

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 2×2 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. Many 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.

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, 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.

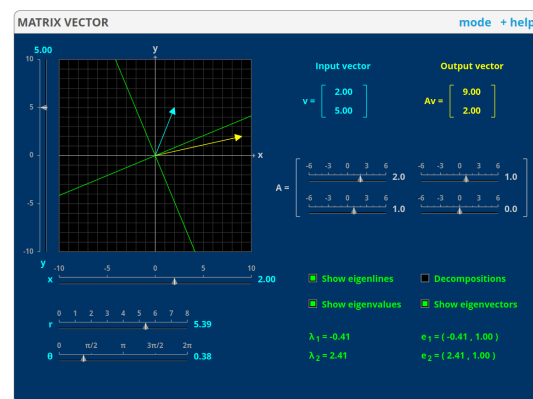


Figure 1.1: The MIT 'Matrix Vector' Mathlet

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 2×2 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

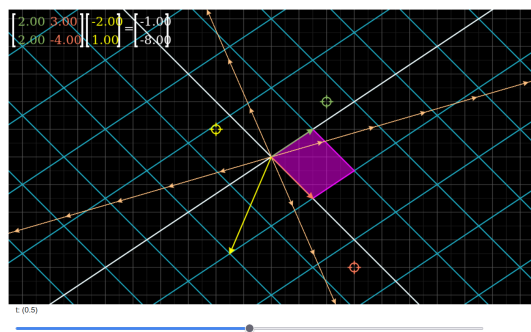


Figure 1.2: 'Linear Transformation Visualizer' halfway through an animation

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 1920×1080 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'¹ or later, or any modern Linux distro². Basically, it just requires an operating system that is compatible with Python 3.10 and 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.

Python 3.10 won't actually be required for the end user, because I will be compiling the app into a

¹Python 3.10 won't compile on any earlier versions of macOS[16]

²Specifying a Linux version is practically impossible. Python 3.10 isn't available in many package repositories, but 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]

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 3.10 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. `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; 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 checker³; `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 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.

³Python has weak, dynamic typing with optional type annotations but `mypy` enforces these static type annotations

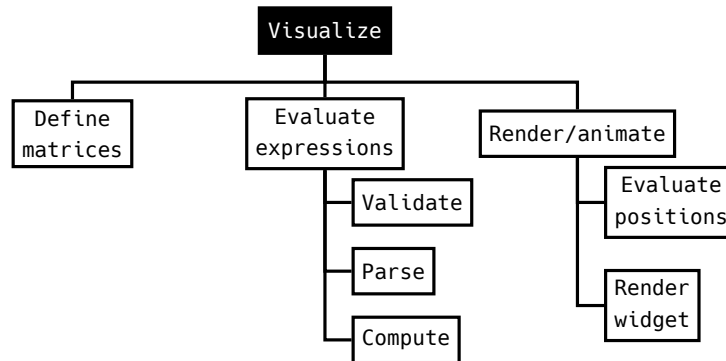
Transforming polygons is the lowest priority item on this list and will likely be implemented last, but it would definitely benefit learning. I wouldn't consider it necessary for success, but it would be very good to include, and it's certainly a feature that I want to have.

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.

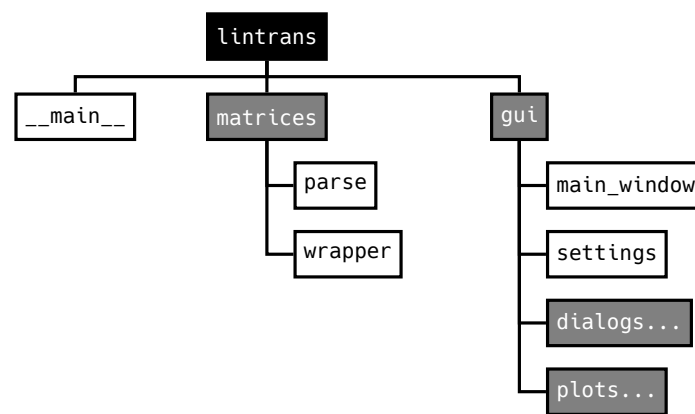
Rendering and animating will likely be the largest part in reality, but I've only decomposed it into simple blocks here. Evaluating positions involves evaluating the matrix expression that the user has input and using the columns of the resultant matrix to find the new positions of the basis vectors, 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

2.2.1 The main project

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.

`matrices` is the package that will allow the user to define, validate, parse, evaluate, and use matrices. The `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 elsewhere. The `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 matrices are actually defined - as well the ability to evaluate matrix expressions, in addition to its basic behaviour of setting and getting matrices. This `matrices` package will also have a `create_rotation_matrix` function that will generate a rotation matrix from an angle using the formula $\begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix}$. It will be in the `wrapper` module since it's related to defining and manipulating matrices, but it will be exported and accessible as `lintrans.matrices.create_rotation_matrix`.

`gui` is the package that will contain all the frontend code for everything GUI-related. `main_window` is the module that will contain a `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. This module will also contain a simple `main()` function to instantiate and launch the application GUI.

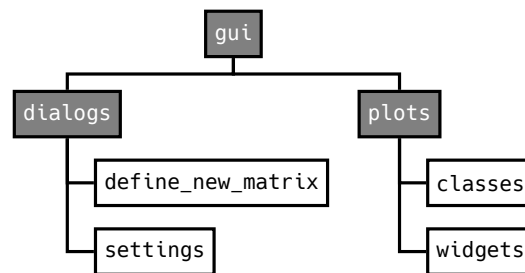
The `settings` module will contain a `DisplaySettings` dataclass⁴ that will represent the settings for visualizing transformations. The `LintransMainWindow` class will have an instance of this class and check against it when rendering things. The user will be able to open a dialog to change these display settings, which will update the main window's instance of this class.

The `settings` module will also have a `GlobalSettings` class, which will represent the global settings for the application, such as the logging level, where to save the logs, whether to ask the user if they want to be prompted with a tutorial whenever they open the app, etc. This class will have defaults for everything, but the constructor will try to read these settings from a config file if possible. This allows for persistent settings between sessions. This config file will be `~/.config/lintrans.conf` on Unix-like systems, including macOS, and `C:\Users\%USER%\AppData\Roaming\lintrans\config.txt` on Windows. This difference is to remain consistent with operating system conventions⁵.

⁴This is the Python equivalent of a `struct` or `record` in other languages

⁵And also to avoid confusing Windows users with a `.conf` file

2.2.2 The gui subpackages



The `dialogs` subpackage will contain modules with different dialog classes. It will have a `define_new_matrices` module, which will have a `DefinedDialog` abstract superclass. It will also contain classes that inherit from this superclass and provide dialogs for defining new matrices visually, numerically, and as an expression in terms of other matrices. Additionally, this subpackage will contain a `settings` module, which will provide a `SettingsDialog` superclass and a `DisplaySettingsDialog` class, which will allow the user to configure the aforementioned display settings. It will also have a `GlobalSettingsDialog` class, which will similarly allow the user to configure the app's global settings through a dialog.

The `plots` subpackage will have a `classes` module and a `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 `plots` subpackage will also contain a `widgets` module, which will have the classes `VisualizeTransformationWidget` and `DefineVisuallyWidget`, both of which will 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.

It's also worth noting here that I don't currently know how I'm going to implement the transformation of arbitrary polygons. It will likely consist of an attribute in `VisualizeTransformationWidget` which is a list of points, and these points can be dragged around with mouse event handlers and then the transformed versions can be rendered, but I'm not yet sure about how I'm going to implement it.

2.3 Algorithm design

This section will be completed later.

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 blindness⁶.

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 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

This project won't actually have many variables. The main ones will be instance attributes on the `LintransMainWindow` class. It will have a `MatrixWrapper` instance, a `DisplaySettings` instance, and a `GlobalSettings` 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 letters⁷ and the matrices will be of type `MatrixType`. This will be a custom type alias representing a 2×2 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* button⁸. 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

⁶I 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

⁷I would make these char but Python only has a str type for strings

⁸Actually 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()`

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.

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`.

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^45.6rot(19.2^T-B^-14.1C^5"	"A--B"

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

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

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

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

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

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

which should parse to give:

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

Any invalid expression will also raise a parse error, 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 from⁹. 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"')
```

⁹A 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@l1D 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

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

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]

```

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

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^{rot()}\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('IIDI') == 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
```

```

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

expressions_and_parsed_expressions: list[tuple[str, MatrixParseList]] = [
    # Simple expressions
    ('A', [(('', 'A', '')]]),
    ('A^2', [(('', 'A', '2')]]),
    ('A^{2}', [(('', 'A', '2')]]),
    ('3A', [(('3', 'A', '')]]),
    ('1.4A^3', [(('1.4', 'A', '3')]]),

    # Multiplications
    ('4A^3 6B^2', [(('4', 'A', '3'), ('6', 'B', '2')]]),
    ('4.2A^{T} 6.1B^{-1}', [(('4.2', 'A', 'T'), ('6.1', 'B', '-1')]]),
    ('-1.2A^2 rot(45)^2', [(('1.2', 'A', '2'), ('', 'rot(45)', '2')]]),
    ('3.2A^T 4.5B^{5} 9.6rot(121.3)', [(('3.2', 'A', 'T'), ('4.5', 'B', '5'), ('9.6', 'rot(121.3)', ''))]]),
    ('-1.18A^{-2} 0.1B^{2} 9rot(34.6)^{-1}', [(('1.18', 'A', '-2'), ('0.1', 'B', '2'), ('9', 'rot(34.6)', '-1')]]),

    # Additions
    ('A + B', [(('', 'A', ''), ('', 'B', ''))]]),
    ('A + B - C', [(('', 'A', ''), ('', 'B', '')), (('1', 'C', ''))]]),
    ('2A^3 + 8B^T - 3C^{-1}', [(('2', 'A', '3'), ('8', 'B', 'T'), ('3', 'C', '-1')]]),

    # Additions with multiplication
    ('2.14A^3 4.5rot(14.5)^{-1} + 8B^T - 3C^{-1}', [(('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'), ('8', 'B', 'T'), ('3', 'C', '-1')]]),
    ('2.14A^3 4.5rot(14.5)^{-1} + 8.5B^T 5.97C^4 - 3.14D^{-1} 6.7E^T',
     [(('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'), ('8.5', 'B', 'T'), ('5.97', 'C', '4'), ('3.14', 'D', '-1'), ('6.7', 'E', 'T')]]),

]

@pytest.mark.skip(reason='parse_matrix_expression() not implemented')
def test_parse_matrix_expression() -> None:
    """Test the parse_matrix_expression() function."""
    for expression, parsed_expression in expressions_and_parsed_expressions:
        # Test it with and without whitespace
        assert parse_matrix_expression(expression) == parsed_expression
        assert parse_matrix_expression(expression.replace(' ', '')) == parsed_expression
```

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

def compile_valid_expression_pattern() -> Pattern[str]:
    """Compile the single regular expression that will match a valid matrix expression."""
    digit_no_zero = '[123456789]'
    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

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

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

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]) == '' else int(index))
185
186            matrix_value *= 1 if (multiplier := matrix[0]) == '' 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 new matrix')
54     self.label_define_new_matrix.setAlignment(QtCore.Qt.AlignCenter)
55
56     # TODO: Implement defining a new matrix visually, numerically, as a rotation, and as an expression
57
58     self.button_define_visually = QtWidgets.QPushButton(self)
59     self.button_define_visually.setText('Visually')
60     self.button_define_visually.setToolTip('Drag the basis vectors')
61
62     self.button_define_numerically = QtWidgets.QPushButton(self)
63     self.button_define_numerically.setText('Numerically')
64     self.button_define_numerically.setToolTip('Define a matrix just with numbers')
65
66     self.button_define_as_rotation = QtWidgets.QPushButton(self)
67     self.button_define_as_rotation.setText('As a rotation')
68     self.button_define_as_rotation.setToolTip('Define an angle to rotate by')
69
70     self.button_define_as_expression = QtWidgets.QPushButton(self)
71     self.button_define_as_expression.setText('As an expression')
72     self.button_define_as_expression.setToolTip('Define a matrix in terms of other matrices')
73
74     # Render buttons
75
76     self.button_render = QtWidgets.QPushButton(self)
77     self.button_render.setText('Render')
78     self.button_render.setEnabled(False)
79     self.button_render.clicked.connect(self.render_expression)
80     self.button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
81
82     self.button_render_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self)
83     self.button_render_shortcut.activated.connect(self.button_render.click)
84
85     self.button_animate = QtWidgets.QPushButton(self)
86     self.button_animate.setText('Animate')
87     self.button_animate.setEnabled(False)
88     self.button_animate.clicked.connect(self.animate_expression)
89     self.button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
90
91     self.button_animate_shortcut = QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Shift+Return'), self)
92     self.button_animate_shortcut.activated.connect(self.button_animate.click)
93
94     # === Arrange widgets
95
96     self.setContentsMargins(10, 10, 10, 10)
97
98     self.vlay_left = QVBoxLayout()
99     self.vlay_left.addWidget(self.plot)
100    self.vlay_left.addWidget(self.text_input_expression)
101
102    self.vlay_misc_buttons = QVBoxLayout()
103    self.vlay_misc_buttons.setSpacing(20)
104    self.vlay_misc_buttons.addWidget(self.button_create_polygon)
105    self.vlay_misc_buttons.addWidget(self.button_change_display_settings)
106
107    self.vlay_define_new_matrix = QVBoxLayout()
108    self.vlay_define_new_matrix.setSpacing(20)
109    self.vlay_define_new_matrix.addWidget(self.label_define_new_matrix)
110    self.vlay_define_new_matrix.addWidget(self.button_define_visually)
111    self.vlay_define_new_matrix.addWidget(self.button_define_numerically)
112    self.vlay_define_new_matrix.addWidget(self.button_define_as_rotation)
113    self.vlay_define_new_matrix.addWidget(self.button_define_as_expression)
114
115    self.vlay_render = QVBoxLayout()
116    self.vlay_render.setSpacing(20)
117    self.vlay_render.addWidget(self.button_animate)
118    self.vlay_render.addWidget(self.button_render)
119
120    self.vlay_right = QVBoxLayout()
121    self.vlay_right.setSpacing(50)
122    self.vlay_right.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 = QWidget()
132     self.central_widget.setLayout(self.hlay_all)
133     self.setCentralWidget(self.central_widget)
134
135     def update_render_buttons(self) -> None:
136         """Enable or disable the render and animate buttons according to the validity of the matrix expression."""
137         valid = self.matrix_wrapper.is_valid_expression(self.text_input_expression.text())
138         self.button_render.setEnabled(valid)
139         self.button_animate.setEnabled(valid)
140
141     def render_expression(self) -> None:
142         """Render the expression in the input box, and then clear the box."""
143         # TODO: Render the expression
144         self.text_input_expression.setText('')
145
146     def animate_expression(self) -> None:
147         """Animate the expression in the input box, and then clear the box."""
148         # TODO: Animate the expression
149         self.text_input_expression.setText('')
150
151
152     def main() -> None:
153         """Run the GUI."""
154         app = QApplication(sys.argv)
155         window = LintransMainWindow()
156         window.show()
157         sys.exit(app.exec_())
158
159
160 if __name__ == '__main__':
161     main()

```

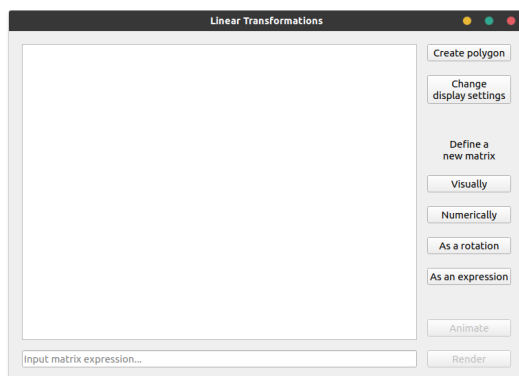


Figure 3.1: The first version of the GUI

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

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

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

3.2.2 Numerical definition dialog

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

```

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

1 """The module to provide dialogs for defining new matrices."""
2
3 from numpy import array
4 from PyQt5 import QtGui, QtWidgets
5 from PyQt5.QtWidgets import QDialog, QGridLayout, QHBoxLayout, QVBoxLayout

```



```

6
7 from lintrans.matrices import MatrixWrapper
8
9 ALPHABET_NO_I = 'ABCDEFGHJKLMNPOQRSTUVWXYZ'
10
11
12 def is_float(string: str) -> bool:
13     """Check if a string is a float."""
14     try:
15         float(string)
16         return True
17     except ValueError:
18         return False
19
20
21 class DefineNumericallyDialog(QDialog):
22     """The dialog class that allows the user to define a new matrix numerically."""
23
24     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
25         """Create the dialog, but don't run it yet.
26
27         :param matrix_wrapper: The MatrixWrapper that this dialog will mutate
28         :type matrix_wrapper: MatrixWrapper
29         """
30         super().__init__(*args, **kwargs)
31
32         self.matrix_wrapper = matrix_wrapper
33         self.setWindowTitle('Define a matrix')
34
35         # === Create the widgets
36
37         self.button_confirm = QtWidgets.QPushButton(self)
38         self.button_confirm.setText('Confirm')
39         self.button_confirm.setEnabled(False)
40         self.button_confirm.clicked.connect(self.confirm_matrix)
41         self.button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
42
43         QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
44
45         self.button_cancel = QtWidgets.QPushButton(self)
46         self.button_cancel.setText('Cancel')
47         self.button_cancel.clicked.connect(self.close)
48         self.button_cancel.setToolTip('Cancel this definition<br><b>(Ctrl + Q)</b>')
49
50         QtWidgets.QShortcut(QtGui.QKeySequence('Ctrl+Q'), self).activated.connect(self.button_cancel.click)
51
52         self.element_tl = QtWidgets.QLineEdit(self)
53         self.element_tl.textChanged.connect(self.update_confirm_button)
54
55         self.element_tr = QtWidgets.QLineEdit(self)
56         self.element_tr.textChanged.connect(self.update_confirm_button)
57
58         self.element_bl = QtWidgets.QLineEdit(self)
59         self.element_bl.textChanged.connect(self.update_confirm_button)
60
61         self.element_br = QtWidgets.QLineEdit(self)
62         self.element_br.textChanged.connect(self.update_confirm_button)
63
64         self.matrix_elements = (self.element_tl, self.element_tr, self.element_bl, self.element_br)
65
66         self.letter_combo_box = QtWidgets.QComboBox(self)
67
68         # Everything except I, because that's the identity
69         for letter in ALPHABET_NO_I:
70             self.letter_combo_box.addItem(letter)
71
72         self.letter_combo_box.activated.connect(self.load_matrix)
73
74         # === Arrange the widgets
75
76         self.setContentsMargins(10, 10, 10, 10)
77
78         self.grid_matrix = QGridLayout()

