinate
110         :param float y: The y component of the grid coordinate
111         :returns: The resultant canvas coordinates
112         :rtype: Tuple[int, int]
113         """
114         return self._canvas_x(x), self._canvas_y(y)
115
116     def _grid_corner(self) -> Tuple[float, float]:
117         """Return the grid coords of the top right corner."""
118         return self.width() / (2 * self.grid_spacing), self.height() / (2 * self.grid_spacing)
119
120     def _grid_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             x, y = point
195
196             possible_snaps: List[Tuple[int, int]] = [
197                 (floor(x), floor(y)),
198                 (floor(x), ceil(y)),
199                 (ceil(x), floor(y)),
200                 (ceil(x), ceil(y))
201             ]
202
203             snap_distances: List[Tuple[float, Tuple[int, int]]] = [
204                 (dist((x, y), coord), coord)
205                 for coord in possible_snaps
206             ]
207
208             for snap_dist, coord in snap_distances:
209                 if GlobalSettings().get_data().snap_to_int_coords and snap_dist < GlobalSettings().get_data().snap_dist:
210                     x, y = coord
211
212             return x, y
213
214         def _is_within_epsilon(self, cursor_pos: Tuple[float, float], point: Tuple[float, float]) -> bool:
215             """Check if the cursor position (in canvas coords) is within range of the given point."""
216             mx, my = cursor_pos

```

```

216         px, py = self.canvas_coords(*point)
217         cursor_epsilon = GlobalSettings().get_data().cursor_epsilon
218         return (abs(px - mx) <= cursor_epsilon and abs(py - my) <= cursor_epsilon)
219
220     @abstractmethod
221     def mousePressEvent(self, event: QMouseEvent) -> None:
222         """Handle the mouse being pressed."""
223
224     @abstractmethod
225     def mouseReleaseEvent(self, event: QMouseEvent) -> None:
226         """Handle the mouse being released."""
227
228     @abstractmethod
229     def mouseMoveEvent(self, event: QMouseEvent) -> None:
230         """Handle the mouse moving on the widget."""
231
232
233 class VectorGridPlot(BackgroundPlot):
234     """This class represents a background plot, with vectors and their grid drawn on top. It provides utility
    ↪ methods.
235
236     .. note::
237         This is a simple superclass for vectors and is not for visualizing transformations.
238         See :class:`VisualizeTransformationPlot`.
239
240     This class should be subclassed to be used for visualization and matrix definition widgets.
241     All useful behaviour should be implemented by any subclass.
242
243     .. warning:: This class should never be directly instantiated, only subclassed.
244     """
245
246     _COLOUR_I = QColor('#0808d8')
247     """This is the colour of the `i` basis vector and associated transformed grid lines."""
248
249     _COLOUR_J = QColor('#e90000')
250     """This is the colour of the `j` basis vector and associated transformed grid lines."""
251
252     _COLOUR_TEXT = QColor('#000000')
253     """This is the colour of the text."""
254
255     _WIDTH_VECTOR_LINE = 1.8
256     """This is the width of the transformed basis vector lines, as a multiple of the :class:`QPainter` line
    ↪ width."""
257
258     _WIDTH_TRANSFORMED_GRID = 0.8
259     """This is the width of the transformed grid lines, as a multiple of the :class:`QPainter` line width."""
260
261     _ARROWHEAD_LENGTH = 0.15
262     """This is the minimum length (in grid coord size) of the arrowhead parts."""
263
264     _MAX_PARALLEL_LINES = 150
265     """This is the maximum number of parallel transformed grid lines that will be drawn.
266
267     The user can zoom out further, but we will stop drawing grid lines beyond this number.
268     """
269
270     def __init__(self, *args, **kwargs):
271         """Create the widget with ``point_i`` and ``point_j`` attributes.
272
273         .. note:: ``*args`` and ``**kwargs`` are passed to the superclass constructor (:class:`BackgroundPlot`).
274         """
275         super().__init__(*args, **kwargs)
276
277         self.point_i: Tuple[float, float] = (1., 0.)
278         self.point_j: Tuple[float, float] = (0., 1.)
279
280     @property
281     def _matrix(self) -> MatrixType:
282         """Return the assembled matrix of the basis vectors."""
283         return np.array([
284             [self.point_i[0], self.point_j[0]],
285             [self.point_i[1], self.point_j[1]]
286         ])

```



```

287
288 @property
289 def _det(self) -> float:
290     """Return the determinant of the assembled matrix."""
291     return float(np.linalg.det(self._matrix))
292
293 @property
294 def _eigs(self) -> 'Iterable[Tuple[float, VectorType]]':
295     """Return the eigenvalues and eigenvectors zipped together to be iterated over.
296
297     :rtype: Iterable[Tuple[float, VectorType]]
298     """
299     values, vectors = np.linalg.eig(self._matrix)
300     return zip(values, vectors.T)
301
302 @abstractmethod
303 def paintEvent(self, event: QPaintEvent) -> None:
304     """Handle a :class:`QPaintEvent`.
305
306 def _draw_parallel_lines(self, painter: QPainter, vector: Tuple[float, float], point: Tuple[float, float]) ->
↪ None:
307     """Draw a set of evenly spaced grid lines parallel to ``vector`` intersecting ``point``.
308
309     :param QPainter painter: The painter to draw the lines with
310     :param vector: The vector to draw the grid lines parallel to
311     :type vector: Tuple[float, float]
312     :param point: The point for the lines to intersect with
313     :type point: Tuple[float, float]
314     """
315     max_x, max_y = self._grid_corner()
316     vector_x, vector_y = vector
317     point_x, point_y = point
318
319     # If the determinant is 0
320     if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
321         rank = np.linalg.matrix_rank(
322             np.array([
323                 [vector_x, point_x],
324                 [vector_y, point_y]
325             ])
326         )
327
328         # If the matrix is rank 1, then we can draw the column space line
329         if rank == 1:
330             # If the vector does not have a 0 x or y component, then we can just draw the line
331             if abs(vector_x) > 1e-12 and abs(vector_y) > 1e-12:
332                 self._draw_oblique_line(painter, vector_y / vector_x, 0)
333
334             # Otherwise, we have to draw lines along the axes
335             elif abs(vector_x) > 1e-12 and abs(vector_y) < 1e-12:
336                 painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
337
338             elif abs(vector_x) < 1e-12 and abs(vector_y) > 1e-12:
339                 painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
340
341             # If the vector is (0, 0), then don't draw a line for it
342             else:
343                 return
344
345         # If the rank is 0, then we don't draw any lines
346         else:
347             return
348
349     elif abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
350         # If both components of the vector are practically 0, then we can't render any grid lines
351         return
352
353     # Draw vertical lines
354     elif abs(vector_x) < 1e-12:
355         painter.drawLine(self._canvas_x(0), 0, self._canvas_x(0), self.height())
356
357     for i in range(min(abs(int(max_x / point_x)), self._MAX_PARALLEL_LINES)):
358         painter.drawLine(

```