```

```

79         self.grid_matrix.setSpacing(20)
80         self.grid_matrix.addWidget(self.element_tl, 0, 0)
81         self.grid_matrix.addWidget(self.element_tr, 0, 1)
82         self.grid_matrix.addWidget(self.element_bl, 1, 0)
83         self.grid_matrix.addWidget(self.element_br, 1, 1)
84
85         self.hlay_buttons = QHBoxLayout()
86         self.hlay_buttons.setSpacing(20)
87         self.hlay_buttons.addWidget(self.button_cancel)
88         self.hlay_buttons.addWidget(self.button_confirm)
89
90         self.vlay_right = QVBoxLayout()
91         self.vlay_right.setSpacing(20)
92         self.vlay_right.addLayout(self.grid_matrix)
93         self.vlay_right.addLayout(self.hlay_buttons)
94
95         self.hlay_all = QHBoxLayout()
96         self.hlay_all.setSpacing(20)
97         self.hlay_all.addWidget(self.letter_combo_box)
98         self.hlay_all.addLayout(self.vlay_right)
99
100        self.setLayout(self.hlay_all)
101
102        # Finally, we load the default matrix A into the boxes
103        self.load_matrix(0)
104
105    def update_confirm_button(self) -> None:
106        """Enable the confirm button if there are numbers in every box."""
107        for elem in self.matrix_elements:
108            if elem.text() == '' or not is_float(elem.text()):
109                # If they're not all numbers, then we can't confirm it
110                self.button_confirm.setEnabled(False)
111                return
112
113        # If we didn't find anything invalid
114        self.button_confirm.setEnabled(True)
115
116    def load_matrix(self, index: int) -> None:
117        """If the selected matrix is defined, load it into the boxes."""
118        matrix = self.matrix_wrapper[ALPHABET_NO_I[index]]
119
120        if matrix is None:
121            for elem in self.matrix_elements:
122                elem.setText('')
123
124        else:
125            self.element_tl.setText(str(matrix[0][0]))
126            self.element_tr.setText(str(matrix[0][1]))
127            self.element_bl.setText(str(matrix[1][0]))
128            self.element_br.setText(str(matrix[1][1]))
129
130        self.update_confirm_button()
131
132    def confirm_matrix(self) -> None:
133        """Confirm the inputted matrix and assign it to the name."""
134        letter = self.letter_combo_box.currentText()
135        matrix = array([
136            [float(self.element_tl.text()), float(self.element_tr.text())],
137            [float(self.element_bl.text()), float(self.element_br.text())]
138        ])
139
140        self.matrix_wrapper[letter] = matrix
141        self.close()

```

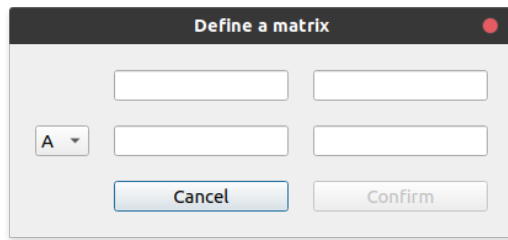


Figure 3.2: The first version of the numerical definition dialog

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

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

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

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

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

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_NO_I:
58             self.letter_combo_box.addItem(letter)
59
60         self.letter_combo_box.activated.connect(self.load_matrix)

```

This superclass just has a constructor that subclasses can use. When I added the `DefineAsARotationDialog` class, I also moved the cancel and confirm buttons into the constructor and added abstract methods that all dialog subclasses must implement.

```

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

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

```

I then added the class for the rotation definition dialog.

```

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

182 class DefineAsARotationDialog(DefinedDialog):
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 π and paste in several decimal places. I expect people to only use degrees, because these are easier to use.

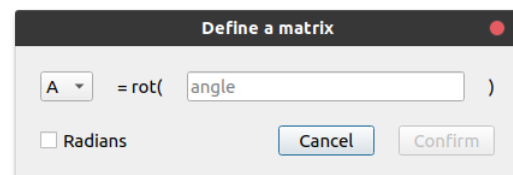


Figure 3.3: The first version of the rotation definition dialog

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

```

# 6269e04d453df7be2d2f9c7ee176e83406cccc139
# src/lintrans/gui/main_window.py

170     def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
171         """Open a generic definition dialog to define a new matrix.
172
173         The class for the desired dialog is passed as an argument. We create an
174         instance of this class and the dialog is opened asynchronously and modally
175         (meaning it blocks interaction with the main window) with the proper method
176         connected to the ``dialog.finished`` slot.
177
178         .. note::

```

```

179         ``dialog_class`` must subclass :class:`lintrans.gui.dialogs.define_new_matrix.DefineDialog`.
180
181     :param dialog_class: The dialog class to instantiate
182     :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineDialog]
183     """
184     # We create a dialog with a deepcopy of the current matrix_wrapper
185     # This avoids the dialog mutating this one
186     dialog = dialog_class(deepcopy(self.matrix_wrapper), self)
187
188     # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
189     dialog.open()
190
191     # So we have to use the finished slot to call a method when the user accepts the dialog
192     # If the user rejects the dialog, this matrix_wrapper will be the same as the current one, because we copied
193     ↪ it
194     # So we don't care, we just assign the wrapper anyway
195     dialog.finished.connect(lambda: self._assign_matrix_wrapper(dialog.matrix_wrapper))
196
197     def _assign_matrix_wrapper(self, matrix_wrapper: MatrixWrapper) -> None:
198         """Assign a new value to self.matrix_wrapper.
199
200         This is a little utility function that only exists because a lambda
201         callback can't directly assign a value to a class attribute.
202
203         :param matrix_wrapper: The new value of the matrix wrapper to assign
204         :type matrix_wrapper: MatrixWrapper
205         """
206         self.matrix_wrapper = matrix_wrapper

```

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

```

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

241 class DefineAsAnExpressionDialog(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)

```

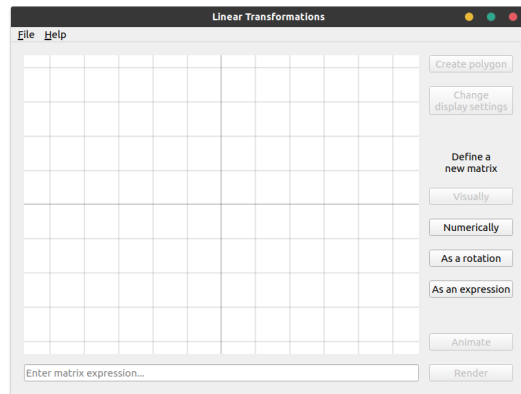


Figure 3.4: The GUI with background axes

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

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

```

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

```

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

```

```

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

```

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

```

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

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.

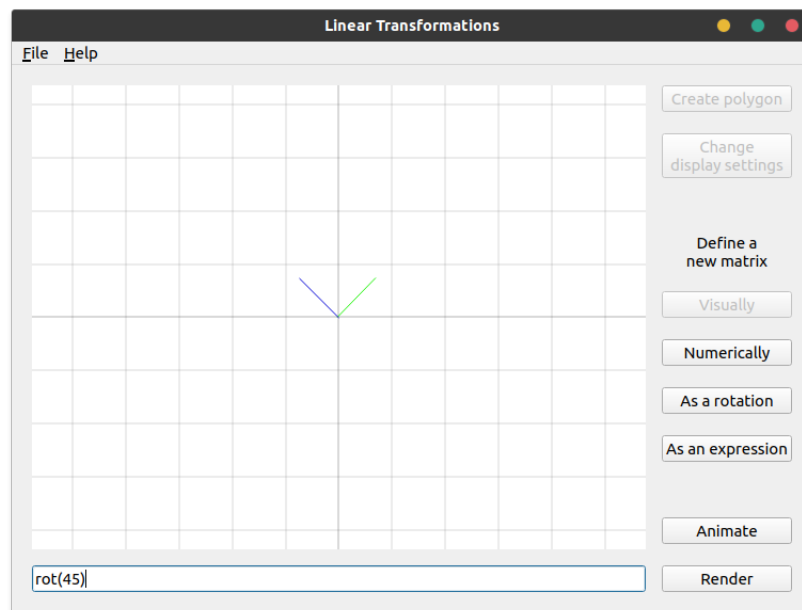
```

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

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° 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

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

126     def draw_parallel_lines(self, painter: QPainter, vector: tuple[float, float], point: tuple[float, float]) ->
127         ↪ None:
128         """Draw a set of grid lines parallel to `vector` intersecting `point`."""
129         max_x, max_y = self.grid_corner()
130         vector_x, vector_y = vector
131         point_x, point_y = point
132
133         if vector_x == 0:
134             painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
135
136         for i in range(int(max_x / point_x)):
137             painter.drawLine(
138                 self.trans_x((i + 1) * point_x),
139                 0,
140                 self.trans_x((i + 1) * point_x),
141                 self.height()
142             )
143             painter.drawLine(
144                 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

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

```

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

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

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

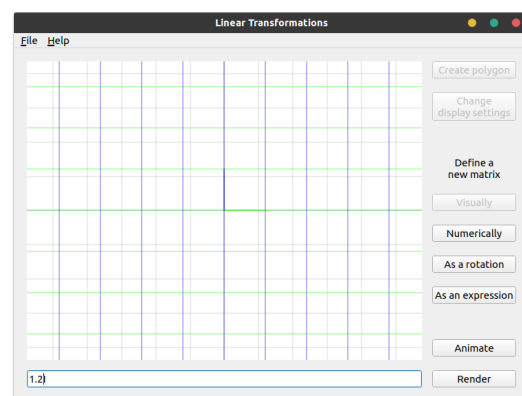


Figure 3.6: Parallel lines being drawn for matrix $1.2\mathbf{I}$

```

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

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

```

```
131
132 print(max_x, max_y, vector_x, vector_y, point_x, point_y)
133
134 # We want to use  $y = mx + c$  but  $m = y / x$  and if either of those are 0, then this
135 # equation is harder to work with, so we deal with these edge cases first
136 if abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
137     # If both components of the vector are practically 0, then we can't render any grid lines
138     return
139
140 elif abs(vector_x) < 1e-12:
141     painter.drawLine(self.trans_x(0), 0, self.trans_x(0), self.height())
142
143     for i in range(abs(int(max_x / point_x))):
144         painter.drawLine(
145             self.trans_x((i + 1) * point_x),
146             0,
147             self.trans_x((i + 1) * point_x),
148             self.height()
149         )
150         painter.drawLine(
151             self.trans_x(-1 * (i + 1) * point_x),
152             0,
153             self.trans_x(-1 * (i + 1) * point_x),
154             self.height()
155         )
156
157 elif abs(vector_y) < 1e-12:
158     painter.drawLine(0, self.trans_y(0), self.width(), self.trans_y(0))
159
160     for i in range(abs(int(max_y / point_y))):
161         painter.drawLine(
162             0,
163             self.trans_y((i + 1) * point_y),
164             self.width(),
165             self.trans_y((i + 1) * point_y)
166         )
167         painter.drawLine(
168             0,
169             self.trans_y(-1 * (i + 1) * point_y),
170             self.width(),
171             self.trans_y(-1 * (i + 1) * point_y)
172         )
173
174 else: # If the line is not horizontal or vertical, then we can use  $y = mx + c$ 
175     m = vector_y / vector_x
176     c = point_y - m * point_x
177
178     # For  $c = 0$ 
179     painter.drawLine(
180         *self.trans_coords(
181             -1 * max_x,
182             m * -1 * max_x
183         ),
184         *self.trans_coords(
185             max_x,
186             m * max_x
187         )
188     )
189
190 # Count up how many multiples of c we can have without wasting time rendering lines off screen
191 multiples_of_c: int = 0
192 ii: int = 1
193 while True:
194     y1 = m * max_x + ii * c
195     y2 = -1 * m * max_x + ii * c
196
197     if y1 < max_y or y2 < max_y:
198         multiples_of_c += 1
199         ii += 1
200
201 else:
202     break
203
```

```

204     # Once we know how many lines we can draw, we just draw them all
205     for i in range(1, multiples_of_c + 1):
206         painter.drawLine(
207             *self.trans_coords(
208                 -1 * max_x,
209                 m * -1 * max_x + i * c
210             ),
211             *self.trans_coords(
212                 max_x,
213                 m * max_x + i * c
214             )
215         )
216         painter.drawLine(
217             *self.trans_coords(
218                 -1 * max_x,
219                 m * -1 * max_x - i * c
220             ),
221             *self.trans_coords(
222                 max_x,
223                 m * max_x - i * c
224             )
225         )

```

This code checks if x or y is zero¹⁰ and if they're not, then we have to use the standard straight line equation $y = mx + c$ to create parallel lines. We find our value of m and then iterate through all the values of c that keep the line within the bounding box.

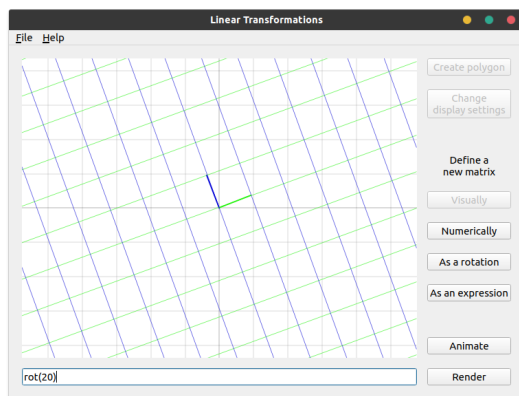


Figure 3.7: An example of a 20° rotation

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

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):

```

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

```

248         self.plot.visualize_matrix_transformation(
249             self.matrix_wrapper['I'] + (i / steps) * matrix_move
250         )
251
252         self.update()
253         self.repaint()
254
255         time.sleep(0.01)
256
257         self.button_render.setEnabled(False)
258         self.button_animate.setEnabled(False)

```

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

3.3.6 Preserving determinants

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

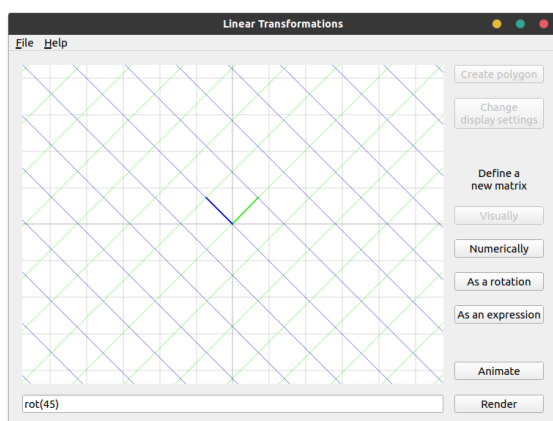


Figure 3.8: What we would expect halfway through a 90° rotation

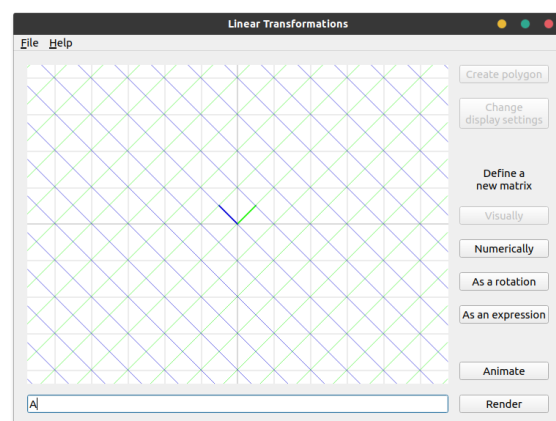


Figure 3.9: What we actually get halfway through a 90° rotation

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

I think I first tried just multiplying **A** by $\frac{1}{\det(\mathbf{A})}$ but that didn't work, so I googled it. I found a post[12] on ResearchGate about the topic, and thanks to a very helpful comment from Jeffrey L Stuart, I learned that for a 2×2 matrix **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 **B** to be $c\mathbf{A}$.

Then I wanted to scale this normalized matrix **B** to have the same determinant as the target matrix **T** using some scalar d . We know that $\det(d\mathbf{B}) = d^2 \det(\mathbf{B}) = \det(\mathbf{T})$. We can just rearrange to find d

and get $d = \sqrt{\left| \frac{\det(\mathbf{T})}{\det(\mathbf{B})} \right|}$. But \mathbf{B} is defined so that $\det(\mathbf{B}) = 1$, so we can get $d = \sqrt{|\det(\mathbf{T})|}$.

However, we want to scale this over time with our proportion variable p , so our final scalar $s = 1 + p \left(\sqrt{|\det(\mathbf{T})|} - 1 \right)$. 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

245     # Get the target matrix and it's determinant
246     matrix_target = self.matrix_wrapper.evaluate_expression(self.lineedit_expression_box.text())
247     det_target = linalg.det(matrix_target)
248
249     identity = self.matrix_wrapper['I']
250     steps: int = 100
251
252     for i in range(0, steps + 1):
253         # This proportion is how far we are through the loop
254         proportion = i / steps
255
256         # matrix_a is the identity plus some part of the target, scaled by the proportion
257         # If we just used matrix_a, then things would animate, but the determinants would be weird
258         matrix_a = identity + proportion * (matrix_target - identity)
259
260         # So to fix the determinant problem, we get the determinant of matrix_a and use it to normalise
261         det_a = linalg.det(matrix_a)
262
263         # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
264         # We want B = cA such that det(B) = 1, so then we can scale it with the animation
265         # So we get c^2 det(A) = 1 => c = sqrt(1 / abs(det(A)))
266         # Then we scale A down to get a determinant of 1, and call that matrix_b
267         if det_a == 0:
268             c = 0
269         else:
270             c = np.sqrt(1 / abs(det_a))
271
272         matrix_b = c * matrix_a
273
274         # matrix_c is the final matrix that we transform by
275         # It's B, but we scale it up over time to have the target determinant
276
277         # We want some C = dB such that det(C) is some target determinant T
278         # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
279         # But we defined B to have det 1, so we can ignore it there
280
281         # We're also subtracting 1 and multiplying by the proportion and then adding one
282         # This just scales the determinant along with the animation
283         scalar = 1 + proportion * (np.sqrt(abs(det_target)) - 1)
284
285         matrix_c = scalar * matrix_b
286
287         self.plot.visualize_matrix_transformation(matrix_c)
288
289         self.repaint()
290         time.sleep(0.01)
```