```

359         self._canvas_x((i + 1) * point_x),
360         0,
361         self._canvas_x((i + 1) * point_x),
362         self.height()
363     )
364     painter.drawLine(
365         self._canvas_x(-1 * (i + 1) * point_x),
366         0,
367         self._canvas_x(-1 * (i + 1) * point_x),
368         self.height()
369     )
370
371     # Draw horizontal lines
372     elif abs(vector_y) < 1e-12:
373         painter.drawLine(0, self._canvas_y(0), self.width(), self._canvas_y(0))
374
375         for i in range(min(abs(int(max_y / point_y)), self._MAX_PARALLEL_LINES)):
376             painter.drawLine(
377                 0,
378                 self._canvas_y((i + 1) * point_y),
379                 self.width(),
380                 self._canvas_y((i + 1) * point_y)
381             )
382             painter.drawLine(
383                 0,
384                 self._canvas_y(-1 * (i + 1) * point_y),
385                 self.width(),
386                 self._canvas_y(-1 * (i + 1) * point_y)
387             )
388
389     # If the line is oblique, then we can use  $y = mx + c$ 
390     else:
391         m = vector_y / vector_x
392         c = point_y - m * point_x
393
394         self._draw_oblique_line(painter, m, 0)
395
396         # We don't want to overshoot the max number of parallel lines,
397         # but we should also stop looping as soon as we can't draw any more lines
398         for i in range(1, self._MAX_PARALLEL_LINES + 1):
399             if not self._draw_pair_of_oblique_lines(painter, m, i * c):
400                 break
401
402     def _draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
403         """Draw a pair of oblique lines, using the equation  $y = mx + c$ .
404
405         This method just calls :meth:`_draw_oblique_line` with ``c`` and ``-c``,
406         and returns True if either call returned True.
407
408         :param QPainter painter: The painter to draw the vectors and grid lines with
409         :param float m: The gradient of the lines to draw
410         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
411         :returns bool: Whether we were able to draw any lines on the canvas
412         """
413         return any([
414             self._draw_oblique_line(painter, m, c),
415             self._draw_oblique_line(painter, m, -c)
416         ])
417
418     def _draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
419         """Draw an oblique line, using the equation  $y = mx + c$ .
420
421         We only draw the part of the line that fits within the canvas, returning True if
422         we were able to draw a line within the boundaries, and False if we couldn't draw a line
423
424         :param QPainter painter: The painter to draw the vectors and grid lines with
425         :param float m: The gradient of the line to draw
426         :param float c: The y-intercept of the line to draw
427         :returns bool: Whether we were able to draw a line on the canvas
428         """
429         max_x, max_y = self._grid_corner()
430
431         # These variable names are shortened for convenience

```

```

432     # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
433     myi = (max_y - c) / m
434     mmyi = (-max_y - c) / m
435     mxi = max_x * m + c
436     mmxi = -max_x * m + c
437
438     # The inner list here is a list of coords, or None
439     # If an intersection fits within the bounds, then we keep its coord,
440     # else it is None, and then gets discarded from the points list
441     # By the end, points is a list of two coords, or an empty list
442     points: List[Tuple[float, float]] = [
443         x for x in [
444             (myi, max_y) if -max_x < myi < max_x else None,
445             (mmyi, -max_y) if -max_x < mmyi < max_x else None,
446             (max_x, mxi) if -max_y < mxi < max_y else None,
447             (-max_x, mmxi) if -max_y < mmxi < max_y else None
448         ] if x is not None
449     ]
450
451     # If no intersections fit on the canvas
452     if len(points) < 2:
453         return False
454
455     # If we can, then draw the line
456     else:
457         painter.drawLine(
458             *self.canvas_coords(*points[0]),
459             *self.canvas_coords(*points[1])
460         )
461         return True
462
463 def _draw_transformed_grid(self, painter: QPainter) -> None:
464     """Draw the transformed version of the grid, given by the basis vectors.
465
466     .. note:: This method draws the grid, but not the basis vectors. Use :meth:`_draw_basis_vectors` to draw
↳ them.
467
468     :param QPainter painter: The painter to draw the grid lines with
469     """
470     # Draw all the parallel lines
471     painter.setPen(QPen(self._COLOUR_I, self._WIDTH_TRANSFORMED_GRID))
472     self._draw_parallel_lines(painter, self.point_i, self.point_j)
473     painter.setPen(QPen(self._COLOUR_J, self._WIDTH_TRANSFORMED_GRID))
474     self._draw_parallel_lines(painter, self.point_j, self.point_i)
475
476 def _draw_arrowhead_away_from_origin(self, painter: QPainter, point: Tuple[float, float]) -> None:
477     """Draw an arrowhead at ``point``, pointing away from the origin.
478
479     :param QPainter painter: The painter to draw the arrowhead with
480     :param point: The point to draw the arrowhead at, given in grid coords
481     :type point: Tuple[float, float]
482     """
483     # This algorithm was adapted from a C# algorithm found at
484     # http://csharpshelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
485
486     # Get the x and y coords of the point, and then normalize them
487     # We have to normalize them, or else the size of the arrowhead will
488     # scale with the distance of the point from the origin
489     x, y = point
490     vector_length = np.sqrt(x * x + y * y)
491
492     if vector_length < 1e-12:
493         return
494
495     nx = x / vector_length
496     ny = y / vector_length
497
498     # We choose a length and find the steps in the x and y directions
499     length = min(
500         self._ARROWHEAD_LENGTH * self.DEFAULT_GRID_SPACING / self.grid_spacing,
501         vector_length
502     )
503     dx = length * (-nx - ny)

```

```

504         dy = length * (nx - ny)
505
506         # Then we just plot those lines
507         painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x + dx, y + dy))
508         painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x - dy, y + dx))
509
510     def _draw_position_vector(self, painter: QPainter, point: Tuple[float, float], colour: QColor) -> None:
511         """Draw a vector from the origin to the given point.
512
513         :param QPainter painter: The painter to draw the position vector with
514         :param point: The tip of the position vector in grid coords
515         :type point: Tuple[float, float]
516         :param QColor colour: The colour to draw the position vector in
517         """
518         painter.setPen(QPen(colour, self._WIDTH_VECTOR_LINE))
519         painter.drawLine(*self._canvas_origin, *self.canvas_coords(*point))
520         self._draw_arrowhead_away_from_origin(painter, point)
521
522     def _draw_basis_vectors(self, painter: QPainter) -> None:
523         """Draw arrowheads at the tips of the basis vectors.
524
525         :param QPainter painter: The painter to draw the basis vectors with
526         """
527         self._draw_position_vector(painter, self.point_i, self._COLOUR_I)
528         self._draw_position_vector(painter, self.point_j, self._COLOUR_J)
529
530     def _draw_basis_vector_labels(self, painter: QPainter) -> None:
531         """Label the basis vectors with 'i' and 'j'."""
532         font = self.font()
533         font.setItalic(True)
534         font.setStyleHint(QFont.Serif)
535
536         self._draw_text_at_vector_tip(painter, self.point_i, 'i', font)
537         self._draw_text_at_vector_tip(painter, self.point_j, 'j', font)
538
539     def _draw_text_at_vector_tip(
540         self,
541         painter: QPainter,
542         point: Tuple[float, float],
543         text: str,
544         font: Optional[QFont] = None
545     ) -> None:
546         """Draw the given text at the point as if it were the tip of a vector, using the custom font if given."""
547         offset = 3
548         top_left: QPoint
549         bottom_right: QPoint
550         alignment_flags: int
551         x, y = point
552
553         if x >= 0 and y >= 0: # Q1
554             top_left = QPoint(self._canvas_x(x) + offset, 0)
555             bottom_right = QPoint(self.width(), self._canvas_y(y) - offset)
556             alignment_flags = Qt.AlignLeft | Qt.AlignBottom
557
558         elif x < 0 and y >= 0: # Q2
559             top_left = QPoint(0, 0)
560             bottom_right = QPoint(self._canvas_x(x) - offset, self._canvas_y(y) - offset)
561             alignment_flags = Qt.AlignRight | Qt.AlignBottom
562
563         elif x < 0 and y < 0: # Q3
564             top_left = QPoint(0, self._canvas_y(y) + offset)
565             bottom_right = QPoint(self._canvas_x(x) - offset, self.height())
566             alignment_flags = Qt.AlignRight | Qt.AlignTop
567
568         else: # Q4
569             top_left = QPoint(self._canvas_x(x) + offset, self._canvas_y(y) + offset)
570             bottom_right = QPoint(self.width(), self.height())
571             alignment_flags = Qt.AlignLeft | Qt.AlignTop
572
573         original_font = painter.font()
574
575         if font is not None:
576             painter.setFont(font)

```