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

3.4 Improving the GUI

3.4.1 Fixing rendering

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

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

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

203         else: # If the line is not horizontal or vertical, then we can use y = mx + c
204             m = vector_y / vector_x
205             c = point_y - m * point_x
206
207             # For c = 0
208             painter.drawLine(
209                 *self.trans_coords(
210                     -1 * max_x,
211                     m * -1 * max_x
212                 ),
213                 *self.trans_coords(
214                     max_x,
215                     m * max_x
216                 )
217             )
218
219             # We keep looping and increasing the multiple of c until we stop drawing lines on the canvas
220             multiple_of_c = 1
221             while self.draw_pair_of_oblique_lines(painter, m, multiple_of_c * c):
222                 multiple_of_c += 1
```

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

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

224     def draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
225         """Draw a pair of oblique lines, using the equation y = mx + c.
226
227         This method just calls :meth:`draw_oblique_line` with ``c`` and ``-c``,
228         and returns True if either call returned True.
229
230         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
231         :param float m: The gradient of the lines to draw
232         :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
233         :returns bool: Whether we were able to draw any lines on the canvas
234         """
235         return any([
236             self.draw_oblique_line(painter, m, c),
237             self.draw_oblique_line(painter, m, -c)
238         ])
239
240     def draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
241         """Draw an oblique line, using the equation y = mx + c.
242
243         We only draw the part of the line that fits within the canvas, returning True if
244         we were able to draw a line within the boundaries, and False if we couldn't draw a line
245
246         :param QPainter painter: The ``QPainter`` object to use for drawing the vectors and grid lines
```

```

247 :param float m: The gradient of the line to draw
248 :param float c: The y-intercept of the line to draw
249 :returns bool: Whether we were able to draw a line on the canvas
250 """
251 max_x, max_y = self.grid_corner()
252
253 # These variable names are shortened for convenience
254 # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
255 myi = (max_y - c) / m
256 mmyi = (-max_y - c) / m
257 mxi = max_x * m + c
258 mmyi = -max_x * m + c
259
260 # The inner list here is a list of coords, or None
261 # If an intersection fits within the bounds, then we keep its coord,
262 # else it is None, and then gets discarded from the points list
263 # By the end, points is a list of two coords, or an empty list
264 points: list[tuple[float, float]] = [
265     x for x in [
266         (myi, max_y) if -max_x < myi < max_x else None,
267         (mmyi, -max_y) if -max_x < mmyi < max_x else None,
268         (max_x, mxi) if -max_y < mxi < max_y else None,
269         (-max_x, mmyi) if -max_y < mmyi < max_y else None
270     ] if x is not None
271 ]
272
273 # If no intersections fit on the canvas
274 if len(points) < 2:
275     return False
276
277 # If we can, then draw the line
278 else:
279     painter.drawLine(
280         *self.trans_coords(*points[0]),
281         *self.trans_coords(*points[1])
282     )
283     return True

```

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

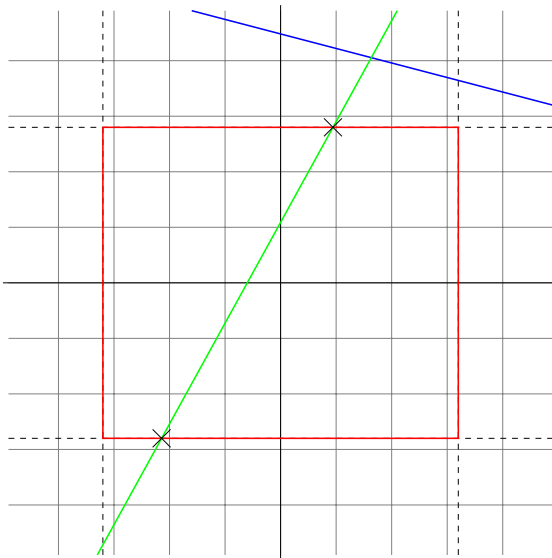


Figure 3.10: Two example lines and the viewport box

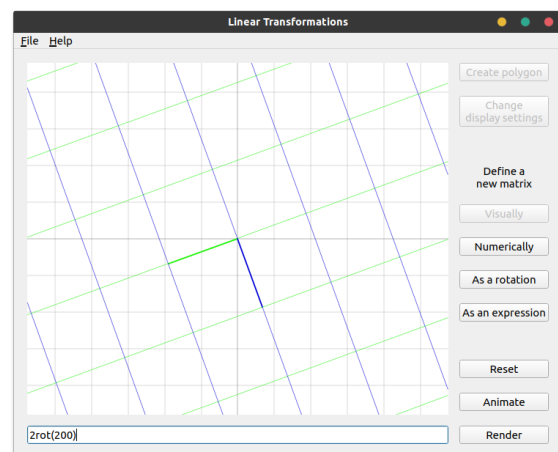


Figure 3.11: A demonstration of the new oblique lines system.

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 myi, mmyi, mxi, and

`mmxi` variables represent. The value of `myi` is the x value where the line intersects the maximum y line, for example.

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

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

3.4.2 Adding vector arrowheads

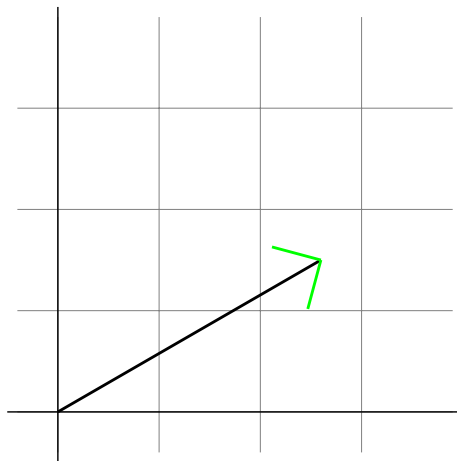


Figure 3.12: An example of a vector with the arrowheads highlighted in green

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.com¹¹, which I adapted for Python.

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

```
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))
```

¹¹This website is currently being rewritten and this arrowheads tutorial is listed as 'not rebuilt' on <http://csharpshelper.com>

```

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()`.

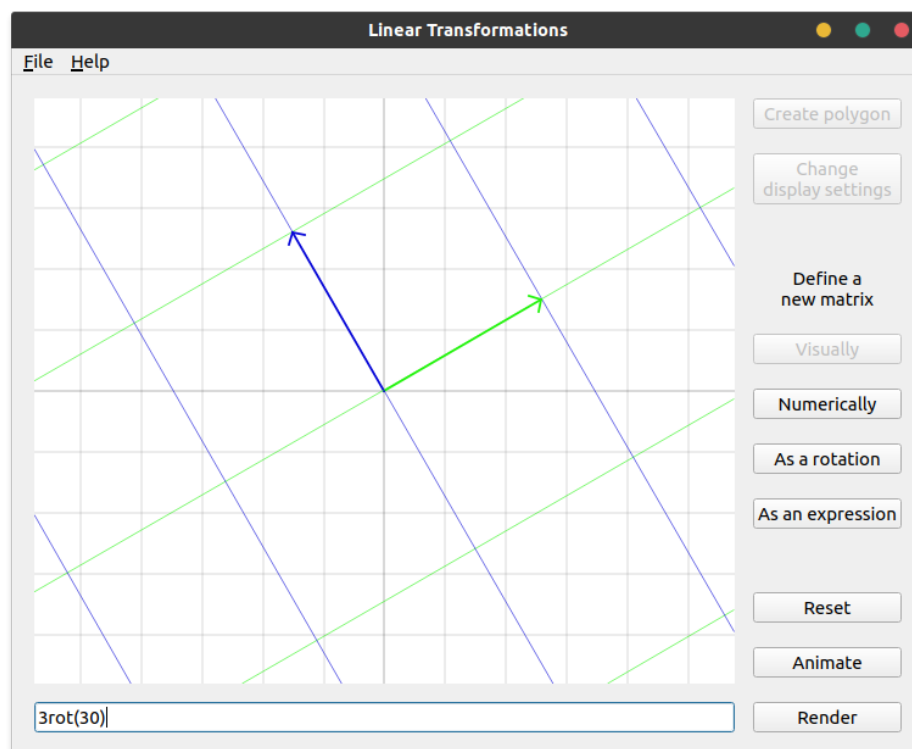


Figure 3.13: An example of the i and j vectors with arrowheads

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

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

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.

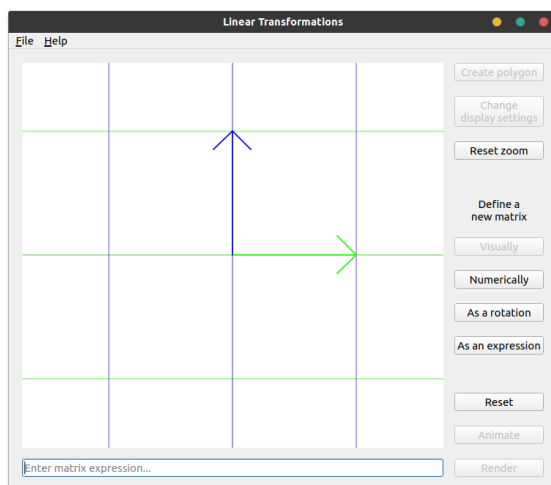


Figure 3.14: The GUI zoomed in a bit

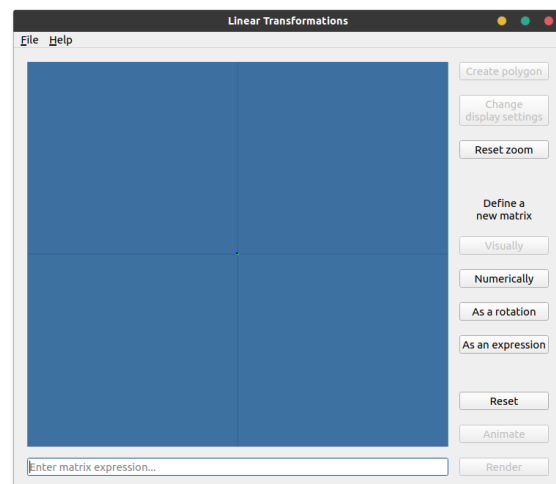


Figure 3.15: The GUI zoomed out as far as possible

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

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.

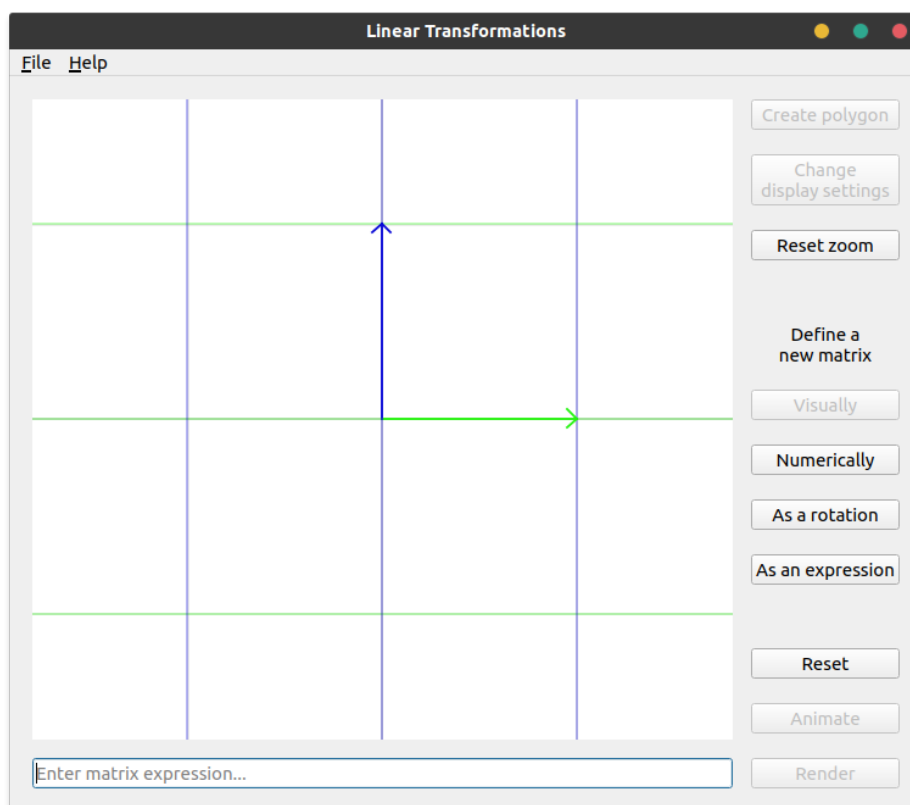


Figure 3.16: The arrowheads adjusted for zoom level

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.msleep()` allows for asynchronous processing and therefore non-blocking animation.

3.4.5 Rank 1 transformations

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

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

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

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

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

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 matrix¹².

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

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
```

¹²This commit didn't get a standalone section in this write-up because it was so small


```

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

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

```

```

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

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) ->
↳ None:
299         """Animate from the start matrix to the target matrix."""
300         det_target = linalg.det(matrix_target)
301         det_start = linalg.det(matrix_start)
302
303         for i in range(0, steps + 1):
304             # This proportion is how far we are through the loop
305             proportion = i / steps
306
307             # matrix_a is the start matrix plus some part of the target, scaled by the proportion
308             # If we just used matrix_a, then things would animate, but the determinants would be weird
309             matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
310
311             # So to fix the determinant problem, we get the determinant of matrix_a and use it to normalise
312             det_a = linalg.det(matrix_a)
313
314             # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
315             # We want B = cA such that det(B) = det(S), where S is the start matrix,
316             # so then we can scale it with the animation, so we get
317             # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
318             # Then we scale A to get the determinant we want, and call that matrix_b
319             if det_a == 0:
320                 c = 0
321             else:
322                 c = np.sqrt(abs(det_start / det_a))
323
324             matrix_b = c * matrix_a
325             det_b = linalg.det(matrix_b)
326
327             # matrix_c is the final matrix that we then render for this frame
328             # It's B, but we scale it over time to have the target determinant
329
330             # We want some C = dB such that det(C) is some target determinant T
331             # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
332
333             # We're also subtracting 1 and multiplying by the proportion and then adding one
334             # This just scales the determinant along with the animation
335             scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
336
337             # If we're animating towards a det 0 matrix, then we don't want to scale the
338             # determinant with the animation, because this makes the process not work
339             # I'm doing this here rather than wrapping the whole animation logic in an
340             # if block mainly because this looks nicer than an extra level of indentation
341             # The extra processing cost is negligible thanks to NumPy's optimizations
342             if det_target == 0:
343                 matrix_c = matrix_a
344             else:
345                 matrix_c = scalar * matrix_b
346
347             if self.is_matrix_too_big(matrix_c):
348                 self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
349                 return
350
351             self.plot.visualize_matrix_transformation(matrix_c)
352
353             # 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 animation¹³, 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

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)
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)
```

¹³I have since changed my thoughts on this, and I allowed sequential transitional animation much later, in commit 41907b81661f3878e435b794d9d719491ef14237

```

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

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

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

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

286 def animate_expression(self) -> None:
287     """Animate from the current matrix to the matrix in the expression box."""
288     self.button_render.setEnabled(False)
289     self.button_animate.setEnabled(False)
290
291     matrix_start: MatrixType = np.array([
292         [self.plot.point_i[0], self.plot.point_j[0]],
293         [self.plot.point_i[1], self.plot.point_j[1]]
294     ])
295
296     text = self.lineedit_expression_box.text()
297
298     # If there's commas in the expression, then we want to animate each part at a time
299     if ',' in text:
300         current_matrix = matrix_start
301
302         # For each expression in the list, right multiply it by the current matrix,
303         # and animate from the current matrix to that new matrix
304         for expr in text.split(',')[:-1]:
305             new_matrix = self.matrix_wrapper.evaluate_expression(expr) @ current_matrix
306
307             self.animate_between_matrices(current_matrix, new_matrix)
308             current_matrix = new_matrix
309
310             # Here we just redraw and allow for other events to be handled while we pause
311             self.plot.update()
312             QApplication.processEvents()
313             QThread.sleep(self.display_settings.animation_pause_length)
314
315     # If there's no commas, then just animate directly from the start to the target
316     else:
317         # Get the target matrix and it's determinant
318         try:
319             matrix_target = self.matrix_wrapper.evaluate_expression(text)
320
321         except linalg.LinAlgError:
322             self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
323             return
324
325     # The concept of applicative animation is explained in /gui/settings.py
326     if self.display_settings.applicative_animation:
327         matrix_target = matrix_target @ matrix_start