```

577
578     painter.setPen(QPen(self._COLOUR_TEXT, 1))
579     painter.drawText(QRectF(top_left, bottom_right), alignment_flags, text)
580
581     painter.setFont(original_font)
582
583
584 class VisualizeTransformationPlot(VectorGridPlot):
585     """This class is a superclass for visualizing transformations. It provides utility methods."""
586
587     _COLOUR_EIGEN = QColor('#13cf00')
588     """This is the colour of the eigenvectors and eigenlines (the spans of the eigenvectors)."""
589
590     @abstractmethod
591     def paintEvent(self, event: QPaintEvent) -> None:
592         """Handle a :class:`QPaintEvent`."""
593
594     def _draw_determinant_parallelogram(self, painter: QPainter) -> None:
595         """Draw the parallelogram of the determinant of the matrix.
596
597         :param QPainter painter: The painter to draw the parallelogram with
598         """
599         if self._det == 0:
600             return
601
602         path = QPainterPath()
603         path.moveTo(*self._canvas_origin)
604         path.lineTo(*self.canvas_coords(*self.point_i))
605         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
606         path.lineTo(*self.canvas_coords(*self.point_j))
607
608         color = (16, 235, 253) if self._det > 0 else (253, 34, 16)
609         brush = QBrush(QColor(*color, alpha=128), Qt.SolidPattern)
610
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         )

```

## A.18 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.19 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.20 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      if degrees:
39          angle = np.radians(angle)
40
41      return radius * np.cos(angle), radius * np.sin(angle)
42
43
44  def rotate_coord(x: float, y: float, angle: float, *, degrees: bool = False) -> Tuple[float, float]:
45      """Rotate a rectilinear coordinate by the given angle."""
46      if degrees:
47          angle = np.radians(angle)
48
49      r, theta = polar_coords(x, y, degrees=degrees)
50      theta = (theta + angle) % (2 * np.pi)
51
52      return rect_coords(r, theta, degrees=degrees)
53
54
55  def create_rotation_matrix(angle: float, *, degrees: bool = True) -> MatrixType:
56      """Create a matrix representing a rotation (anticlockwise) by the given angle.
57
58      :Example:
59
60      >>> create_rotation_matrix(30)
61      array([[ 0.8660254, -0.5
62              [ 0.5      ,  0.8660254]])

```



```

63     >>> create_rotation_matrix(45)
64     array([[ 0.70710678, -0.70710678],
65            [ 0.70710678,  0.70710678]])
66     >>> create_rotation_matrix(np.pi / 3, degrees=False)
67     array([[ 0.5, -0.8660254],
68            [ 0.8660254,  0.5 ]])
69
70     :param float angle: The angle to rotate anticlockwise by
71     :param bool degrees: Whether to interpret the angle as degrees (True) or radians (False)
72     :returns MatrixType: The resultant matrix
73     """
74     rad = np.deg2rad(angle % 360) if degrees else angle % (2 * np.pi)
75     return np.array([
76         [np.cos(rad), -1 * np.sin(rad)],
77         [np.sin(rad), np.cos(rad)]
78     ])
79
80
81 def is_valid_float(string: str) -> bool:
82     """Check if the string is a valid float (or anything that can be cast to a float, such as an int).
83
84     This function simply checks that ``float(string)`` doesn't raise an error.
85
86     .. note:: An empty string is not a valid float, so will return False.
87
88     :param str string: The string to check
89     :returns bool: Whether the string is a valid float
90     """
91     try:
92         float(string)
93         return True
94     except ValueError:
95         return False
96
97
98 def round_float(num: float, precision: int = 5) -> str:
99     """Round a floating point number to a given number of decimal places for pretty printing.
100
101     :param float num: The number to round
102     :param int precision: The number of decimal places to round to
103     :returns str: The rounded number for pretty printing
104     """
105     # Round to ``precision`` number of decimal places
106     string = str(round(num, precision))
107
108     # Cut off the potential final zero
109     if string.endswith('.0'):
110         return string[:-2]
111
112     elif 'e' in string: # Scientific notation
113         split = string.split('e')
114         # The leading 0 only happens when the exponent is negative, so we know there'll be a minus sign
115         return split[0] + 'e-' + split[1][1:].lstrip('0')
116
117     else:
118         return string

```

## A.21 matrices/wrapper.py

```

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

```

```

12 from copy import copy
13 from functools import reduce
14 from operator import add, matmul
15 from typing import Any, Dict, List, Optional, Set, Tuple, Union
16
17 import numpy as np
18
19 from lintrans.typing_ import MatrixType, is_matrix_type
20
21 from .parse import (get_matrix_identifiers, parse_matrix_expression,
22                     validate_matrix_expression)
23 from .utility import create_rotation_matrix
24
25 _ALPHABET_NO_I = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
26
27
28 class MatrixWrapper:
29     """A wrapper class to hold all possible matrices and allow access to them.
30
31     .. note::
32         When defining a custom matrix, its name must be a capital letter and cannot be ``I``.
33
34     The contained matrices can be accessed and assigned to using square bracket notation.
35
36     :Example:
37
38     >>> wrapper = MatrixWrapper()
39     >>> wrapper['I']
40     array([[1., 0.],
41           [0., 1.]])
42     >>> wrapper['M'] # Returns None
43     >>> wrapper['M'] = np.array([[1, 2], [3, 4]])
44     >>> wrapper['M']
45     array([[1., 2.],
46           [3., 4.]])
47     """
48
49     def __init__(self):
50         """Initialize a :class:`MatrixWrapper` object with a dictionary of matrices which can be accessed."""
51         self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
52             'A': None, 'B': None, 'C': None, 'D': None,
53             'E': None, 'F': None, 'G': None, 'H': None,
54             'I': np.eye(2), # I is always defined as the identity matrix
55             'J': None, 'K': None, 'L': None, 'M': None,
56             'N': None, 'O': None, 'P': None, 'Q': None,
57             'R': None, 'S': None, 'T': None, 'U': None,
58             'V': None, 'W': None, 'X': None, 'Y': None,
59             'Z': None
60         }
61
62     def __repr__(self) -> str:
63         """Return a nice string repr of the :class:`MatrixWrapper` for debugging."""
64         defined_matrices = ''.join([k for k, v in self._matrices.items() if v is not None])
65         return f'<{self.__class__.__module__}.{self.__class__.__name__} object with ' \
66             f'{len(defined_matrices)} defined matrices: '{defined_matrices}'>'
67
68     def __eq__(self, other: Any) -> bool:
69         """Check for equality in wrappers by comparing dictionaries.
70
71         :param Any other: The object to compare this wrapper to
72         """
73         if not isinstance(other, self.__class__):
74             return NotImplemented
75
76         # We loop over every matrix and check if every value is equal in each
77         for name in self._matrices:
78             s_matrix = self[name]
79             o_matrix = other[name]
80
81             if s_matrix is None and o_matrix is None:
82                 continue
83
84             elif (s_matrix is None and o_matrix is not None) or \

```

```

85         (s_matrix is not None and o_matrix is None):
86             return False
87
88         # This is mainly to satisfy mypy, because we know these must be matrices
89         elif not is_matrix_type(s_matrix) or not is_matrix_type(o_matrix):
90             return False
91
92         # Now we know they're both NumPy arrays
93         elif np.array_equal(s_matrix, o_matrix):
94             continue
95
96         else:
97             return False
98
99     return True
100
101     def __hash__(self) -> int:
102         """Return the hash of the matrices dictionary."""
103         return hash(self._matrices)
104
105     def __getitem__(self, name: str) -> Optional[MatrixType]:
106         """Get the matrix with the given identifier.
107
108         If it is a simple name, it will just be fetched from the dictionary. If the identifier is ``rot(x)`, with
109         a given angle in degrees, then we return a new matrix representing a rotation by that angle. If the
110         ↪ identifier
111         is something like ``[1 2;3 4]`, then we will evaluate this matrix (we assume it will have whitespace
112         ↪ exactly
113         like the example; see :func:`lintrans.matrices.parse.strip_whitespace`).
114
115         .. note::
116             If the named matrix is defined as an expression, then this method will return its evaluation.
117             If you want the expression itself, use :meth:`get_expression`.
118
119         :param str name: The name of the matrix to get
120         :returns Optional[MatrixType]: The value of the matrix (could be None)
121
122         :raises NameError: If there is no matrix with the given name
123         """
124         # Return a new rotation matrix
125         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
126             return create_rotation_matrix(float(match.group(1)))
127
128         if (match := re.match(
129             r'\[(-?\d+(:?\.\d+)?) (-?\d+(:?\.\d+)?) (-?\d+(:?\.\d+)?) (-?\d+(:?\.\d+)?)\]',
130             name
131         )) is not None:
132             a = float(match.group(1))
133             b = float(match.group(2))
134             c = float(match.group(3))
135             d = float(match.group(4))
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         return matrix
151
152     def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:
153         """Set the value of matrix ``name`` with the new_matrix.
154
155         The new matrix may be a simple 2x2 NumPy array, or it could be a string, representing an
156         expression in terms of other, previously defined matrices.

```

```

156         :param str name: The name of the matrix to set the value of
157         :param Optional[Union[MatrixType, str]] new_matrix: The value of the new matrix (could be None)
158
159         :raises NameError: If the name isn't a legal matrix name
160         :raises TypeError: If the matrix isn't a valid 2x2 NumPy array or expression in terms of other defined
161     ↪ matrices
162         :raises ValueError: If you attempt to define a matrix in terms of itself
163         """
164         if not (name in self._matrices and name != 'I'):
165             raise NameError('Matrix name is illegal')
166
167         if new_matrix is None:
168             self._matrices[name] = None
169             return
170
171         if isinstance(new_matrix, str):
172             if self.is_valid_expression(new_matrix):
173                 if name not in new_matrix and \
174                     name not in self.get_expression_dependencies(new_matrix):
175                     self._matrices[name] = new_matrix
176                     return
177             else:
178                 raise ValueError('Cannot define a matrix recursively')
179
180         if not is_matrix_type(new_matrix):
181             raise TypeError('Matrix must be a 2x2 NumPy array')
182
183         # All matrices must have float entries
184         a = float(new_matrix[0][0])
185         b = float(new_matrix[0][1])
186         c = float(new_matrix[1][0])
187         d = float(new_matrix[1][1])
188
189         self._matrices[name] = np.array([[a, b], [c, d]])
190
191     def get_matrix_dependencies(self, matrix_name: str) -> Set[str]:
192         """Return all the matrices (as identifiers) that the given matrix (indirectly) depends on.
193
194         If A depends on nothing, B directly depends on A, and C directly depends on B,
195         then we say C depends on B `and` A.
196         """
197         expression = self.get_expression(matrix_name)
198         if expression is None:
199             return set()
200
201         s = set()
202         identifiers = get_matrix_identifiers(expression)
203         for identifier in identifiers:
204             s.add(identifier)
205             s.update(self.get_matrix_dependencies(identifier))
206
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

```

```

228
229         :raises NameError: If the name is invalid
230         """
231         if name not in self._matrices:
232             raise NameError('Matrix must have a legal name')
233
234         matrix = self._matrices[name]
235         if isinstance(matrix, str):
236             return matrix
237
238         return None
239
240     def is_valid_expression(self, expression: str) -> bool:
241         """Check if the given expression is valid, using the context of the wrapper.
242
243         This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
244         ensures that all the matrices in the expression are defined in the wrapper.
245
246         :param str expression: The expression to validate
247         :returns bool: Whether the expression is valid in this wrapper
248
249         :raises LinAlgError: If a matrix is defined in terms of the inverse of a singular matrix
250         """
251         # Get rid of the transposes to check all capital letters
252         new_expression = expression.replace('^T', '').replace('^{T}', '')
253
254         # Make sure all the referenced matrices are defined
255         for matrix in [x for x in new_expression if re.match('[A-Z]', x)]:
256             if self[matrix] is None:
257                 return False
258
259             if (expr := self.get_expression(matrix)) is not None:
260                 if not self.is_valid_expression(expr):
261                     return False
262
263         return validate_matrix_expression(expression)
264
265     def evaluate_expression(self, expression: str) -> MatrixType:
266         """Evaluate a given expression and return the matrix evaluation.
267
268         :param str expression: The expression to be parsed
269         :returns MatrixType: The matrix result of the expression
270
271         :raises ValueError: If the expression is invalid
272         """
273         if not self.is_valid_expression(expression):
274             raise ValueError('The expression is invalid')
275
276         parsed_result = parse_matrix_expression(expression)
277         final_groups: List[List[MatrixType]] = []
278
279         for group in parsed_result:
280             f_group: List[MatrixType] = []
281
282             for multiplier, identifier, index in group:
283                 if index == 'T':
284                     m = self[identifier]
285
286                     # This assertion is just so mypy doesn't complain
287                     # We know this won't be None, because we know that this matrix is defined in this wrapper
288                     assert m is not None
289                     matrix_value = m.T
290
291                 else:
292                     # Again, this assertion is just for mypy
293                     # We know this will be a matrix, but since upgrading from NumPy 1.21 to 1.23
294                     # (to fix a bug with GH Actions on Windows), mypy complains about matrix_power()
295                     base_matrix = self[identifier]
296                     assert is_matrix_type(base_matrix)
297
298                     matrix_value = np.linalg.matrix_power(base_matrix, 1 if index == '' else int(index))
299
300             matrix_value *= 1 if multiplier == '' else float(multiplier)

```

```

301         f_group.append(matrix_value)
302
303         final_groups.append(f_group)
304
305     return reduce(add, [reduce(matmul, group) for group in final_groups])
306
307 def get_defined_matrices(self) -> List[Tuple[str, Union[MatrixType, str]]]:
308     """Return a list of tuples containing the name and value of all defined matrices in the wrapper.
309
310     :returns: A list of tuples where the first element is the name, and the second element is the value
311     :rtype: List[Tuple[str, Union[MatrixType, str]]]
312     """
313     matrices = []
314
315     for name, value in self._matrices.items():
316         if value is not None:
317             matrices.append((name, value))
318
319     return matrices
320
321 def undefine_matrix(self, name: str) -> Set[str]:
322     """Safely undefine the given matrix by also undefining any matrices that depend on it."""
323     if not (name in self._matrices and name != 'I'):
324         raise NameError('Matrix name is illegal')
325
326     # This maps each matrix to all the matrices that depend on it
327     dependents_map = {
328         x: set(y for y in _ALPHABET_NO_I if x in self.get_matrix_dependencies(y))
329         for x in _ALPHABET_NO_I
330     }
331
332     s: Set[str] = set(name)
333     self[name] = None
334     for x in dependents_map[name]:
335         s.update(self.undefine_matrix(x))
336
337     return s

```

## A.22 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.23 matrices/parse.py

```

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