```



```

328
329         self.animate_between_matrices(matrix_start, matrix_target)
330
331     self.update_render_buttons()

```

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

333     def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType, steps: int = 100) ->
334         ↪ None:
335         """Animate from the start matrix to the target matrix."""
336         det_target = linalg.det(matrix_target)
337         det_start = linalg.det(matrix_start)
338
339         for i in range(0, steps + 1):
340             # This proportion is how far we are through the loop
341             proportion = i / steps
342
343             # matrix_a is the start matrix plus some part of the target, scaled by the proportion
344             # If we just used matrix_a, then things would animate, but the determinants would be weird
345             matrix_a = matrix_start + proportion * (matrix_target - matrix_start)
346
347             if self.display_settings.animate_determinant and det_target != 0:
348                 # To fix the determinant problem, we get the determinant of matrix_a and use it to normalise
349                 det_a = linalg.det(matrix_a)
350
351                 # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
352                 # We want B = cA such that det(B) = det(S), where S is the start matrix,
353                 # so then we can scale it with the animation, so we get
354                 # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
355                 # Then we scale A to get the determinant we want, and call that matrix_b
356                 if det_a == 0:
357                     c = 0
358                 else:
359                     c = np.sqrt(abs(det_start / det_a))
360
361                 matrix_b = c * matrix_a
362                 det_b = linalg.det(matrix_b)
363
364                 # matrix_to_render is the final matrix that we then render for this frame
365                 # It's B, but we scale it over time to have the target determinant
366
367                 # We want some C = dB such that det(C) is some target determinant T
368                 # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
369
370                 # We're also subtracting 1 and multiplying by the proportion and then adding one
371                 # This just scales the determinant along with the animation
372                 scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
373                 matrix_to_render = scalar * matrix_b
374
375             else:
376                 matrix_to_render = matrix_a
377
378             if self.is_matrix_too_big(matrix_to_render):
379                 self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
380                 return
381
382             self.plot.visualize_matrix_transformation(matrix_to_render)
383
384             # We schedule the plot to be updated, tell the event loop to
385             # process events, and asynchronously sleep for 10ms
386             # This allows for other events to be processed while animating, like zooming in and out
387             self.plot.update()
388             QApplication.processEvents()
389             QThread.sleep(1000 // steps)

```

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A Project code

A.1 `__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 gui, matrices, typing_
10
11  __version__ = '0.3.0-alpha'
12
13  __all__ = ['gui', 'matrices', 'typing_', '__version__']

```

A.2 `__main__.py`

```

1  #!/usr/bin/env python
2
3  # lintrans - The linear transformation visualizer
4  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
5
6  # This program is licensed under GNU GPLv3, available here:
7  # <https://www.gnu.org/licenses/gpl-3.0.html>
8
9  """This module provides a :func:`main` function to interpret command line arguments and run the program."""
10
11  import sys
12  from argparse import ArgumentParser
13  from textwrap import dedent
14  from typing import List
15
16  from lintrans import __version__, gui
17
18
19  def main(args: List[str]) -> None:
20      """Interpret program-specific command line arguments and run the main window in most cases.
21
22      If the user supplies --help or --version, then we simply respond to that and then return.
23      If they don't supply either of these, then we run :func:`lintrans.gui.main_window.main`.
24
25      :param List[str] args: The full argument list (including program name)
26      """
27      parser = ArgumentParser(add_help=False)
28
29      parser.add_argument(
30          '-h',
31          '--help',
32          default=False,
33          action='store_true'
34      )
35
36      parser.add_argument(
37          '-V',
38          '--version',
39          default=False,
40          action='store_true'
41      )
42
43      parsed_args, unparsed_args = parser.parse_known_args()
44
45      if parsed_args.help:
46          print(dedent('''
47              Usage: lintrans [option]
48          '''))

```

```

49         Options:
50             -h, --help      Display this help text and exit
51             -V, --version   Display the version information and exit
52
53         Any other options will get passed to the QApplication constructor.
54         If you don't know what that means, then don't provide any arguments and just the run the program.'''[1:]))
55         return
56
57     if parsed_args.version:
58         print(dedent(f'''
59             lintrans (version {__version__})
60             The linear transformation visualizer
61
62             Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
63
64             This program is licensed under GNU GPLv3, available here:
65             <https://www.gnu.org/licenses/gpl-3.0.html>'''[1:]))
66         return
67
68     for arg in unparsed_args:
69         print(f'Passing "{arg}" to QApplication. See --help for recognised args')
70
71     gui.main(args[:1] + unparsed_args)
72
73
74 if __name__ == '__main__':
75     main(sys.argv)

```

A.3 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 re
12  import sys
13  import webbrowser
14  from copy import deepcopy
15  from typing import List, Tuple, Type
16
17  import numpy as np
18  from numpy import linalg
19  from numpy.linalg import LinAlgError
20  from PyQt5 import QtWidgets
21  from PyQt5.QtCore import pyqtSlot, QApplication, QThread
22  from PyQt5.QtGui import QCloseEvent, QKeySequence
23  from PyQt5.QtWidgets import (QApplication, QHBoxLayout, QMainWindow, QMessageBox,
24                               QShortcut, QSizePolicy, QSpacerItem, QStyleFactory, QVBoxLayout)
25
26  import lintrans
27  from lintrans.matrices import MatrixWrapper
28  from lintrans.matrices.parse import validate_matrix_expression
29  from lintrans.matrices.utility import polar_coords, rotate_coord
30  from lintrans.typing_ import MatrixType, VectorType
31  from .dialogs import (AboutDialog, DefineAsAnExpressionDialog, DefinedDialog,
32                       DefineNumericallyDialog, DefineVisuallyDialog, InfoPanelDialog)
33  from .dialogs.settings import DisplaySettingsDialog
34  from .plots import VisualizeTransformationWidget
35  from .settings import DisplaySettings
36  from .validate import MatrixExpressionValidator
37
38
39  class LintransMainWindow(QMainWindow):
40     """This class provides a main window for the GUI using the Qt framework.

```

```

41
42 This class should not be used directly, instead call :func:`lintrans.gui.main_window.main` to create the GUI.
43 """
44
45 def __init__(self):
46     """Create the main window object, and create and arrange every widget in it.
47
48     This doesn't show the window, it just constructs it.
49     Use :func:`lintrans.gui.main_window.main` to show the GUI.
50     """
51     super().__init__()
52
53     self.matrix_wrapper = MatrixWrapper()
54
55     self.setWindowTitle('lintrans')
56     self.setMinimumSize(1000, 750)
57
58     self.animating: bool = False
59     self.animating_sequence: bool = False
60
61     # == Create menubar
62
63     self.menubar = QtWidgets.QMenuBar(self)
64
65     self.menu_file = QtWidgets.QMenu(self.menubar)
66     self.menu_file.setTitle('&File')
67
68     self.menu_help = QtWidgets.QMenu(self.menubar)
69     self.menu_help.setTitle('&Help')
70
71     self.action_new = QtWidgets.QAction(self)
72     self.action_new.setText('&New')
73     self.action_new.setShortcut('Ctrl+N')
74     self.action_new.triggered.connect(lambda: print('new'))
75
76     self.action_open = QtWidgets.QAction(self)
77     self.action_open.setText('&Open')
78     self.action_open.setShortcut('Ctrl+O')
79     self.action_open.triggered.connect(lambda: print('open'))
80
81     self.action_save = QtWidgets.QAction(self)
82     self.action_save.setText('&Save')
83     self.action_save.setShortcut('Ctrl+S')
84     self.action_save.triggered.connect(lambda: print('save'))
85
86     self.action_save_as = QtWidgets.QAction(self)
87     self.action_save_as.setText('Save as...')
88     self.action_save_as.triggered.connect(lambda: print('save as'))
89
90     self.action_tutorial = QtWidgets.QAction(self)
91     self.action_tutorial.setText('&Tutorial')
92     self.action_tutorial.setShortcut('F1')
93     self.action_tutorial.triggered.connect(lambda: print('tutorial'))
94
95     self.action_docs = QtWidgets.QAction(self)
96     self.action_docs.setText('&Docs')
97
98     # If this is an old release, use the docs for this release. Else, use the latest docs
99     # We use the latest because most use cases for non-stable releases will be in development and testing
100     docs_link = 'https://lintrans.readthedocs.io/en/'
101
102     if re.match(r'^\d+\.\d+\.\d+$', lintrans.__version__):
103         docs_link += 'v' + lintrans.__version__
104     else:
105         docs_link += 'latest'
106
107     self.action_docs.triggered.connect(
108         lambda: webbrowser.open_new_tab(docs_link)
109     )
110
111     self.action_about = QtWidgets.QAction(self)
112     self.action_about.setText('&About')
113     self.action_about.triggered.connect(lambda: AboutDialog(self).open())

```

```

114
115     # TODO: Implement these actions and enable them
116     self.action_new.setEnabled(False)
117     self.action_open.setEnabled(False)
118     self.action_save.setEnabled(False)
119     self.action_save_as.setEnabled(False)
120     self.action_tutorial.setEnabled(False)
121
122     self.menu_file.addAction(self.action_new)
123     self.menu_file.addAction(self.action_open)
124     self.menu_file.addSeparator()
125     self.menu_file.addAction(self.action_save)
126     self.menu_file.addAction(self.action_save_as)
127
128     self.menu_help.addAction(self.action_tutorial)
129     self.menu_help.addAction(self.action_docs)
130     self.menu_help.addSeparator()
131     self.menu_help.addAction(self.action_about)
132
133     self.menubar.addAction(self.menu_file.menuAction())
134     self.menubar.addAction(self.menu_help.menuAction())
135
136     self.setMenuBar(self.menubar)
137
138     # === Create widgets
139
140     # Left layout: the plot and input box
141
142     self.plot = VisualizeTransformationWidget(self, display_settings=DisplaySettings())
143
144     self.lineedit_expression_box = QtWidgets.QLineEdit(self)
145     self.lineedit_expression_box.setPlaceholderText('Enter matrix expression...')
146     self.lineedit_expression_box.setValidator(MatrixExpressionValidator(self))
147     self.lineedit_expression_box.textChanged.connect(self.update_render_buttons)
148
149     # Right layout: all the buttons
150
151     # Misc buttons
152
153     self.button_create_polygon = QtWidgets.QPushButton(self)
154     self.button_create_polygon.setText('Create polygon')
155     # self.button_create_polygon.clicked.connect(self.create_polygon)
156     self.button_create_polygon.setToolTip('Define a new polygon to view the transformation of')
157
158     # TODO: Implement this and enable button
159     self.button_create_polygon.setEnabled(False)
160
161     self.button_change_display_settings = QtWidgets.QPushButton(self)
162     self.button_change_display_settings.setText('Change\ndisplay settings')
163     self.button_change_display_settings.clicked.connect(self.dialog_change_display_settings)
164     self.button_change_display_settings.setToolTip(
165         "Change which things are rendered and how they're rendered<br><b>(Ctrl + D)</b>"
166     )
167     QShortcut(QKeySequence('Ctrl+D'), self).activated.connect(self.button_change_display_settings.click)
168
169     self.button_reset_zoom = QtWidgets.QPushButton(self)
170     self.button_reset_zoom.setText('Reset zoom')
171     self.button_reset_zoom.clicked.connect(self.reset_zoom)
172     self.button_reset_zoom.setToolTip('Reset the zoom level back to normal<br><b>(Ctrl + Shift + R)</b>')
173     QShortcut(QKeySequence('Ctrl+Shift+R'), self).activated.connect(self.button_reset_zoom.click)
174
175     # Define new matrix buttons and their groupbox
176
177     self.button_define_visually = QtWidgets.QPushButton(self)
178     self.button_define_visually.setText('Visually')
179     self.button_define_visually.setToolTip('Drag the basis vectors<br><b>(Alt + 1)</b>')
180     self.button_define_visually.clicked.connect(lambda: self.dialog_define_matrix(DefineVisuallyDialog))
181     QShortcut(QKeySequence('Alt+1'), self).activated.connect(self.button_define_visually.click)
182
183     self.button_define_numerically = QtWidgets.QPushButton(self)
184     self.button_define_numerically.setText('Numerically')
185     self.button_define_numerically.setToolTip('Define a matrix just with numbers<br><b>(Alt + 2)</b>')
186     self.button_define_numerically.clicked.connect(lambda: self.dialog_define_matrix(DefineNumericallyDialog))

```

```

187     QShortcut(QKeySequence( 'Alt+2' ), self).activated.connect(self.button_define_numerically.click)
188
189     self.button_define_as_expression = QtWidgets.QPushButton(self)
190     self.button_define_as_expression.setText('As an expression')
191     self.button_define_as_expression.setToolTip('Define a matrix in terms of other matrices<br><b>(Alt +  

    ↳ 3)</b>')
192     self.button_define_as_expression.clicked.connect(lambda:
    ↳ self.dialog_define_matrix(DefineAsAnExpressionDialog))
193     QShortcut(QKeySequence( 'Alt+3' ), self).activated.connect(self.button_define_as_expression.click)
194
195     self.vlay_define_new_matrix = QVBoxLayout()
196     self.vlay_define_new_matrix.setSpacing(20)
197     self.vlay_define_new_matrix.addWidget(self.button_define_visually)
198     self.vlay_define_new_matrix.addWidget(self.button_define_numerically)
199     self.vlay_define_new_matrix.addWidget(self.button_define_as_expression)
200
201     self.groupbox_define_new_matrix = QtWidgets.QGroupBox('Define a new matrix', self)
202     self.groupbox_define_new_matrix.setLayout(self.vlay_define_new_matrix)
203
204     # Info panel button
205
206     self.button_info_panel = QtWidgets.QPushButton(self)
207     self.button_info_panel.setText('Show defined matrices')
208     self.button_info_panel.clicked.connect(
209         # We have to use a lambda instead of 'InfoPanelDialog(self.matrix_wrapper, self).open' here
210         # because that would create an unnamed instance of InfoPanelDialog when LintransMainWindow is
211         # constructed, but we need to create a new instance every time to keep self.matrix_wrapper up to date
212         lambda: InfoPanelDialog(self.matrix_wrapper, self).open()
213     )
214     self.button_info_panel.setToolTip(
215         'Open an info panel with all matrices that have been defined in this session<br><b>(Ctrl + M)</b>'
216     )
217     QShortcut(QKeySequence( 'Ctrl+M' ), self).activated.connect(self.button_info_panel.click)
218
219     # Render buttons
220
221     self.button_reset = QtWidgets.QPushButton(self)
222     self.button_reset.setText('Reset')
223     self.button_reset.clicked.connect(self.reset_transformation)
224     self.button_reset.setToolTip('Reset the visualized transformation back to the identity<br><b>(Ctrl +  

    ↳ R)</b>')
225     QShortcut(QKeySequence( 'Ctrl+R' ), self).activated.connect(self.button_reset.click)
226
227     self.button_render = QtWidgets.QPushButton(self)
228     self.button_render.setText('Render')
229     self.button_render.setEnabled(False)
230     self.button_render.clicked.connect(self.render_expression)
231     self.button_render.setToolTip('Render the expression<br><b>(Ctrl + Enter)</b>')
232     QShortcut(QKeySequence( 'Ctrl+Return' ), self).activated.connect(self.button_render.click)
233
234     self.button_animate = QtWidgets.QPushButton(self)
235     self.button_animate.setText('Animate')
236     self.button_animate.setEnabled(False)
237     self.button_animate.clicked.connect(self.animate_expression)
238     self.button_animate.setToolTip('Animate the expression<br><b>(Ctrl + Shift + Enter)</b>')
239     QShortcut(QKeySequence( 'Ctrl+Shift+Return' ), self).activated.connect(self.button_animate.click)
240
241     # == Arrange widgets
242
243     self.vlay_left = QVBoxLayout()
244     self.vlay_left.addWidget(self.plot)
245     self.vlay_left.addWidget(self.lineedit_expression_box)
246
247     self.vlay_misc_buttons = QVBoxLayout()
248     self.vlay_misc_buttons.setSpacing(20)
249     self.vlay_misc_buttons.addWidget(self.button_create_polygon)
250     self.vlay_misc_buttons.addWidget(self.button_change_display_settings)
251     self.vlay_misc_buttons.addWidget(self.button_reset_zoom)
252
253     self.vlay_info_buttons = QVBoxLayout()
254     self.vlay_info_buttons.setSpacing(20)
255     self.vlay_info_buttons.addWidget(self.button_info_panel)
256

```

```

257     self.vlay_render = QVBoxLayout()
258     self.vlay_render.setSpacing(20)
259     self.vlay_render.addWidget(self.button_reset)
260     self.vlay_render.addWidget(self.button_animate)
261     self.vlay_render.addWidget(self.button_render)
262
263     self.vlay_right = QVBoxLayout()
264     self.vlay_right.setSpacing(50)
265     self.vlay_right.addLayout(self.vlay_misc_buttons)
266     self.vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
267     self.vlay_right.addWidget(self.groupbox_define_new_matrix)
268     self.vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
269     self.vlay_right.addLayout(self.vlay_info_buttons)
270     self.vlay_right.addItem(QSpacerItem(100, 2, hPolicy=QSizePolicy.Minimum, vPolicy=QSizePolicy.Expanding))
271     self.vlay_right.addLayout(self.vlay_render)
272
273     self.hlay_all = QHBoxLayout()
274     self.hlay_all.setSpacing(15)
275     self.hlay_all.addLayout(self.vlay_left)
276     self.hlay_all.addLayout(self.vlay_right)
277
278     self.central_widget = QtWidgets.QWidget()
279     self.central_widget.setLayout(self.hlay_all)
280     self.central_widget.setContentsMargins(10, 10, 10, 10)
281
282     self.setCentralWidget(self.central_widget)
283
284     def closeEvent(self, event: QCloseEvent) -> None:
285         """Handle a :class:`QCloseEvent` by cancelling animation first."""
286         self.animating = False
287         event.accept()
288
289     def update_render_buttons(self) -> None:
290         """Enable or disable the render and animate buttons according to whether the matrix expression is valid."""
291         text = self.linedit_expression_box.text()
292
293         # Let's say that the user defines a non-singular matrix A, then defines B as A^-1
294         # If they then redefine A and make it singular, then we get a LinAlgError when
295         # trying to evaluate an expression with B in it
296         # To fix this, we just do naive validation rather than aware validation
297         if ',' in text:
298             self.button_render.setEnabled(False)
299
300             try:
301                 valid = all(self.matrix_wrapper.is_valid_expression(x) for x in text.split(','))
302             except LinAlgError:
303                 valid = all(validate_matrix_expression(x) for x in text.split(','))
304
305             self.button_animate.setEnabled(valid)
306
307         else:
308             try:
309                 valid = self.matrix_wrapper.is_valid_expression(text)
310             except LinAlgError:
311                 valid = validate_matrix_expression(text)
312
313             self.button_render.setEnabled(valid)
314             self.button_animate.setEnabled(valid)
315
316     @pyqtSlot()
317     def reset_zoom(self) -> None:
318         """Reset the zoom level back to normal."""
319         self.plot.grid_spacing = self.plot.default_grid_spacing
320         self.plot.update()
321
322     @pyqtSlot()
323     def reset_transformation(self) -> None:
324         """Reset the visualized transformation back to the identity."""
325         self.plot.visualize_matrix_transformation(self.matrix_wrapper['I'])
326         self.animating = False
327         self.animating_sequence = False
328         self.plot.update()
329

```



```

330     @pyqtSlot()
331     def render_expression(self) -> None:
332         """Render the transformation given by the expression in the input box."""
333         try:
334             matrix = self.matrix_wrapper.evaluate_expression(self.lineEdit_expression_box.text())
335
336         except LinAlgError:
337             self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
338             return
339
340         if self.is_matrix_too_big(matrix):
341             self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
342             return
343
344         self.plot.visualize_matrix_transformation(matrix)
345         self.plot.update()
346
347     @pyqtSlot()
348     def animate_expression(self) -> None:
349         """Animate from the current matrix to the matrix in the expression box."""
350         self.button_render.setEnabled(False)
351         self.button_animate.setEnabled(False)
352
353         matrix_start: MatrixType = np.array([
354             [self.plot.point_i[0], self.plot.point_j[0]],
355             [self.plot.point_i[1], self.plot.point_j[1]]
356         ])
357
358         text = self.lineEdit_expression_box.text()
359
360         # If there's commas in the expression, then we want to animate each part at a time
361         if ',' in text:
362             current_matrix = matrix_start
363             self.animating_sequence = True
364
365             # For each expression in the list, right multiply it by the current matrix,
366             # and animate from the current matrix to that new matrix
367             for expr in text.split(',')[::-1]:
368                 try:
369                     new_matrix = self.matrix_wrapper.evaluate_expression(expr)
370
371                     if self.plot.display_settings.applicative_animation:
372                         new_matrix = new_matrix @ current_matrix
373                 except LinAlgError:
374                     self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
375                     return
376
377                 if not self.animating_sequence:
378                     break
379
380                 self.animate_between_matrices(current_matrix, new_matrix)
381                 current_matrix = new_matrix
382
383                 # Here we just redraw and allow for other events to be handled while we pause
384                 self.plot.update()
385                 QApplication.processEvents()
386                 QThread.msleep(self.plot.display_settings.animation_pause_length)
387
388             self.animating_sequence = False
389
390         # If there's no commas, then just animate directly from the start to the target
391         else:
392             # Get the target matrix and it's determinant
393             try:
394                 matrix_target = self.matrix_wrapper.evaluate_expression(text)
395
396             except LinAlgError:
397                 self.show_error_message('Singular matrix', 'Cannot take inverse of singular matrix')
398                 return
399
400             # The concept of applicative animation is explained in /gui/settings.py
401             if self.plot.display_settings.applicative_animation:
402                 matrix_target = matrix_target @ matrix_start

```

```

403
404     # If we want a transitional animation and we're animating the same matrix, then restart the animation
405     # We use this check rather than equality because of small floating point errors
406     elif (abs(matrix_start - matrix_target) < 1e-12).all():
407         matrix_start = self.matrix_wrapper['I']
408
409         # We pause here for 200 ms to make the animation look a bit nicer
410         self.plot.visualize_matrix_transformation(matrix_start)
411         self.plot.update()
412         QApplication.processEvents()
413         QThread.sleep(200)
414
415         self.animate_between_matrices(matrix_start, matrix_target)
416
417     self.update_render_buttons()
418
419 def _get_animation_frame(self, start: MatrixType, target: MatrixType, proportion: float) -> MatrixType:
420     """Get the matrix to render for this frame of the animation.
421
422     This method will smoothen the determinant if that setting is enabled and if the determinant is positive.
423     It also animates rotation-like matrices using a logarithmic spiral to rotate around and scale continuously.
424     Essentially, it just makes things look good when animating.
425
426     :param MatrixType start: The starting matrix
427     :param MatrixType target: The target matrix
428     :param float proportion: How far we are through the loop
429     """
430     det_target = linalg.det(target)
431     det_start = linalg.det(start)
432
433     # This is the matrix that we're applying to get from start to target
434     # We want to check if it's rotation-like
435     if linalg.det(start) == 0:
436         matrix_application = None
437     else:
438         matrix_application = target @ linalg.inv(start)
439
440     # For a matrix to represent a rotation, it must have a positive determinant,
441     # its vectors must be perpendicular, and its vectors must be the same length
442     # The checks for 'abs(value) < 1e-10' are to account for floating point error
443     if matrix_application is not None \
444         and self.plot.display_settings.smoothen_determinant \
445         and linalg.det(matrix_application) > 0 \
446         and abs(np.dot(matrix_application.T[0], matrix_application.T[1])) < 1e-10 \
447         and abs(np.hypot(*matrix_application.T[0]) - np.hypot(*matrix_application.T[1])) < 1e-10:
448         rotation_vector: VectorType = matrix_application.T[0] # Take the i column
449         radius, angle = polar_coords(*rotation_vector)
450
451         # We want the angle to be in [-pi, pi), so we have to subtract 2pi from it if it's too big
452         if angle > np.pi:
453             angle -= 2 * np.pi
454
455         i: VectorType = start.T[0]
456         j: VectorType = start.T[1]
457
458         # Scale the coords with a list comprehension
459         # It's a bit janky, but rotate_coords() will always return a 2-tuple,
460         # so new_i and new_j will always be lists of length 2
461         scale = (radius - 1) * proportion + 1
462         new_i = [scale * c for c in rotate_coord(i[0], i[1], angle * proportion)]
463         new_j = [scale * c for c in rotate_coord(j[0], j[1], angle * proportion)]
464
465         return np.array(
466             [
467                 [new_i[0], new_j[0]],
468                 [new_i[1], new_j[1]]
469             ]
470         )
471
472     # matrix_a is the start matrix plus some part of the target, scaled by the proportion
473     # If we just used matrix_a, then things would animate, but the determinants would be weird
474     matrix_a = start + proportion * (target - start)
475

```

```

476     if not self.plot.display_settings.smoothen_determinant or det_start * det_target <= 0:
477         return matrix_a
478
479     # To fix the determinant problem, we get the determinant of matrix_a and use it to normalize
480     det_a = linalg.det(matrix_a)
481
482     # For a 2x2 matrix A and a scalar c, we know that det(cA) = c^2 det(A)
483     # We want B = cA such that det(B) = det(S), where S is the start matrix,
484     # so then we can scale it with the animation, so we get
485     # det(cA) = c^2 det(A) = det(S) => c = sqrt(abs(det(S) / det(A)))
486     # Then we scale A to get the determinant we want, and call that matrix_b
487     if det_a == 0:
488         c = 0
489     else:
490         c = np.sqrt(abs(det_start / det_a))
491
492     matrix_b = c * matrix_a
493     det_b = linalg.det(matrix_b)
494
495     # We want to return B, but we have to scale it over time to have the target determinant
496
497     # We want some C = dB such that det(C) is some target determinant T
498     # det(dB) = d^2 det(B) = T => d = sqrt(abs(T / det(B)))
499
500     # We're also subtracting 1 and multiplying by the proportion and then adding one
501     # This just scales the determinant along with the animation
502
503     # That is all of course, if we can do that
504     # We'll crash if we try to do this with det(B) == 0
505     if det_b == 0:
506         return matrix_a
507
508     scalar = 1 + proportion * (np.sqrt(abs(det_target / det_b)) - 1)
509     return scalar * matrix_b
510
511 def animate_between_matrices(self, matrix_start: MatrixType, matrix_target: MatrixType) -> None:
512     """Animate from the start matrix to the target matrix."""
513     self.animating = True
514
515     # Making steps depend on animation_time ensures a smooth animation without
516     # massive overheads for small animation times
517     steps = self.plot.display_settings.animation_time // 10
518
519     for i in range(0, steps + 1):
520         if not self.animating:
521             break
522
523         matrix_to_render = self._get_animation_frame(matrix_start, matrix_target, i / steps)
524
525         if self.is_matrix_too_big(matrix_to_render):
526             self.show_error_message('Matrix too big', "This matrix doesn't fit on the canvas")
527             self.animating = False
528             return
529
530         self.plot.visualize_matrix_transformation(matrix_to_render)
531
532         # We schedule the plot to be updated, tell the event loop to
533         # process events, and asynchronously sleep for 10ms
534         # This allows for other events to be processed while animating, like zooming in and out
535         self.plot.update()
536         QApplication.processEvents()
537         QThread.sleep(self.plot.display_settings.animation_time // steps)
538
539     self.animating = False
540
541 @pyqtSlot(DefineDialog)
542 def dialog_define_matrix(self, dialog_class: Type[DefineDialog]) -> None:
543     """Open a generic definition dialog to define a new matrix.
544
545     The class for the desired dialog is passed as an argument. We create an
546     instance of this class and the dialog is opened asynchronously and modally
547     (meaning it blocks interaction with the main window) with the proper method
548     connected to the :meth:`QDialog.accepted` signal.

```

```

549
550 .. note:: ``dialog_class`` must subclass :class:`lintrans.gui.dialogs.define_new_matrix.DefineDialog`.
551
552 :param dialog_class: The dialog class to instantiate
553 :type dialog_class: Type[lintrans.gui.dialogs.define_new_matrix.DefineDialog]
554 """
555 # We create a dialog with a deepcopy of the current matrix_wrapper
556 # This avoids the dialog mutating this one
557 dialog: DefineDialog
558
559 if dialog_class == DefineVisuallyDialog:
560     dialog = DefineVisuallyDialog(
561         self,
562         matrix_wrapper=deepcopy(self.matrix_wrapper),
563         display_settings=self.plot.display_settings
564     )
565 else:
566     dialog = dialog_class(self, matrix_wrapper=deepcopy(self.matrix_wrapper))
567
568 # .open() is asynchronous and doesn't spawn a new event loop, but the dialog is still modal (blocking)
569 dialog.open()
570
571 # So we have to use the accepted signal to call a method when the user accepts the dialog
572 dialog.accepted.connect(self.assign_matrix_wrapper)
573
574 @pyqtSlot()
575 def assign_matrix_wrapper(self) -> None:
576     """Assign a new value to ``self.matrix_wrapper`` and give the expression box focus."""
577     self.matrix_wrapper = self.sender().matrix_wrapper
578     self.lineedit_expression_box.setFocus()
579     self.update_render_buttons()
580
581 @pyqtSlot()
582 def dialog_change_display_settings(self) -> None:
583     """Open the dialog to change the display settings."""
584     dialog = DisplaySettingsDialog(self, display_settings=self.plot.display_settings)
585     dialog.open()
586     dialog.accepted.connect(lambda: self.assign_display_settings(dialog.display_settings))
587
588 @pyqtSlot(DisplaySettings)
589 def assign_display_settings(self, display_settings: DisplaySettings) -> None:
590     """Assign a new value to ``self.plot.display_settings`` and give the expression box focus."""
591     self.plot.display_settings = display_settings
592     self.plot.update()
593     self.lineedit_expression_box.setFocus()
594     self.update_render_buttons()
595
596 def show_error_message(self, title: str, text: str, info: str | None = None) -> None:
597     """Show an error message in a dialog box.
598
599     :param str title: The window title of the dialog box
600     :param str text: The simple error message
601     :param info: The more informative error message
602     :type info: Optional[str]
603     """
604     dialog = QMessageBox(self)
605     dialog.setIcon(QMessageBox.Critical)
606     dialog.setWindowTitle(title)
607     dialog.setText(text)
608
609     if info is not None:
610         dialog.setInformativeText(info)
611
612     dialog.open()
613
614 # This is `finished` rather than `accepted` because we want to update the buttons no matter what
615 dialog.finished.connect(self.update_render_buttons)
616
617 def is_matrix_too_big(self, matrix: MatrixType) -> bool:
618     """Check if the given matrix will actually fit onto the canvas.
619
620     Convert the elements of the matrix to canvas coords and make sure they fit within Qt's 32-bit integer limit.
621

```

```

622         :param MatrixType matrix: The matrix to check
623         :returns bool: Whether the matrix is too big to fit on the canvas
624         """
625         coords: List[Tuple[int, int]] = [self.plot.canvas_coords(*vector) for vector in matrix.T]
626
627         for x, y in coords:
628             if not (-2147483648 <= x <= 2147483647 and -2147483648 <= y <= 2147483647):
629                 return True
630
631         return False
632
633
634 def qapp() -> QCoreApplication:
635     """Return the equivalent of the global :class:`QApp` pointer.
636
637     :raises RuntimeError: If :meth:`QCoreApplication.instance` returns ``None``
638     """
639     instance = QCoreApplication.instance()
640
641     if instance is None:
642         raise RuntimeError('qApp undefined')
643
644     return instance
645
646
647 def main(args: List[str]) -> None:
648     """Run the GUI by creating and showing an instance of :class:`LintransMainWindow`.
649
650     :param List[str] args: The args to pass to :class:`QApplication`
651     """
652     app = QApplication(args)
653     app.setApplicationName('lintrans')
654     app.setApplicationVersion(lintrans.__version__)
655
656     qapp().setStyle(QStyleFactory.create('fusion'))
657
658     window = LintransMainWindow()
659     window.show()
660
661     sys.exit(app.exec_())

```

A.4 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  from dataclasses import dataclass
12
13
14  @dataclass
15  class DisplaySettings:
16      """This class simply holds some attributes to configure display."""
17
18      # === Basic stuff
19
20      draw_background_grid: bool = True
21      """This controls whether we want to draw the background grid.
22
23      The background axes will always be drawn. This makes it easy to identify the center of the space.
24      """
25
26      draw_transformed_grid: bool = True
27      """This controls whether we want to draw the transformed grid. Vectors are handled separately."""

```

```

28
29 draw_basis_vectors: bool = True
30 """This controls whether we want to draw the transformed basis vectors."""
31
32 # === Animations
33
34 smoothen_determinant: bool = True
35 """This controls whether we want the determinant to change smoothly during the animation.
36
37 .. note::
38     Even if this is True, it will be ignored if we're animating from a positive det matrix to
39     a negative det matrix, or vice versa, because if we try to smoothly animate that determinant,
40     things blow up and the app often crashes.
41 """
42
43 applicative_animation: bool = True
44 """There are two types of simple animation, transitional and applicative.
45
46 Let ``C`` be the matrix representing the currently displayed transformation, and let ``T`` be the target matrix.
47 Transitional animation means that we animate directly from ``C`` from ``T``,
48 and applicative animation means that we animate from ``C`` to ``TC``, so we apply ``T`` to ``C``.
49 """
50
51 animation_time: int = 1200
52 """This is the number of milliseconds that an animation takes."""
53
54 animation_pause_length: int = 400
55 """This is the number of milliseconds that we wait between animations when using comma syntax."""
56
57 # === Matrix info
58
59 draw_determinant_parallelogram: bool = False
60 """This controls whether or not we should shade the parallelogram representing the determinant of the matrix."""
61
62 show_determinant_value: bool = True
63 """This controls whether we should write the text value of the determinant inside the parallelogram.
64
65 The text only gets draw if :attr:`draw_determinant_parallelogram` is also True.
66 """
67
68 draw_eigenvectors: bool = False
69 """This controls whether we should draw the eigenvectors of the transformation."""
70
71 draw_eigenlines: bool = False
72 """This controls whether we should draw the eigenlines of the transformation."""