```

```

13 from typing import List, Pattern, Set, Tuple
14
15 from lintrans.typing import MatrixParseList
16
17 _ALPHABET = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
18
19 NAIVE_CHARACTER_CLASS = r'[-+\sA-Z0-9.rot()\{\}\[\];]'
20 """This is a RegEx character class that just holds all the valid characters for an expression.
21 """
22 See :func:`validate_matrix_expression` to actually validate matrix expressions.
23 """
24
25
26 class MatrixParseError(Exception):
27     """A simple exception to be raised when an error is found when parsing."""
28
29
30 def compile_naive_expression_pattern() -> Pattern[str]:
31     """Compile the single RegEx pattern that will match a valid matrix expression."""
32     digit_no_zero = '[123456789]'
33     digits = '\\d+'
34     integer_no_zero = digit_no_zero + '(' + digits + ')?'
35     real_number = f'({integer_no_zero}(\\.\\{digits}\\{0\\.\\{digits}\\})'
36
37     anonymous_matrix = r'\\((-?\\d+(?:\\.\\d+)?)(-?\\d+(?:\\.\\d+)?);(-?\\d+(?:\\.\\d+)?)(-?\\d+(?:\\.\\d+)?\\))\\'
38
39     index_content = f'(-?{integer_no_zero}|T)'
40     index = f'\\^{{{index_content}}}|\\^{{{index_content}}}'
41     matrix_identifier = f'([A-Z]|rot\\((-?{real_number}\\{0\\.\\{digits}\\})|{anonymous_matrix}|\\({NAIVE_CHARACTER_CLASS}\\+\\))'
42     matrix = '(' + real_number + '?' + matrix_identifier + index + '?'
43     expression = f'^~?{matrix}+(\\+~?|-){matrix}+*$'
44
45     return re.compile(expression)
46
47
48 # This is an expensive pattern to compile, so we compile it when this module is initialized
49 _naive_expression_pattern = compile_naive_expression_pattern()
50
51
52 def find_sub_expressions(expression: str) -> List[str]:
53     """Find all the sub-expressions in the given expression.
54     This function only goes one level deep, so may return strings like ``A(BC)D``.
55     """
56
57     :raises MatrixParseError: If there are unbalanced parentheses
58     """
59     sub_expressions: List[str] = []
60     string = ''
61     paren_depth = 0
62     pointer = 0
63
64     expression = strip_whitespace(expression)
65
66     while True:
67         char = expression[pointer]
68
69         if char == '(' and expression[pointer - 3:pointer] != 'rot':
70             paren_depth += 1
71
72             # This is a bit of a manual bodge, but it eliminates extraneous parens
73             if paren_depth == 1:
74                 pointer += 1
75                 continue
76
77         elif char == ')' and re.match(f'{NAIVE_CHARACTER_CLASS}*rot\\((-?\\d\\.]+$', expression[:pointer]) is None:
78             paren_depth -= 1
79
80         if paren_depth > 0:
81             string += char
82
83         if paren_depth == 0 and string:
84             sub_expressions.append(string)
85             string = ''

```

```

86
87     pointer += 1
88
89     if pointer >= len(expression):
90         break
91
92     if paren_depth != 0:
93         raise MatrixParseError('Unbalanced parentheses in expression')
94
95     return sub_expressions
96
97
98 def strip_whitespace(expression: str) -> str:
99     """Strip the whitespace from the given expression, preserving whitespace in anonymous matrices.
100
101     Whitespace in anonymous matrices is preserved such that there is exactly one space in the middle of each pair of
102     numbers, but no space after the semi-colon, like so: `[1 -2;3.4 5]`.
103     """
104     # We replace the necessary whitespace with null bytes to preserve it
105     expression = re.sub(
106         r'\\s*(-?\\d+(?:\\.\\d+)?)\\s+(-?\\d+(?:\\.\\d+)?)\\s*;\\s*(-?\\d+(?:\\.\\d+)?)\\s+(-?\\d+(?:\\.\\d+)?)\\s*\\]',
107         r'\\g<1> \\g<2>;\\g<3> \\g<4>'.replace(' ', '\\x00'),
108         expression
109     )
110
111     expression = re.sub(r'\\s', ' ', expression)
112     return re.sub('\\x00', ' ', expression)
113
114
115 def validate_matrix_expression(expression: str) -> bool:
116     """Validate the given matrix expression.
117
118     This function simply checks the expression against the BNF schema documented in
119     :ref:`expression-syntax-docs`. It is not aware of which matrices are actually defined
120     in a wrapper. For an aware version of this function, use the
121     :meth:`~lintrans.matrices.wrapper.MatrixWrapper.is_valid_expression` method on
122     :class:`~lintrans.matrices.wrapper.MatrixWrapper`.
123
124     :param str expression: The expression to be validated
125     :returns bool: Whether the expression is valid according to the schema
126     """
127     # Remove all whitespace
128     expression = strip_whitespace(expression)
129     match = _naive_expression_pattern.match(expression)
130
131     if match is None:
132         return False
133
134     if re.search(r'\\^~?\\d*\\.\\d+', expression) is not None:
135         return False
136
137     # Check that the whole expression was matched against
138     if expression != match.group(0):
139         return False
140
141     try:
142         sub_expressions = find_sub_expressions(expression)
143     except MatrixParseError:
144         return False
145
146     if len(sub_expressions) == 0:
147         return True
148
149     return all(validate_matrix_expression(m) for m in sub_expressions)
150
151
152 @dataclass
153 class MatrixToken:
154     """A simple dataclass to hold information about a matrix token being parsed."""
155
156     multiplier: str = ''
157     identifier: str = ''
158     exponent: str = ''

```



```

159
160 @property
161 def tuple(self) -> Tuple[str, str, str]:
162     """Create a tuple of the token for parsing."""
163     return self.multiplier, self.identifier, self.exponent
164
165
166 class ExpressionParser:
167     """A class to hold state during parsing.
168
169     Most of the methods in this class are class-internal and should not be used from outside.
170
171     This class should be used like this:
172
173     >>> ExpressionParser('3A^-1B').parse()
174     [[('3', 'A', '-1'), ('', 'B', '')]]
175     >>> ExpressionParser('4(M^TA^2)^-2').parse()
176     [[('4', 'M^{T}A^{2}', '-2')]]
177     """
178
179     def __init__(self, expression: str):
180         """Create an instance of the parser with the given expression and initialise variables to use during
181         ↪ parsing."""
182         # Remove all whitespace
183         expression = strip_whitespace(expression)
184
185         # Check if it's valid
186         if not validate_matrix_expression(expression):
187             raise MatrixParseError('Invalid expression')
188
189         # Wrap all exponents and transposition powers with {}
190         expression = re.sub(r'(?<=^)(-?\d+|T)(?=[^}]|$)', 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}")'
212
213     @property
214     def _char(self) -> str:
215         """Return the character pointed to by the pointer."""
216         return self._expression[self._pointer]
217
218     def parse(self) -> MatrixParseList:
219         """Fully parse the instance's matrix expression and return the :attr:`~lintrans.typing_.MatrixParseList`.
220
221         This method uses all the private methods of this class to parse the
222         expression in parts. All private methods mutate the instance variables.
223
224         :returns: The parsed expression
225         :rtype: :attr:`~lintrans.typing_.MatrixParseList`
226         """
227         self._parse_multiplication_group()
228
229         while self._pointer < len(self._expression):
230             if self._expression[self._pointer] != '+':
231                 raise MatrixParseError('Expected "+" between multiplication groups')