```

A.5 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, settings, validate
10 from .main_window import main
11
12 __all__ = ['dialogs', 'main', 'plots', 'settings', 'validate']

```

A.6 gui/validate.py

```

1 # lintrans - The linear transformation visualizer
2 # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)
3
4 # This program is licensed under GNU GPLv3, available here:
5 # <https://www.gnu.org/licenses/gpl-3.0.html>

```

```

6
7 """This simple module provides a :class:`MatrixExpressionValidator` class to validate matrix expression input."""
8
9 from __future__ import annotations
10
11 import re
12 from typing import Tuple
13
14 from PyQt5.QtGui import QValidator
15
16 from lintrans.matrices import parse
17
18 class MatrixExpressionValidator(QValidator):
19     """This class validates matrix expressions in a Qt input box."""
20
21     def validate(self, text: str, pos: int) -> Tuple[QValidator.State, str, int]:
22         """Validate the given text according to the rules defined in the :mod:`lintrans.matrices` module."""
23         clean_text = re.sub(parse.NAIVE_CHARACTER_CLASS[:-1] + ',]', '', text)
24
25         if clean_text == '':
26             if parse.validate_matrix_expression(clean_text):
27                 return QValidator.Acceptable, text, pos
28             else:
29                 return QValidator.Intermediate, text, pos
30         return QValidator.Invalid, text, pos
31
32

```

A.7 gui/dialogs/misc.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 """This module provides miscellaneous dialog classes like :class:`AboutDialog`."""
8
9 from __future__ import annotations
10
11 import platform
12 from typing import Union
13
14 from PyQt5.QtCore import PYQT_VERSION_STR, QT_VERSION_STR, Qt
15 from PyQt5.QtWidgets import QDialog, QGridLayout, QLabel, QVBoxLayout, QWidget
16
17 import lintrans
18 from lintrans.matrices.utility import round_float
19 from lintrans.matrices import MatrixWrapper
20 from lintrans.typing_ import is_matrix_type, MatrixType
21
22
23 class FixedSizeDialog(QDialog):
24     """A simple superclass to create modal dialog boxes with fixed size.
25
26     We override the :meth:`open` method to set the fixed size as soon as the dialog is opened modally.
27     """
28
29     def open(self) -> None:
30         """Override :meth:`QDialog.open` to set the dialog to a fixed size."""
31         super().open()
32         self.setFixedSize(self.size())
33
34
35 class AboutDialog(FixedSizeDialog):
36     """A simple dialog class to display information about the app to the user.
37
38     It only has an :meth:`__init__` method because it only has label widgets, so no other methods are necessary
39     ↪ here.
40     """

```

```

40
41 def __init__(self, *args, **kwargs):
42     """Create an :class:`AboutDialog` object with all the label widgets."""
43     super().__init__(*args, **kwargs)
44
45     self.setWindowTitle('About lintrans')
46
47     # === Create the widgets
48
49     label_title = QLabel(self)
50     label_title.setText(f'lintrans (version {lintrans.__version__})')
51     label_title.setAlignment(Qt.AlignCenter)
52
53     font_title = label_title.font()
54     font_title.setPointSize(font_title.pointSize() * 2)
55     label_title.setFont(font_title)
56
57     label_version_info = QLabel(self)
58     label_version_info.setText(
59         f'With Python version {platform.python_version()}\n'
60         f'Qt version {QT_VERSION_STR} and PyQt5 version {PYQT_VERSION_STR}\n'
61         f'Running on {platform.platform()}'
62     )
63     label_version_info.setAlignment(Qt.AlignCenter)
64
65     label_info = QLabel(self)
66     label_info.setText(
67         'lintrans is a program designed to help visualise<br>'
68         '2D linear transformations represented with matrices.<br><br>'
69         'It's designed for teachers and students and any feedback<br>'
70         'is greatly appreciated at <a href="https://github.com/DoctorDalek1963/lintrans" '
71         'style="color: black;">my GitHub page</a><br>or via email '
72         '(<a href="mailto:dyson.dyson@icloud.com" style="color: black;">dyson.dyson@icloud.com</a>).'
73     )
74     label_info.setAlignment(Qt.AlignCenter)
75     label_info.setTextFormat(Qt.RichText)
76     label_info.setOpenExternalLinks(True)
77
78     label_copyright = QLabel(self)
79     label_copyright.setText(
80         'This program is free software.<br>Copyright 2021-2022 D. Dyson (DoctorDalek1963).<br>'
81         'This program is licensed under GPLv3, which can be found '
82         '<a href="https://www.gnu.org/licenses/gpl-3.0.html" style="color: black;">here</a>.'
83     )
84     label_copyright.setAlignment(Qt.AlignCenter)
85     label_copyright.setTextFormat(Qt.RichText)
86     label_copyright.setOpenExternalLinks(True)
87
88     # === Arrange the widgets
89
90     self.setContentsMargins(10, 10, 10, 10)
91
92     vlay = QVBoxLayout()
93     vlay.setSpacing(20)
94     vlay.addWidget(label_title)
95     vlay.addWidget(label_version_info)
96     vlay.addWidget(label_info)
97     vlay.addWidget(label_copyright)
98
99     self.setLayout(vlay)
100
101
102 class InfoPanelDialog(FixedSizeDialog):
103     """A simple dialog class to display an info panel that shows all currently defined matrices."""
104
105     def __init__(self, matrix_wrapper: MatrixWrapper, *args, **kwargs):
106         """Create the dialog box with all the widgets needed to show the information."""
107         super().__init__(*args, **kwargs)
108         self.wrapper = matrix_wrapper
109
110         self.setWindowTitle('Defined matrices')
111
112         grid_layout = QGridLayout()

```



```

113         grid_layout.setSpacing(20)
114
115         bold_font = self.font()
116         bold_font.setBold(True)
117
118         name_value_pair: tuple[str, Union[MatrixType, str]]
119
120         # Each defined matrix will get a widget group. Each group will be a label for the name,
121         # a label for '=', and a container widget to either show the matrix numerically, or to
122         # show the expression that it's defined as
123         for i, name_value_pair in enumerate(self.wrapper.get_defined_matrices()):
124             name, value = name_value_pair
125
126             # Create all the widgets first
127             label_name = QLabel(self)
128             label_name.setText(name)
129             label_name.setFont(bold_font)
130
131             label_equals = QLabel(self)
132             label_equals.setText('=')
133
134             widget_matrix = self._get_matrix_widget(value)
135
136             # We want columns of at most 6 widget groups
137             # This column variable manages which column of defined matrices we're on
138             # It's multiplied by 3 because all the widgets are in a single grid layout
139             # I could factor out each triplet of widgets for a defined matrix into a container widget,
140             # but I prefer to keep the widget count lower to reduce any possible lag
141             column = 3 * (i // 6)
142
143             grid_layout.addWidget(
144                 label_name,
145                 i - 2 * column,
146                 column,
147                 Qt.AlignCenter
148             )
149             grid_layout.addWidget(
150                 label_equals,
151                 i - 2 * column,
152                 column + 1,
153                 Qt.AlignCenter
154             )
155             grid_layout.addWidget(
156                 widget_matrix,
157                 i - 2 * column,
158                 column + 2,
159                 Qt.AlignCenter
160             )
161
162         self.setContentsMargins(10, 10, 10, 10)
163         self.setLayout(grid_layout)
164
165     def _get_matrix_widget(self, matrix: Union[MatrixType, str]) -> QWidget:
166         """Return a :class:`QWidget` containing the value of the matrix.
167
168         If the matrix is defined as an expression, it will be a simple :class:`QLabel`.
169         If the matrix is defined as a matrix, it will be a :class:`QWidget` container
170         with multiple :class:`QLabel` objects in it.
171         """
172         if isinstance(matrix, str):
173             label = QLabel(self)
174             label.setText(matrix)
175             return label
176
177         elif is_matrix_type(matrix):
178             # tl = top left, br = bottom right, etc.
179             label_tl = QLabel(self)
180             label_tl.setText(round_float(matrix[0][0]))
181
182             label_tr = QLabel(self)
183             label_tr.setText(round_float(matrix[0][1]))
184
185             label_bl = QLabel(self)

```

```

186         label_bl.setText(round_float(matrix[1][0]))
187
188         label_br = QLabel(self)
189         label_br.setText(round_float(matrix[1][1]))
190
191         # The parens need to be bigger than the numbers, but increasing the font size also
192         # makes the font thicker, so we have to reduce the font weight by the same factor
193         font_parens = self.font()
194         font_parens.setPointSize(int(font_parens.pointSize() * 2.5))
195         font_parens.setWeight(int(font_parens.weight() / 2.5))
196
197         label_paren_left = QLabel(self)
198         label_paren_left.setText('(')
199         label_paren_left.setFont(font_parens)
200
201         label_paren_right = QLabel(self)
202         label_paren_right.setText(')')
203         label_paren_right.setFont(font_parens)
204
205         container = QWidget(self)
206         grid_layout = QGridLayout()
207
208         grid_layout.addWidget(label_paren_left, 0, 0, -1, 1)
209         grid_layout.addWidget(label_tl, 0, 1)
210         grid_layout.addWidget(label_tr, 0, 2)
211         grid_layout.addWidget(label_bl, 1, 1)
212         grid_layout.addWidget(label_br, 1, 2)
213         grid_layout.addWidget(label_paren_right, 0, 3, -1, 1)
214
215         container.setLayout(grid_layout)
216
217         return container
218
219     raise ValueError('Matrix was not MatrixType or str')

```

A.8 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.QtGui import QIntValidator, QKeyEvent, QKeySequence
16  from PyQt5.QtWidgets import QCheckBox, QGroupBox, QHBoxLayout, QShortcut, QSizePolicy, QSpacerItem, QVBoxLayout
17
18  from lintrans.gui.dialogs.misc import FixedSizeDialog
19  from lintrans.gui.settings import DisplaySettings
20
21
22  class SettingsDialog(FixedSizeDialog):
23      """An abstract superclass for other simple dialogs."""
24
25      def __init__(self, *args, **kwargs):
26          """Create the widgets and layout of the dialog, passing ``*args`` and ``**kwargs`` to super."""
27          super().__init__(*args, **kwargs)
28
29          # === Create the widgets
30
31          self.button_confirm = QtWidgets.QPushButton(self)
32          self.button_confirm.setText('Confirm')
33          self.button_confirm.clicked.connect(self.confirm_settings)

```

```

34     self.button_confirm.setToolTip('Confirm these new settings<br><b>(Ctrl + Enter)</b>')
35     QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
36
37     self.button_cancel = QtWidgets.QPushButton(self)
38     self.button_cancel.setText('Cancel')
39     self.button_cancel.clicked.connect(self.reject)
40     self.button_cancel.setToolTip('Revert these settings<br><b>(Escape)</b>')
41
42     # === Arrange the widgets
43
44     self.setContentsMargins(10, 10, 10, 10)
45
46     self.hlay_buttons = QHBoxLayout()
47     self.hlay_buttons.setSpacing(20)
48     self.hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
49     self.hlay_buttons.addWidget(self.button_cancel)
50     self.hlay_buttons.addWidget(self.button_confirm)
51
52     self.vlay_options = QVBoxLayout()
53     self.vlay_options.setSpacing(20)
54
55     self.vlay_all = QVBoxLayout()
56     self.vlay_all.setSpacing(20)
57     self.vlay_all.addLayout(self.vlay_options)
58     self.vlay_all.addLayout(self.hlay_buttons)
59
60     self.setLayout(self.vlay_all)
61
62     @abc.abstractmethod
63     def load_settings(self) -> None:
64         """Load the current settings into the widgets."""
65
66     @abc.abstractmethod
67     def confirm_settings(self) -> None:
68         """Confirm the settings chosen in the dialog."""
69
70
71 class DisplaySettingsDialog(SettingsDialog):
72     """The dialog to allow the user to edit the display settings."""
73
74     def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
75         """Create the widgets and layout of the dialog.
76
77         :param DisplaySettings display_settings: The :class:`lintrans.gui.settings.DisplaySettings` object to mutate
78         """
79         super().__init__(*args, **kwargs)
80
81         self.display_settings = display_settings
82         self.setWindowTitle('Change display settings')
83
84         self.dict_checkboxes: Dict[str, QCheckBox] = dict()
85
86         # === Create the widgets
87
88         # Basic stuff
89
90         self.checkbox_draw_background_grid = QCheckBox(self)
91         self.checkbox_draw_background_grid.setText('Draw &background grid')
92         self.checkbox_draw_background_grid.setToolTip(
93             'Draw the background grid (axes are always drawn)'
94         )
95         self.dict_checkboxes['b'] = self.checkbox_draw_background_grid
96
97         self.checkbox_draw_transformed_grid = QCheckBox(self)
98         self.checkbox_draw_transformed_grid.setText('Draw &ttransformed grid')
99         self.checkbox_draw_transformed_grid.setToolTip(
100             'Draw the transformed grid (vectors are handled separately)'
101         )
102         self.dict_checkboxes['r'] = self.checkbox_draw_transformed_grid
103
104         self.checkbox_draw_basis_vectors = QCheckBox(self)
105         self.checkbox_draw_basis_vectors.setText('Draw basis &vectors')
106         self.checkbox_draw_basis_vectors.setToolTip(

```

```

107         'Draw the transformed basis vectors'
108     )
109     self.dict_checkboxes['v'] = self.checkbox_draw_basis_vectors
110
111     # Animations
112
113     self.checkbox_smooththen_determinant = QCheckBox(self)
114     self.checkbox_smooththen_determinant.setText('&Smoothen determinant')
115     self.checkbox_smooththen_determinant.setToolTip(
116         'Smoothly animate the determinant transition during animation (if possible)'
117     )
118     self.dict_checkboxes['s'] = self.checkbox_smooththen_determinant
119
120     self.checkbox_applicative_animation = QCheckBox(self)
121     self.checkbox_applicative_animation.setText('&Applicative animation')
122     self.checkbox_applicative_animation.setToolTip(
123         'Animate the new transformation applied to the current one,\n'
124         'rather than just that transformation on its own'
125     )
126     self.dict_checkboxes['a'] = self.checkbox_applicative_animation
127
128     self.label_animation_time = QtWidgets.QLabel(self)
129     self.label_animation_time.setText('Total animation length (ms)')
130     self.label_animation_time.setToolTip(
131         'How long it takes for an animation to complete'
132     )
133
134     self.lineedit_animation_time = QtWidgets.QLineEdit(self)
135     self.lineedit_animation_time.setValidator(QIntValidator(1, 9999, self))
136
137     self.label_animation_pause_length = QtWidgets.QLabel(self)
138     self.label_animation_pause_length.setText('Animation pause length (ms)')
139     self.label_animation_pause_length.setToolTip(
140         'How many milliseconds to pause for in comma-separated animations'
141     )
142
143     self.lineedit_animation_pause_length = QtWidgets.QLineEdit(self)
144     self.lineedit_animation_pause_length.setValidator(QIntValidator(1, 999, self))
145
146     # Matrix info
147
148     self.checkbox_draw_determinant_parallelogram = QCheckBox(self)
149     self.checkbox_draw_determinant_parallelogram.setText('Draw &determinant parallelogram')
150     self.checkbox_draw_determinant_parallelogram.setToolTip(
151         'Shade the parallelogram representing the determinant of the matrix'
152     )
153     self.checkbox_draw_determinant_parallelogram.clicked.connect(self.update_gui)
154     self.dict_checkboxes['d'] = self.checkbox_draw_determinant_parallelogram
155
156     self.checkbox_show_determinant_value = QCheckBox(self)
157     self.checkbox_show_determinant_value.setText('Show de&terminant value')
158     self.checkbox_show_determinant_value.setToolTip(
159         'Show the value of the determinant inside the parallelogram'
160     )
161     self.dict_checkboxes['t'] = self.checkbox_show_determinant_value
162
163     self.checkbox_draw_eigenvectors = QCheckBox(self)
164     self.checkbox_draw_eigenvectors.setText('Draw &eigenvectors')
165     self.checkbox_draw_eigenvectors.setToolTip('Draw the eigenvectors of the transformations')
166     self.dict_checkboxes['e'] = self.checkbox_draw_eigenvectors
167
168     self.checkbox_draw_eigenlines = QCheckBox(self)
169     self.checkbox_draw_eigenlines.setText('Draw eigen&lines')
170     self.checkbox_draw_eigenlines.setToolTip('Draw the eigenlines (invariant lines) of the transformations')
171     self.dict_checkboxes['l'] = self.checkbox_draw_eigenlines
172
173     # === Arrange the widgets in QGroupBoxes
174
175     # Basic stuff
176
177     self.vlay_groupbox_basic_stuff = QVBoxLayout()
178     self.vlay_groupbox_basic_stuff.setSpacing(20)
179     self.vlay_groupbox_basic_stuff.addWidget(self.checkbox_draw_background_grid)

```