```

```

231         self._pointer += 1
232         self._parse_multiplication_group()
233
234     return self._final_list
235
236
237 def _parse_multiplication_group(self) -> None:
238     """Parse a group of matrices to be multiplied together.
239
240     This method just parses matrices until we get to a ``+``.
241     """
242     # This loop continues to parse matrices until we fail to do so
243     while self._parse_matrix():
244         # Once we get to the end of the multiplication group, we add it the final list and reset the group list
245         if self._pointer >= len(self._expression) or self._char == '+':
246             self._final_list.append(self._current_group)
247             self._current_group = []
248             self._pointer += 1
249
250 def _parse_matrix(self) -> bool:
251     """Parse a full matrix using :meth:`_parse_matrix_part`.
252
253     This method will parse an optional multiplier, an identifier, and an optional exponent. If we
254     do this successfully, we return True. If we fail to parse a matrix (maybe we've reached the
255     end of the current multiplication group and the next char is ``+``), then we return False.
256
257     :returns bool: Success or failure
258     """
259     self._current_token = MatrixToken()
260
261     while self._parse_matrix_part():
262         pass # The actual execution is taken care of in the loop condition
263
264     if self._current_token.identifier == '':
265         return False
266
267     self._current_group.append(self._current_token.tuple)
268     return True
269
270 def _parse_matrix_part(self) -> bool:
271     """Parse part of a matrix (multiplier, identifier, or exponent).
272
273     Which part of the matrix we parse is dependent on the current value of the pointer and the expression.
274     This method will parse whichever part of matrix token that it can. If it can't parse a part of a matrix,
275     or it's reached the next matrix, then we just return False. If we succeeded to parse a matrix part, then
276     we return True.
277
278     :returns bool: Success or failure
279     :raises MatrixParseError: If we fail to parse this part of the matrix
280     """
281     if self._pointer >= len(self._expression):
282         return False
283
284     if self._char.isdigit() or self._char == '-':
285         if self._current_token.multiplier != '' \
286             or (self._current_token.multiplier == '' and self._current_token.identifier != ''):
287             return False
288
289         self._parse_multiplier()
290
291     elif self._char.isalpha() and self._char.isupper():
292         if self._current_token.identifier != '':
293             return False
294
295         self._current_token.identifier = self._char
296         self._pointer += 1
297
298     elif self._char == 'r':
299         if self._current_token.identifier != '':
300             return False
301
302         self._parse_rot_identifier()
303

```

```

304         elif self._char == '[':
305             if self._current_token.identifier != '':
306                 return False
307
308             self._parse_anonymous_identifer()
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_identifer(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_identifer(self) -> None:
373         # *****
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     def parse_matrix_expression(expression: str) -> MatrixParseList:
447         """Parse the matrix expression and return a :attr:`~lintrans.typing.MatrixParseList`.
448
449

```

```

450     :Example:
451
452     >>> parse_matrix_expression('A')
453     [[(' ', 'A', ' ')]]
454     >>> parse_matrix_expression('-3M^2')
455     [[(' -3', 'M', '2')]]
456     >>> parse_matrix_expression('1.2rot(12)^{3}2B^T')
457     [[('1.2', 'rot(12)', '3'), ('2', 'B', 'T')]]
458     >>> parse_matrix_expression('A^2 + 3B')
459     [[(' ', 'A', '2')], [('3', 'B', ' ')]]
460     >>> parse_matrix_expression('-3A^{-1}3B^T - 45M^2')
461     [[(' -3', 'A', ' -1'), ('3', 'B', 'T')], [(' -45', 'M', '2')]]
462     >>> parse_matrix_expression('5.3A^{4} 2.6B^{-2} + 4.6D^T 8.9E^{-1}')
463     [[('5.3', 'A', '4'), ('2.6', 'B', ' -2')], [('4.6', 'D', 'T'), ('8.9', 'E', ' -1')]]
464     >>> parse_matrix_expression('2(A+B^TC)^2D')
465     [[('2', 'A+B^TC', '2'), (' ', 'D', ' ')]]
466
467     :param str expression: The expression to be parsed
468     :returns: A list of parsed components
469     :rtype: :attr:`~lintrans.typing_.MatrixParseList`
470     """
471     return ExpressionParser(expression).parse()
472
473
474 def get_matrix_identifiers(expression: str) -> Set[str]:
475     """Return all the matrix identifiers used in the given expression.
476
477     This method works recursively with sub-expressions.
478     """
479     s = set()
480     top_level = [id for sublist in parse_matrix_expression(expression) for _, id, _ in sublist]
481
482     for body in top_level:
483         if body in _ALPHABET:
484             s.add(body)
485
486         elif re.match(r'rot\((\d+(\.\d+)?)\)', body):
487             continue
488
489         else:
490             s.update(get_matrix_identifiers(body))
491
492     return s

```

## 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 ]
30
31
32 def test_find_sub_expressions() -> None:
33     """Test the :func:`lintrans.matrices.parse.find_sub_expressions` function."""
34     for inp, output in expected_sub_expressions:
35         assert find_sub_expressions(inp) == output
36
37
38 expected_stripped_whitespace: List[Tuple[str, str]] = [
39     ('[ 1 2 ; 3 4 ]', '[1 2;3 4]'),
40     ('[-3.4 6; 1.2 -9 ]', '[-3.4 6;1.2 -9]'),
41     ('A 4 [ 43 -653.23 ; 32523 -4.3 ] Z^2', 'A4[43 -653.23;32523 -4.3]Z^2'),
42     ('[ 1 2; -4 3.64] [-5 6; 8.3 2]', '[1 2;-4 3.64][-5 6;8.3 2]')
43 ]
44
45

```

```

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

```



```

119     ('A^2 + 0.5B', [[(' ', 'A', '2')], [('0.5', 'B', '')]]),
120     ('2A^3 + 8B^T - 3C^-1', [[('2', 'A', '3')], [('8', 'B', 'T')], [(' -3', 'C', '-1')]]),
121     ('4.9A^2 - 3rot(134.2)^-1 + 7.6B^8', [[('4.9', 'A', '2')], [(' -3', 'rot(134.2)', '-1')], [('7.6', 'B', '8')]]),
122
123     # Additions with multiplication
124     ('2.14A^3 4.5rot(14.5)^-1 + 8B^T - 3C^-1', [[('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1')],
125                                                    [('8', 'B', 'T')], [(' -3', 'C', '-1')]]),
126     ('2.14A^3 4.5rot(14.5)^-1 + 8.5B^T 5.97C^14 - 3.14D^-1 6.7E^T',
127      [[('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1')], [('8.5', 'B', 'T'), ('5.97', 'C', '14')],
128      [('-3.14', 'D', '-1'), ('6.7', 'E', 'T')]]),
129
130     # Parenthesized expressions
131     ('(AB)^-1', [[(' ', 'AB', '-1')]]),
132     ('-3(A+B)^2-C(B^TA)^-1', [[(' -3', 'A+B', '2')], [(' -1', 'C', ''), (' ', 'B^T A', '-1')]]),
133     ('2.3(3B^TA)^2', [[('2.3', '3B^T A', '2')]]),
134     ('-3.4(9D^2 3F^-1)^T+C', [[(' -3.4', '9D^2 3F^-1', 'T')], [(' ', 'C', '')]]),
135     ('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',
136     ↪ '-1')]]),
137
138     # Anonymous matrices
139     ('[1 2; 3 4]', [[(' ', '[1 2; 3 4]', '')]]),
140     ('A[-3 4; 16.2 87.93]', [[(' ', 'A', ''), (' ', '[-3 4; 16.2 87.93]', '')]]),
141     (
142         '3A^2(M-[ 1 2 ; 5 4 ]^T)^-1 18([13.2 -6.4; -11 0.2]+F)^2+Z',
143         [[('3', 'A', '2'), (' ', 'M-[ 1 2; 5 4 ]^T', '-1'), ('18', '[13.2 -6.4; -11 0.2]+F', '2')], [(' ', 'Z', '')]]
144     )
145 ]
146
147 def test_parse_matrix_expression() -> None:
148     """Test the parse_matrix_expression() function."""
149     for expression, parsed_expression in expressions_and_parsed_expressions:
150         # Test it with and without whitespace
151         assert parse_matrix_expression(expression) == parsed_expression
152         assert parse_matrix_expression(strip_whitespace(expression)) == parsed_expression
153
154     for expression in valid_inputs:
155         # Assert that it doesn't raise MatrixParseError
156         parse_matrix_expression(expression)
157
158
159 def test_parse_error() -> None:
160     """Test that parse_matrix_expression() raises a MatrixParseError."""
161     for expression in invalid_inputs:
162         with pytest.raises(MatrixParseError):
163             parse_matrix_expression(expression)
164
165
166 def test_get_matrix_identifiers() -> None:
167     """Test that matrix identifiers can be properly found."""
168     assert get_matrix_identifiers('M^T') == {'M'}
169     assert get_matrix_identifiers('ABCDE F') == {'A', 'B', 'C', 'D', 'E', 'F'}
170     assert get_matrix_identifiers('AB^-1 3Crot(45)2A(B^2C^-1)') == {'A', 'B', 'C'}
171     assert get_matrix_identifiers('A^2 3A^-1A^TA') == {'A'}
172     assert get_matrix_identifiers('rot(45)(rot(25)rot(20))^2') == set()
173
174     for expression in invalid_inputs:
175         with pytest.raises(MatrixParseError):
176             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
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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\_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 = 'ABCDEFGHJKLMNPOQRSTUVWXYZ'
19  invalid_matrix_names = ['bad name', '123456', 'Th15 Is an 1nV@l1D n@m3', 'abc', 'a']
20
21  test_matrix: MatrixType = np.array([[1, 2], [4, 3]])
22
23
24  def test_basic_get_matrix(new_wrapper: MatrixWrapper) -> None:
25      """Test MatrixWrapper().__getitem__()."""
26      for name in valid_matrix_names:
27          assert new_wrapper[name] is None
28
29      assert (new_wrapper['I'] == np.array([[1, 0], [0, 1]]).all()

```