```

180     self.vlay_groupbox_basic_stuff.addWidget(self.checkbox_draw_transformed_grid)
181     self.vlay_groupbox_basic_stuff.addWidget(self.checkbox_draw_basis_vectors)
182
183     self.groupbox_basic_stuff = QGroupBox('Basic stuff', self)
184     self.groupbox_basic_stuff.setLayout(self.vlay_groupbox_basic_stuff)
185
186     # Animations
187
188     self.hlay_animation_time = QHBoxLayout()
189     self.hlay_animation_time.addWidget(self.label_animation_time)
190     self.hlay_animation_time.addWidget(self.lineedit_animation_time)
191
192     self.hlay_animation_pause_length = QHBoxLayout()
193     self.hlay_animation_pause_length.addWidget(self.label_animation_pause_length)
194     self.hlay_animation_pause_length.addWidget(self.lineedit_animation_pause_length)
195
196     self.vlay_groupbox_animations = QVBoxLayout()
197     self.vlay_groupbox_animations.setSpacing(20)
198     self.vlay_groupbox_animations.addWidget(self.checkbox_smoother_determinant)
199     self.vlay_groupbox_animations.addWidget(self.checkbox_applicative_animation)
200     self.vlay_groupbox_animations.addLayout(self.hlay_animation_time)
201     self.vlay_groupbox_animations.addLayout(self.hlay_animation_pause_length)
202
203     self.groupbox_animations = QGroupBox('Animations', self)
204     self.groupbox_animations.setLayout(self.vlay_groupbox_animations)
205
206     # Matrix info
207
208     self.vlay_groupbox_matrix_info = QVBoxLayout()
209     self.vlay_groupbox_matrix_info.setSpacing(20)
210     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_draw_determinant_parallelogram)
211     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_show_determinant_value)
212     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_draw_eigenvectors)
213     self.vlay_groupbox_matrix_info.addWidget(self.checkbox_draw_eigenlines)
214
215     self.groupbox_matrix_info = QGroupBox('Matrix info', self)
216     self.groupbox_matrix_info.setLayout(self.vlay_groupbox_matrix_info)
217
218     # Now arrange the groupboxes
219     self.vlay_options.addWidget(self.groupbox_basic_stuff)
220     self.vlay_options.addWidget(self.groupbox_animations)
221     self.vlay_options.addWidget(self.groupbox_matrix_info)
222
223     # Finally, we load the current settings and update the GUI
224     self.load_settings()
225     self.update_gui()
226
227 def load_settings(self) -> None:
228     """Load the current display settings into the widgets."""
229     # Basic stuff
230     self.checkbox_draw_background_grid.setChecked(self.display_settings.draw_background_grid)
231     self.checkbox_draw_transformed_grid.setChecked(self.display_settings.draw_transformed_grid)
232     self.checkbox_draw_basis_vectors.setChecked(self.display_settings.draw_basis_vectors)
233
234     # Animations
235     self.checkbox_smoother_determinant.setChecked(self.display_settings.smoother_determinant)
236     self.checkbox_applicative_animation.setChecked(self.display_settings.applicative_animation)
237     self.lineedit_animation_time.setText(str(self.display_settings.animation_time))
238     self.lineedit_animation_pause_length.setText(str(self.display_settings.animation_pause_length))
239
240     # Matrix info
241     self.checkbox_draw_determinant_parallelogram.setChecked(
242         ↪ self.display_settings.draw_determinant_parallelogram)
243     self.checkbox_show_determinant_value.setChecked(self.display_settings.show_determinant_value)
244     self.checkbox_draw_eigenvectors.setChecked(self.display_settings.draw_eigenvectors)
245     self.checkbox_draw_eigenlines.setChecked(self.display_settings.draw_eigenlines)
246
247 def confirm_settings(self) -> None:
248     """Build a :class:`lintrans.gui.settings.DisplaySettings` object and assign it."""
249     # Basic stuff
250     self.display_settings.draw_background_grid = self.checkbox_draw_background_grid.isChecked()
251     self.display_settings.draw_transformed_grid = self.checkbox_draw_transformed_grid.isChecked()
252     self.display_settings.draw_basis_vectors = self.checkbox_draw_basis_vectors.isChecked()

```

```

252
253     # Animations
254     self.display_settings.smoothen_determinant = self.checkbox_smoothen_determinant.isChecked()
255     self.display_settings.applicative_animation = self.checkbox_applicative_animation.isChecked()
256     self.display_settings.animation_time = int(self.lineedit_animation_time.text())
257     self.display_settings.animation_pause_length = int(self.lineedit_animation_pause_length.text())
258
259     # Matrix info
260     self.display_settings.draw_determinant_parallelogram =
261     ↪ self.checkbox_draw_determinant_parallelogram.isChecked()
262     self.display_settings.show_determinant_value = self.checkbox_show_determinant_value.isChecked()
263     self.display_settings.draw_eigenvectors = self.checkbox_draw_eigenvectors.isChecked()
264     self.display_settings.draw_eigenlines = self.checkbox_draw_eigenlines.isChecked()
265
266     self.accept()
267
268     def update_gui(self) -> None:
269         """Update the GUI according to other widgets in the GUI.
270
271         For example, this method updates which checkboxes are enabled based on the values of other checkboxes.
272         """
273         self.checkbox_show_determinant_value.setEnabled(self.checkbox_draw_determinant_parallelogram.isChecked())
274
275     def keyPressEvent(self, event: QKeyEvent) -> None:
276         """Handle a :class:`QKeyEvent` by manually activating toggling checkboxes.
277
278         Qt handles these shortcuts automatically and allows the user to do ``Alt + Key``
279         to activate a simple shortcut defined with ``&``. However, I like to be able to
280         just hit ``Key`` and have the shortcut activate.
281         """
282         letter = event.text().lower()
283         key = event.key()
284
285         if letter in self.dict_checkboxes:
286             self.dict_checkboxes[letter].animateClick()
287
288         # Return or keypad enter
289         elif key == 0x01000004 or key == 0x01000005:
290             self.button_confirm.click()
291
292         # Escape
293         elif key == 0x01000000:
294             self.button_cancel.click()
295
296         else:
297             event.ignore()

```

A.9 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 DefineAsAnExpressionDialog, DefineDialog, DefineNumericallyDialog,
13 ↪ DefineVisuallyDialog
14 from .misc import AboutDialog, InfoPanelDialog
15 from .settings import DisplaySettingsDialog
16
17 __all__ = ['AboutDialog', 'DefineAsAnExpressionDialog', 'DefineDialog', 'DefineNumericallyDialog',
18           'DefineVisuallyDialog', 'DisplaySettingsDialog', 'InfoPanelDialog']

```

A.10 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:`DefineDialog` class and subclasses, allowing definition of new
   ↪ matrices."""
8
9  from __future__ import annotations
10
11  import abc
12
13  from numpy import array
14  from PyQt5 import QtWidgets
15  from PyQt5.QtCore import pyqtSlot
16  from PyQt5.QtGui import QDoubleValidator, QKeySequence
17  from PyQt5.QtWidgets import QGridLayout, QHBoxLayout, QShortcut, QSizePolicy, QSpacerItem, QVBoxLayout
18
19  from lintrans.gui.dialogs.misc import FixedSizeDialog
20  from lintrans.gui.plots import DefineVisuallyWidget
21  from lintrans.gui.settings import DisplaySettings
22  from lintrans.gui.validate import MatrixExpressionValidator
23  from lintrans.matrices import MatrixWrapper
24  from lintrans.matrices.utility import is_valid_float, round_float
25  from lintrans.typing_ import MatrixType
26
27  ALPHABET_NO_I = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
28
29
30  class DefineDialog(FixedSizeDialog):
31      """An abstract superclass for definitions dialogs.
32
33      .. warning:: This class should never be directly instantiated, only subclassed.
34
35      .. note::
36          I would make this class have ``metaclass=abc.ABCMeta``, but I can't because it subclasses :class:`QDialog`,
37          and every superclass of a class must have the same metaclass, and :class:`QDialog` is not an abstract class.
38      """
39
40      def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
41          """Create the widgets and layout of the dialog.
42
43          .. note:: ``*args`` and ``**kwargs`` are passed to the super constructor (:class:`QDialog`).
44
45          :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
46          """
47          super().__init__(*args, **kwargs)
48
49          self.matrix_wrapper = matrix_wrapper
50          self.setWindowTitle('Define a matrix')
51
52          # === Create the widgets
53
54          self.button_confirm = QtWidgets.QPushButton(self)
55          self.button_confirm.setText('Confirm')
56          self.button_confirm.setEnabled(False)
57          self.button_confirm.clicked.connect(self.confirm_matrix)
58          self.button_confirm.setToolTip('Confirm this as the new matrix<br><b>(Ctrl + Enter)</b>')
59          QShortcut(QKeySequence('Ctrl+Return'), self).activated.connect(self.button_confirm.click)
60
61          self.button_cancel = QtWidgets.QPushButton(self)
62          self.button_cancel.setText('Cancel')
63          self.button_cancel.clicked.connect(self.reject)
64          self.button_cancel.setToolTip('Cancel this definition<br><b>(Escape)</b>')
65
66          self.label_equals = QtWidgets.QLabel()
67          self.label_equals.setText('=')
68
69          self.combobox_letter = QtWidgets.QComboBox(self)

```

```

70
71     for letter in ALPHABET_NO_I:
72         self.combobox_letter.addItem(letter)
73
74     self.combobox_letter.activated.connect(self.load_matrix)
75
76     # === Arrange the widgets
77
78     self.setContentsMargins(10, 10, 10, 10)
79
80     self.hlay_buttons = QHBoxLayout()
81     self.hlay_buttons.setSpacing(20)
82     self.hlay_buttons.addItem(QSpacerItem(50, 5, hPolicy=QSizePolicy.Expanding, vPolicy=QSizePolicy.Minimum))
83     self.hlay_buttons.addWidget(self.button_cancel)
84     self.hlay_buttons.addWidget(self.button_confirm)
85
86     self.hlay_definition = QHBoxLayout()
87     self.hlay_definition.setSpacing(20)
88     self.hlay_definition.addWidget(self.combobox_letter)
89     self.hlay_definition.addWidget(self.label_equals)
90
91     self.vlay_all = QVBoxLayout()
92     self.vlay_all.setSpacing(20)
93
94     self.setLayout(self.vlay_all)
95
96     @property
97     def selected_letter(self) -> str:
98         """Return the letter currently selected in the combo box."""
99         return str(self.combobox_letter.currentText())
100
101     @abc.abstractmethod
102     @pyqtSlot()
103     def update_confirm_button(self) -> None:
104         """Enable the confirm button if it should be enabled, else, disable it."""
105
106     @pyqtSlot(int)
107     def load_matrix(self, index: int) -> None:
108         """Load the selected matrix into the dialog.
109
110         This method is optionally able to be overridden. If it is not overridden,
111         then no matrix is loaded when selecting a name.
112
113         We have this method in the superclass so that we can define it as the slot
114         for the :meth:`QComboBox.activated` signal in this constructor, rather than
115         having to define that in the constructor of every subclass.
116         """
117
118     @abc.abstractmethod
119     @pyqtSlot()
120     def confirm_matrix(self) -> None:
121         """Confirm the inputted matrix and assign it.
122
123         .. note:: When subclassing, this method should mutate ``self.matrix_wrapper`` and then call
124         ↪ ``self.accept()``.
125         """
126
127     class DefineVisuallyDialog(DefineDialog):
128         """The dialog class that allows the user to define a matrix visually."""
129
130     def __init__(self, *args, matrix_wrapper: MatrixWrapper, display_settings: DisplaySettings, **kwargs):
131         """Create the widgets and layout of the dialog.
132
133         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
134         """
135         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
136
137         self.setMinimumSize(700, 550)
138
139         # === Create the widgets
140
141         self.plot = DefineVisuallyWidget(self, display_settings=display_settings)

```



```

142
143     # === Arrange the widgets
144
145     self.hlay_definition.addWidget(self.plot)
146     self.hlay_definition.setStretchFactor(self.plot, 1)
147
148     self.vlay_all.addLayout(self.hlay_definition)
149     self.vlay_all.addLayout(self.hlay_buttons)
150
151     # We load the default matrix A into the plot
152     self.load_matrix(0)
153
154     # We also enable the confirm button, because any visually defined matrix is valid
155     self.button_confirm.setEnabled(True)
156
157 @pyqtSlot()
158 def update_confirm_button(self) -> None:
159     """Enable the confirm button.
160
161     .. note::
162         The confirm button is always enabled in this dialog and this method is never actually used,
163         so it's got an empty body. It's only here because we need to implement the abstract method.
164     """
165
166 @pyqtSlot(int)
167 def load_matrix(self, index: int) -> None:
168     """Show the selected matrix on the plot. If the matrix is None, show the identity."""
169     matrix = self.matrix_wrapper[self.selected_letter]
170
171     if matrix is None:
172         matrix = self.matrix_wrapper['I']
173
174     self.plot.visualize_matrix_transformation(matrix)
175     self.plot.update()
176
177 @pyqtSlot()
178 def confirm_matrix(self) -> None:
179     """Confirm the matrix that's been defined visually."""
180     matrix: MatrixType = array([
181         [self.plot.point_i[0], self.plot.point_j[0]],
182         [self.plot.point_i[1], self.plot.point_j[1]]
183     ])
184
185     self.matrix_wrapper[self.selected_letter] = matrix
186     self.accept()
187
188
189 class DefineNumericallyDialog(DefinedDialog):
190     """The dialog class that allows the user to define a new matrix numerically."""
191
192     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
193         """Create the widgets and layout of the dialog.
194
195         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
196         """
197         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
198
199         # === Create the widgets
200
201         # tl = top left, br = bottom right, etc.
202         self.element_tl = QtWidgets.QLineEdit(self)
203         self.element_tl.textChanged.connect(self.update_confirm_button)
204         self.element_tl.setValidator(QDoubleValidator())
205
206         self.element_tr = QtWidgets.QLineEdit(self)
207         self.element_tr.textChanged.connect(self.update_confirm_button)
208         self.element_tr.setValidator(QDoubleValidator())
209
210         self.element_bl = QtWidgets.QLineEdit(self)
211         self.element_bl.textChanged.connect(self.update_confirm_button)
212         self.element_bl.setValidator(QDoubleValidator())
213
214         self.element_br = QtWidgets.QLineEdit(self)

```

```

215     self.element_br.textChanged.connect(self.update_confirm_button)
216     self.element_br.setValidator(QDoubleValidator())
217
218     self.matrix_elements = (self.element_tl, self.element_tr, self.element_bl, self.element_br)
219
220     # === Arrange the widgets
221
222     self.grid_matrix = QGridLayout()
223     self.grid_matrix.setSpacing(20)
224     self.grid_matrix.addWidget(self.element_tl, 0, 0)
225     self.grid_matrix.addWidget(self.element_tr, 0, 1)
226     self.grid_matrix.addWidget(self.element_bl, 1, 0)
227     self.grid_matrix.addWidget(self.element_br, 1, 1)
228
229     self.hlay_definition.addLayout(self.grid_matrix)
230
231     self.vlay_all.addLayout(self.hlay_definition)
232     self.vlay_all.addLayout(self.hlay_buttons)
233
234     # We load the default matrix A into the boxes
235     self.load_matrix(0)
236
237     self.element_tl.setFocus()
238
239     @pyqtSlot()
240     def update_confirm_button(self) -> None:
241         """Enable the confirm button if there are valid floats in every box."""
242         for elem in self.matrix_elements:
243             if not is_valid_float(elem.text()):
244                 # If they're not all numbers, then we can't confirm it
245                 self.button_confirm.setEnabled(False)
246                 return
247
248         # If we didn't find anything invalid
249         self.button_confirm.setEnabled(True)
250
251     @pyqtSlot(int)
252     def load_matrix(self, index: int) -> None:
253         """If the selected matrix is defined, load its values into the boxes."""
254         matrix = self.matrix_wrapper[self.selected_letter]
255
256         if matrix is None:
257             for elem in self.matrix_elements:
258                 elem.setText('')
259
260         else:
261             self.element_tl.setText(round_float(matrix[0][0]))
262             self.element_tr.setText(round_float(matrix[0][1]))
263             self.element_bl.setText(round_float(matrix[1][0]))
264             self.element_br.setText(round_float(matrix[1][1]))
265
266         self.update_confirm_button()
267
268     @pyqtSlot()
269     def confirm_matrix(self) -> None:
270         """Confirm the matrix in the boxes and assign it to the name in the combo box."""
271         matrix: MatrixType = array([
272             [float(self.element_tl.text()), float(self.element_tr.text())],
273             [float(self.element_bl.text()), float(self.element_br.text())]
274         ])
275
276         self.matrix_wrapper[self.selected_letter] = matrix
277         self.accept()
278
279
280 class DefineAsAnExpressionDialog(DefinedDialog):
281     """The dialog class that allows the user to define a matrix as an expression of other matrices."""
282
283     def __init__(self, *args, matrix_wrapper: MatrixWrapper, **kwargs):
284         """Create the widgets and layout of the dialog.
285
286         :param MatrixWrapper matrix_wrapper: The MatrixWrapper that this dialog will mutate
287         """

```

```

288         super().__init__(*args, matrix_wrapper=matrix_wrapper, **kwargs)
289
290         self.setMinimumWidth(450)
291
292         # === Create the widgets
293
294         self.linedit_expression_box = QtWidgets.QLineEdit(self)
295         self.linedit_expression_box.setPlaceholderText('Enter matrix expression...')
296         self.linedit_expression_box.textChanged.connect(self.update_confirm_button)
297         self.linedit_expression_box.setValidator(MatrixExpressionValidator())
298
299         # === Arrange the widgets
300
301         self.hlay_definition.addWidget(self.linedit_expression_box)
302
303         self.vlay_all.addLayout(self.hlay_definition)
304         self.vlay_all.addLayout(self.hlay_buttons)
305
306         # Load the matrix if it's defined as an expression
307         self.load_matrix(0)
308
309         self.linedit_expression_box.setFocus()
310
311     @pyqtSlot()
312     def update_confirm_button(self) -> None:
313         """Enable the confirm button if the matrix expression is valid in the wrapper."""
314         text = self.linedit_expression_box.text()
315         valid_expression = self.matrix_wrapper.is_valid_expression(text)
316
317         self.button_confirm.setEnabled(valid_expression and self.selected_letter not in text)
318
319     @pyqtSlot(int)
320     def load_matrix(self, index: int) -> None:
321         """If the selected matrix is defined an expression, load that expression into the box."""
322         if (expr := self.matrix_wrapper.get_expression(self.selected_letter)) is not None:
323             self.linedit_expression_box.setText(expr)
324         else:
325             self.linedit_expression_box.setText('')
326
327     @pyqtSlot()
328     def confirm_matrix(self) -> None:
329         """Evaluate the matrix expression and assign its value to the name in the combo box."""
330         self.matrix_wrapper[self.selected_letter] = self.linedit_expression_box.text()
331         self.accept()

```

A.11 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 from .widgets import DefineVisuallyWidget, VisualizeTransformationWidget
11
12 __all__ = ['BackgroundPlot', 'DefineVisuallyWidget', 'VectorGridPlot', 'VisualizeTransformationWidget']