```

30
31
32 def test_get_name_error(new_wrapper: MatrixWrapper) -> None:
33     """Test that MatrixWrapper().__getitem__() raises a NameError if called with an invalid name."""
34     for name in invalid_matrix_names:
35         with pytest.raises(NameError):
36             _ = new_wrapper[name]
37
38
39 def test_basic_set_matrix(new_wrapper: MatrixWrapper) -> None:
40     """Test MatrixWrapper().__setitem__()."""
41     for name in valid_matrix_names:
42         new_wrapper[name] = test_matrix
43         assert (new_wrapper[name] == test_matrix).all()
44
45         new_wrapper[name] = None
46         assert new_wrapper[name] is None
47
48
49 def test_set_expression(test_wrapper: MatrixWrapper) -> None:
50     """Test that MatrixWrapper.__setitem__() can accept a valid expression."""
51     test_wrapper['N'] = 'A^2'
52     test_wrapper['O'] = 'BA+2C'
53     test_wrapper['P'] = 'E^T'
54     test_wrapper['Q'] = 'C^-1B'
55     test_wrapper['R'] = 'A^{2}3B'
56     test_wrapper['S'] = 'N^-1'
57     test_wrapper['T'] = 'PQP^-1'
58
59     with pytest.raises(TypeError):
60         test_wrapper['U'] = 'A+1'
61
62     with pytest.raises(TypeError):
63         test_wrapper['V'] = 'K'
64
65     with pytest.raises(TypeError):
66         test_wrapper['W'] = 'L^2'
67
68     with pytest.raises(TypeError):
69         test_wrapper['X'] = 'M^-1'
70
71     with pytest.raises(TypeError):
72         test_wrapper['Y'] = 'A^2B+C'
73
74
75 def test_simple_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
76     """Test that expression-defined matrices are evaluated dynamically."""
77     test_wrapper['N'] = 'A^2'
78     test_wrapper['O'] = '4B'
79     test_wrapper['P'] = 'A+C'
80
81     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
82     assert (test_wrapper['O'] == test_wrapper.evaluate_expression('4B')).all()
83     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
84
85     assert (test_wrapper.evaluate_expression('N^2 + 3O') ==
86             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
87             3 * test_wrapper.evaluate_expression('4B')
88             ).all()
89     assert (test_wrapper.evaluate_expression('P^-1 - 3N^2') ==
90             la.inv(test_wrapper.evaluate_expression('A+C')) -
91             (3 * test_wrapper.evaluate_expression('A^2')) @
92             la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
93             ).all()
94
95     test_wrapper['A'] = np.array([
96         [19, -21.5],
97         [84, 96.572]
98     ])
99     test_wrapper['B'] = np.array([
100         [-0.993, 2.52],
101         [1e10, 0]
102     ])

```

```

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

```

```

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

```

## B.8 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 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 def test_identity_multiplication(test_wrapper: MatrixWrapper) -> None:

```



```

63     """Test that multiplying by the identity doesn't change the value of a matrix."""
64     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
65           test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
66           test_wrapper['G'] is not None
67
68     assert (test_wrapper.evaluate_expression('I') == test_wrapper['I']).all()
69     assert (test_wrapper.evaluate_expression('AI') == test_wrapper['A']).all()
70     assert (test_wrapper.evaluate_expression('IA') == test_wrapper['A']).all()
71     assert (test_wrapper.evaluate_expression('GI') == test_wrapper['G']).all()
72     assert (test_wrapper.evaluate_expression('IG') == test_wrapper['G']).all()
73
74     assert (test_wrapper.evaluate_expression('EID') == test_wrapper['E'] @ test_wrapper['D']).all()
75     assert (test_wrapper.evaluate_expression('IED') == test_wrapper['E'] @ test_wrapper['D']).all()
76     assert (test_wrapper.evaluate_expression('EDI') == test_wrapper['E'] @ test_wrapper['D']).all()
77     assert (test_wrapper.evaluate_expression('IEIDI') == test_wrapper['E'] @ test_wrapper['D']).all()
78     assert (test_wrapper.evaluate_expression('EI^3D') == test_wrapper['E'] @ test_wrapper['D']).all()
79
80     assert test_wrapper == get_test_wrapper()
81
82
83 def test_simple_three_matrix_multiplication(test_wrapper: MatrixWrapper) -> None:
84     """Test simple multiplication of two matrices."""
85     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
86           test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
87           test_wrapper['G'] is not None
88
89     assert (test_wrapper.evaluate_expression('ABC') == test_wrapper['A'] @ test_wrapper['B'] @
90           ↪ test_wrapper['C']).all()
91     assert (test_wrapper.evaluate_expression('ACB') == test_wrapper['A'] @ test_wrapper['C'] @
92           ↪ test_wrapper['B']).all()
93     assert (test_wrapper.evaluate_expression('BAC') == test_wrapper['B'] @ test_wrapper['A'] @
94           ↪ test_wrapper['C']).all()
95     assert (test_wrapper.evaluate_expression('EFG') == test_wrapper['E'] @ test_wrapper['F'] @
96           ↪ test_wrapper['G']).all()
97     assert (test_wrapper.evaluate_expression('DAC') == test_wrapper['D'] @ test_wrapper['A'] @
98           ↪ test_wrapper['C']).all()
99     assert (test_wrapper.evaluate_expression('GAE') == test_wrapper['G'] @ test_wrapper['A'] @
100           ↪ test_wrapper['E']).all()
101     assert (test_wrapper.evaluate_expression('FAG') == test_wrapper['F'] @ test_wrapper['A'] @
102           ↪ test_wrapper['G']).all()
103     assert (test_wrapper.evaluate_expression('GAF') == test_wrapper['G'] @ test_wrapper['A'] @
104           ↪ test_wrapper['F']).all()
105
106     assert test_wrapper == get_test_wrapper()
107
108
109 def test_matrix_inverses(test_wrapper: MatrixWrapper) -> None:
110     """Test the inverses of single matrices."""
111     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
112           test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
113           test_wrapper['G'] is not None
114
115     assert (test_wrapper.evaluate_expression('A^{-1}') == la.inv(test_wrapper['A'])).all()
116     assert (test_wrapper.evaluate_expression('B^{-1}') == la.inv(test_wrapper['B'])).all()
117     assert (test_wrapper.evaluate_expression('C^{-1}') == la.inv(test_wrapper['C'])).all()
118     assert (test_wrapper.evaluate_expression('D^{-1}') == la.inv(test_wrapper['D'])).all()
119     assert (test_wrapper.evaluate_expression('E^{-1}') == la.inv(test_wrapper['E'])).all()
120     assert (test_wrapper.evaluate_expression('F^{-1}') == la.inv(test_wrapper['F'])).all()
121     assert (test_wrapper.evaluate_expression('G^{-1}') == la.inv(test_wrapper['G'])).all()
122
123     assert (test_wrapper.evaluate_expression('A^{-1}') == la.inv(test_wrapper['A'])).all()
124     assert (test_wrapper.evaluate_expression('B^{-1}') == la.inv(test_wrapper['B'])).all()
125     assert (test_wrapper.evaluate_expression('C^{-1}') == la.inv(test_wrapper['C'])).all()
126     assert (test_wrapper.evaluate_expression('D^{-1}') == la.inv(test_wrapper['D'])).all()
127     assert (test_wrapper.evaluate_expression('E^{-1}') == la.inv(test_wrapper['E'])).all()
128     assert (test_wrapper.evaluate_expression('F^{-1}') == la.inv(test_wrapper['F'])).all()
129     assert (test_wrapper.evaluate_expression('G^{-1}') == la.inv(test_wrapper['G'])).all()
130
131     assert test_wrapper == get_test_wrapper()
132
133
134 def test_matrix_powers(test_wrapper: MatrixWrapper) -> None:
135     """Test that matrices can be raised to integer powers."""

```

```

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()
207
208
209 def test_complicated_expressions(test_wrapper: MatrixWrapper) -> None:
210     """Test evaluation of complicated expressions."""
211     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
212            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
213            test_wrapper['G'] is not None
214
215     assert (test_wrapper.evaluate_expression('-3.2A^T 4B^{-1} 6C^{-1} + 8.1D^{2} 3.2E^4') ==
216            (-3.2 * test_wrapper['A'].T) @ (4 * la.inv(test_wrapper['B'])) @ (6 * la.inv(test_wrapper['C']))
217            + (8.1 * la.matrix_power(test_wrapper['D'], 2)) @ (3.2 * la.matrix_power(test_wrapper['E'], 4))).all()
218
219     assert (test_wrapper.evaluate_expression('53.6D^{2} 3B^T - 4.9F^{2} 2D + A^3 B^{-1}') ==
220            (53.6 * la.matrix_power(test_wrapper['D'], 2)) @ (3 * test_wrapper['B'].T)
221            - (4.9 * la.matrix_power(test_wrapper['F'], 2)) @ (2 * test_wrapper['D'])
222            + la.matrix_power(test_wrapper['A'], 3) @ la.inv(test_wrapper['B'])).all()
223
224     assert test_wrapper == get_test_wrapper()
225
226
227 def test_parenthesized_expressions(test_wrapper: MatrixWrapper) -> None:
228     """Test evaluation of parenthesized expressions."""
229     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
230            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
231            test_wrapper['G'] is not None
232
233     assert (test_wrapper.evaluate_expression('(A^T)^2') == la.matrix_power(test_wrapper['A'].T, 2)).all()
234     assert (test_wrapper.evaluate_expression('(B^T)^3') == la.matrix_power(test_wrapper['B'].T, 3)).all()
235     assert (test_wrapper.evaluate_expression('(C^T)^4') == la.matrix_power(test_wrapper['C'].T, 4)).all()
236     assert (test_wrapper.evaluate_expression('(D^T)^5') == la.matrix_power(test_wrapper['D'].T, 5)).all()
237     assert (test_wrapper.evaluate_expression('(E^T)^6') == la.matrix_power(test_wrapper['E'].T, 6)).all()
238     assert (test_wrapper.evaluate_expression('(F^T)^7') == la.matrix_power(test_wrapper['F'].T, 7)).all()
239     assert (test_wrapper.evaluate_expression('(G^T)^8') == la.matrix_power(test_wrapper['G'].T, 8)).all()
240
241     assert (test_wrapper.evaluate_expression('(rot(45)^1)^T') == create_rotation_matrix(45).T).all()
242     assert (test_wrapper.evaluate_expression('(rot(45)^2)^T') == la.matrix_power(create_rotation_matrix(45),
243     ↪ 2).T).all()
244     assert (test_wrapper.evaluate_expression('(rot(45)^3)^T') == la.matrix_power(create_rotation_matrix(45),
245     ↪ 3).T).all()
246     assert (test_wrapper.evaluate_expression('(rot(45)^4)^T') == la.matrix_power(create_rotation_matrix(45),
247     ↪ 4).T).all()
248     assert (test_wrapper.evaluate_expression('(rot(45)^5)^T') == la.matrix_power(create_rotation_matrix(45),
249     ↪ 5).T).all()
250
251     assert (test_wrapper.evaluate_expression('D^3(A+6.2F-0.397G^TE)^{-2+A}') ==
252            la.matrix_power(test_wrapper['D'], 3) @ la.matrix_power(
253                test_wrapper['A'] + 6.2 * test_wrapper['F'] - 0.397 * test_wrapper['G'].T @ test_wrapper['E'],
254                -2
255            ) + test_wrapper['A']).all()
256
257     assert (test_wrapper.evaluate_expression('-1.2F^{3}4.9D^T(A^2(B+3E^TF)^{-1})^2') ==
258            -1.2 * la.matrix_power(test_wrapper['F'], 3) @ (4.9 * test_wrapper['D'].T) @
259            la.matrix_power(
260                la.matrix_power(test_wrapper['A'], 2) @ la.matrix_power(
261                    test_wrapper['B'] + 3 * test_wrapper['E'].T @ test_wrapper['F'],
262                    -1
263                ),
264                2
265            ),
266            2
267        ).all()
268
269 def test_value_errors(test_wrapper: MatrixWrapper) -> None:
270     """Test that evaluate_expression() raises a ValueError for any malformed input."""
271     invalid_expressions = ['', '+', '-', 'This is not a valid expression', '3+4',
272                            'A+2', 'A^', '^2', 'A^-', 'At', 'A^t', '3^2']
273
274     for expression in invalid_expressions:

```

```
270         with pytest.raises(ValueError):
271             test_wrapper.evaluate_expression(expression)
272
273
274 def test_linalgerror() -> None:
275     """Test that certain expressions raise np.linalg.LinAlgError."""
276     matrix_a: MatrixType = np.array([
277         [0, 0],
278         [0, 0]
279     ])
280
281     matrix_b: MatrixType = np.array([
282         [1, 2],
283         [1, 2]
284     ])
285
286     wrapper = MatrixWrapper()
287     wrapper['A'] = matrix_a
288     wrapper['B'] = matrix_b
289
290     assert (wrapper.evaluate_expression('A') == matrix_a).all()
291     assert (wrapper.evaluate_expression('B') == matrix_b).all()
292
293     with pytest.raises(np.linalg.LinAlgError):
294         wrapper.evaluate_expression('A~-1')
295
296     with pytest.raises(np.linalg.LinAlgError):
297         wrapper.evaluate_expression('B~-1')
298
299     assert (wrapper['A'] == matrix_a).all()
300     assert (wrapper['B'] == matrix_b).all()
```