```

A.12 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     from math import ceil, dist, floor
12     from typing import List, Tuple
13
14     from PyQt5.QtCore import Qt
15     from PyQt5.QtGui import QMouseEvent, QPainter, QPaintEvent
16
17     from lintrans.typing_ import MatrixType
18     from lintrans.gui.settings import DisplaySettings
19     from .classes import VectorGridPlot
20
21
22     class VisualizeTransformationWidget(VectorGridPlot):
23         """This class is the widget that is used in the main window to visualize transformations.
24
25         It handles all the rendering itself, and the only method that the user needs to
26         worry about is :meth:`visualize_matrix_transformation`, which allows you to visualize
27         the given matrix transformation.
28         """
29
30         def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
31             """Create the widget and assign its display settings, passing ``*args`` and ``**kwargs`` to super."""
32             super().__init__(*args, **kwargs)
33
34             self.display_settings = display_settings
35
36         def visualize_matrix_transformation(self, matrix: MatrixType) -> None:
37             """Transform the grid by the given matrix.
38
39             .. warning:: This method does not call ``update()``. This must be done by the caller.
40
41             .. note::
42                 This method transforms the background grid, not the basis vectors. This
43                 means that it cannot be used to compose transformations. Compositions
44                 should be done by the user.
45
46             :param MatrixType matrix: The matrix to transform by
47             """
48             self.point_i = (matrix[0][0], matrix[1][0])
49             self.point_j = (matrix[0][1], matrix[1][1])
50
51         def paintEvent(self, event: QPaintEvent) -> None:
52             """Handle a :class:`QPaintEvent` by drawing the background grid and the transformed grid.
53
54             The transformed grid is defined by the basis vectors i and j, which can
55             be controlled with the :meth:`visualize_matrix_transformation` method.
56             """
57             painter = QPainter()
58             painter.begin(self)
59
60             painter.setRenderHint(QPainter.Antialiasing)
61             painter.setBrush(Qt.NoBrush)
62
63             self.draw_background(painter, self.display_settings.draw_background_grid)
64
65             if self.display_settings.draw_eigenlines:
66                 self.draw_eigenlines(painter)
67
68             if self.display_settings.draw_eigenvectors:
69                 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     painter.end()
84     event.accept()
85
86
87 class DefineVisuallyWidget(VisualizeTransformationWidget):
88     """This class is the widget that allows the user to visually define a matrix.
89
90     This is just the widget itself. If you want the dialog, use
91     :class:`lintrans.gui.dialogs.define_new_matrix.DefineVisuallyDialog`.
92     """
93
94     def __init__(self, *args, display_settings: DisplaySettings, **kwargs):
95         """Create the widget and enable mouse tracking. ``*args`` and ``**kwargs`` are passed to ``super()``."""
96         super().__init__(*args, display_settings=display_settings, **kwargs)
97
98         self.dragged_point: Tuple[float, float] | None = None
99
100        # This is the distance that the cursor needs to be from the point to drag it
101        self.epsilon: int = 5
102
103    def mousePressEvent(self, event: QMouseEvent) -> None:
104        """Handle a :class:`QMouseEvent` when the user presses a button."""
105        mx = event.x()
106        my = event.y()
107        button = event.button()
108
109        if button != Qt.LeftButton:
110            event.ignore()
111            return
112
113        for point in (self.point_i, self.point_j):
114            px, py = self.canvas_coords(*point)
115            if abs(px - mx) <= self.epsilon and abs(py - my) <= self.epsilon:
116                self.dragged_point = point[0], point[1]
117
118        event.accept()
119
120    def mouseReleaseEvent(self, event: QMouseEvent) -> None:
121        """Handle a :class:`QMouseEvent` when the user releases a button."""
122        if event.button() == Qt.LeftButton:
123            self.dragged_point = None
124            event.accept()
125        else:
126            event.ignore()
127
128    def mouseMoveEvent(self, event: QMouseEvent) -> None:
129        """Handle the mouse moving on the canvas."""
130        mx = event.x()
131        my = event.y()
132
133        if self.dragged_point is None:
134            event.ignore()
135            return
136
137        x, y = self.grid_coords(mx, my)
138
139        possible_snaps: List[Tuple[int, int]] = [
140            (floor(x), floor(y)),
141            (floor(x), ceil(y)),
142            (ceil(x), floor(y)),
143            (ceil(x), ceil(y))
144        ]
145
146        snap_distances: List[Tuple[float, Tuple[int, int]]] = [
147            (dist((x, y), coord), coord)
148            for coord in possible_snaps
149        ]
150
151        for snap_dist, coord in snap_distances:
152            if snap_dist < 0.1:

```

```

153         x, y = coord
154
155         if self.dragged_point == self.point_i:
156             self.point_i = x, y
157
158         elif self.dragged_point == self.point_j:
159             self.point_j = x, y
160
161         self.dragged_point = x, y
162
163         self.update()
164
165         event.accept()

```

A.13 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 typing import Iterable, List, Tuple
13
14  import numpy as np
15  from nptyping import Float, NDArray
16  from PyQt5.QtCore import QPoint, QRectF, Qt
17  from PyQt5.QtGui import QBrush, QColor, QPainter, QPainterPath, QPaintEvent, QPen, QWheelEvent
18  from PyQt5.QtWidgets import QWidget
19
20  from lintrans.typing_ import MatrixType
21
22
23  class BackgroundPlot(QWidget):
24      """This class provides a background for plotting, as well as setup for a Qt widget.
25
26      This class provides a background (untransformed) plane, and all the backend
27      details for a Qt application, but does not provide useful functionality. To
28      be useful, this class must be subclassed and behaviour must be implemented
29      by the subclass.
30
31      .. warning:: This class should never be directly instantiated, only subclassed.
32
33      .. note::
34      I would make this class have ``metaclass=abc.ABCMeta``, but I can't because it subclasses :class:`QWidget`,
35      and every superclass of a class must have the same metaclass, and :class:`QWidget` is not an abstract class.
36      """
37
38      default_grid_spacing: int = 85
39      minimum_grid_spacing: int = 5
40
41      def __init__(self, *args, **kwargs):
42          """Create the widget and setup backend stuff for rendering.
43
44          .. note:: ``*args`` and ``**kwargs`` are passed the superclass constructor (:class:`QWidget`).
45          """
46          super().__init__(*args, **kwargs)
47
48          self.setAutoFillBackground(True)
49
50          # Set the background to white
51          palette = self.palette()
52          palette.setColor(self.backgroundRole(), Qt.white)
53          self.setPalette(palette)
54

```

```

55         # Set the grid colour to grey and the axes colour to black
56         self.colour_background_grid = QColor('#808080')
57         self.colour_background_axes = QColor('#000000')
58
59         self.grid_spacing = BackgroundPlot.default_grid_spacing
60         self.width_background_grid: float = 0.3
61
62     @property
63     def canvas_origin(self) -> Tuple[int, int]:
64         """Return the canvas coords of the grid origin.
65
66         The return value is intended to be unpacked and passed to a :meth:`QPainter.drawLine:iiii` call.
67
68         See :meth:`canvas_coords`.
69
70         :returns: The canvas coordinates of the grid origin
71         :rtype: Tuple[int, int]
72         """
73         return self.width() // 2, self.height() // 2
74
75     def canvas_x(self, x: float) -> int:
76         """Convert an x coordinate from grid coords to canvas coords."""
77         return int(self.canvas_origin[0] + x * self.grid_spacing)
78
79     def canvas_y(self, y: float) -> int:
80         """Convert a y coordinate from grid coords to canvas coords."""
81         return int(self.canvas_origin[1] - y * self.grid_spacing)
82
83     def canvas_coords(self, x: float, y: float) -> Tuple[int, int]:
84         """Convert a coordinate from grid coords to canvas coords.
85
86         This method is intended to be used like
87
88         .. code::
89
90             painter.drawLine(*self.canvas_coords(x1, y1), *self.canvas_coords(x2, y2))
91
92         or like
93
94         .. code::
95
96             painter.drawLine(*self.canvas_origin, *self.canvas_coords(x, y))
97
98         See :attr:`canvas_origin`.
99
100         :param float x: The x component of the grid coordinate
101         :param float y: The y component of the grid coordinate
102         :returns: The resultant canvas coordinates
103         :rtype: Tuple[int, int]
104         """
105         return self.canvas_x(x), self.canvas_y(y)
106
107     def grid_corner(self) -> Tuple[float, float]:
108         """Return the grid coords of the top right corner."""
109         return self.width() / (2 * self.grid_spacing), self.height() / (2 * self.grid_spacing)
110
111     def grid_coords(self, x: int, y: int) -> Tuple[float, float]:
112         """Convert a coordinate from canvas coords to grid coords.
113
114         :param int x: The x component of the canvas coordinate
115         :param int y: The y component of the canvas coordinate
116         :returns: The resultant grid coordinates
117         :rtype: Tuple[float, float]
118         """
119         # We get the maximum grid coords and convert them into canvas coords
120         return (x - self.canvas_origin[0]) / self.grid_spacing, (-y + self.canvas_origin[1]) / self.grid_spacing
121
122     @abstractmethod
123     def paintEvent(self, event: QPaintEvent) -> None:
124         """Handle a :class:`QPaintEvent`.
125
126         .. note:: This method is abstract and must be overridden by all subclasses.
127         """

```

```

128
129 def draw_background(self, painter: QPainter, draw_grid: bool) -> None:
130     """Draw the background grid.
131
132     .. note:: This method is just a utility method for subclasses to use to render the background grid.
133
134     :param QPainter painter: The painter to draw the background with
135     :param bool draw_grid: Whether to draw the grid lines
136     """
137     if draw_grid:
138         painter.setPen(QPen(self.colour_background_grid, self.width_background_grid))
139
140         # Draw equally spaced vertical lines, starting in the middle and going out
141         # We loop up to half of the width. This is because we draw a line on each side in each iteration
142         for x in range(self.width() // 2 + self.grid_spacing, self.width(), self.grid_spacing):
143             painter.drawLine(x, 0, x, self.height())
144             painter.drawLine(self.width() - x, 0, self.width() - x, self.height())
145
146         # Same with the horizontal lines
147         for y in range(self.height() // 2 + self.grid_spacing, self.height(), self.grid_spacing):
148             painter.drawLine(0, y, self.width(), y)
149             painter.drawLine(0, self.height() - y, self.width(), self.height() - y)
150
151         # Now draw the axes
152         painter.setPen(QPen(self.colour_background_axes, self.width_background_grid))
153         painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
154         painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
155
156 def wheelEvent(self, event: QWheelEvent) -> None:
157     """Handle a :class:`QWheelEvent` by zooming in or out of the grid."""
158     # angleDelta() returns a number of units equal to 8 times the number of degrees rotated
159     degrees = event.angleDelta() / 8
160
161     if degrees is not None:
162         new_spacing = max(1, self.grid_spacing + degrees.y())
163
164         if new_spacing >= self.minimum_grid_spacing:
165             self.grid_spacing = new_spacing
166
167     event.accept()
168     self.update()
169
170
171 class VectorGridPlot(BackgroundPlot):
172     """This class represents a background plot, with vectors and their grid drawn on top.
173
174     This class should be subclassed to be used for visualization and matrix definition widgets.
175     All useful behaviour should be implemented by any subclass.
176
177     .. warning:: This class should never be directly instantiated, only subclassed.
178     """
179
180     def __init__(self, *args, **kwargs):
181         """Create the widget with ``point_i`` and ``point_j`` attributes.
182
183         .. note:: ``*args`` and ``**kwargs`` are passed to the superclass constructor (:class:`BackgroundPlot`).
184         """
185         super().__init__(*args, **kwargs)
186
187         self.point_i: Tuple[float, float] = (1., 0.)
188         self.point_j: Tuple[float, float] = (0., 1.)
189
190         self.colour_i = QColor('#0808d8')
191         self.colour_j = QColor('#e90000')
192         self.colour_eigen = QColor('#13cf00')
193         self.colour_text = QColor('#000000')
194
195         self.width_vector_line = 1.8
196         self.width_transformed_grid = 0.8
197
198         self.arrowhead_length = 0.15
199
200         self.max_parallel_lines = 150

```



```

201
202 @property
203 def matrix(self) -> MatrixType:
204     """Return the assembled matrix of the basis vectors."""
205     return np.array([
206         [self.point_i[0], self.point_j[0]],
207         [self.point_i[1], self.point_j[1]]
208     ])
209
210 @property
211 def det(self) -> float:
212     """Return the determinant of the assembled matrix."""
213     return float(np.linalg.det(self.matrix))
214
215 @property
216 def eigs(self) -> Iterable[Tuple[float, NDArray[(1, 2), Float]]]:
217     """Return the eigenvalues and eigenvectors zipped together to be iterated over.
218
219     :rtype: Iterable[Tuple[float, NDArray[(1, 2), Float]]]
220     """
221     values, vectors = np.linalg.eig(self.matrix)
222     return zip(values, vectors.T)
223
224 @abstractmethod
225 def paintEvent(self, event: QPaintEvent) -> None:
226     """Handle a :class:`QPaintEvent`.
227
228     .. note:: This method is abstract and must be overridden by all subclasses.
229     """
230
231 def draw_parallel_lines(self, painter: QPainter, vector: Tuple[float, float], point: Tuple[float, float]) ->
232     ↪ None:
233     """Draw a set of evenly spaced grid lines parallel to ``vector`` intersecting ``point``.
234
235     :param QPainter painter: The painter to draw the lines with
236     :param vector: The vector to draw the grid lines parallel to
237     :type vector: Tuple[float, float]
238     :param point: The point for the lines to intersect with
239     :type point: Tuple[float, float]
240     """
241     max_x, max_y = self.grid_corner()
242     vector_x, vector_y = vector
243     point_x, point_y = point
244
245     # If the determinant is 0
246     if abs(vector_x * point_y - vector_y * point_x) < 1e-12:
247         rank = np.linalg.matrix_rank(
248             np.array([
249                 [vector_x, point_x],
250                 [vector_y, point_y]
251             ])
252         )
253
254         # If the matrix is rank 1, then we can draw the column space line
255         if rank == 1:
256             # If the vector does not have a 0 x or y component, then we can just draw the line
257             if abs(vector_x) > 1e-12 and abs(vector_y) > 1e-12:
258                 self.draw_oblique_line(painter, vector_y / vector_x, 0)
259
260             # Otherwise, we have to draw lines along the axes
261             elif abs(vector_x) > 1e-12 and abs(vector_y) < 1e-12:
262                 painter.drawLine(0, self.height() // 2, self.width(), self.height() // 2)
263
264             elif abs(vector_x) < 1e-12 and abs(vector_y) > 1e-12:
265                 painter.drawLine(self.width() // 2, 0, self.width() // 2, self.height())
266
267             # If the vector is (0, 0), then don't draw a line for it
268             else:
269                 return
270
271         # If the rank is 0, then we don't draw any lines
272         else:
273             return

```

```

273
274     elif abs(vector_x) < 1e-12 and abs(vector_y) < 1e-12:
275         # If both components of the vector are practically 0, then we can't render any grid lines
276         return
277
278     # Draw vertical lines
279     elif abs(vector_x) < 1e-12:
280         painter.drawLine(self.canvas_x(0), 0, self.canvas_x(0), self.height())
281
282         for i in range(max(abs(int(max_x / point_x)), self.max_parallel_lines)):
283             painter.drawLine(
284                 self.canvas_x((i + 1) * point_x),
285                 0,
286                 self.canvas_x((i + 1) * point_x),
287                 self.height()
288             )
289             painter.drawLine(
290                 self.canvas_x(-1 * (i + 1) * point_x),
291                 0,
292                 self.canvas_x(-1 * (i + 1) * point_x),
293                 self.height()
294             )
295
296     # Draw horizontal lines
297     elif abs(vector_y) < 1e-12:
298         painter.drawLine(0, self.canvas_y(0), self.width(), self.canvas_y(0))
299
300         for i in range(max(abs(int(max_y / point_y)), self.max_parallel_lines)):
301             painter.drawLine(
302                 0,
303                 self.canvas_y((i + 1) * point_y),
304                 self.width(),
305                 self.canvas_y((i + 1) * point_y)
306             )
307             painter.drawLine(
308                 0,
309                 self.canvas_y(-1 * (i + 1) * point_y),
310                 self.width(),
311                 self.canvas_y(-1 * (i + 1) * point_y)
312             )
313
314     # If the line is oblique, then we can use  $y = mx + c$ 
315     else:
316         m = vector_y / vector_x
317         c = point_y - m * point_x
318
319         self.draw_oblique_line(painter, m, 0)
320
321         # We don't want to overshoot the max number of parallel lines,
322         # but we should also stop looping as soon as we can't draw any more lines
323         for i in range(1, self.max_parallel_lines + 1):
324             if not self.draw_pair_of_oblique_lines(painter, m, i * c):
325                 break
326
327 def draw_pair_of_oblique_lines(self, painter: QPainter, m: float, c: float) -> bool:
328     """Draw a pair of oblique lines, using the equation  $y = mx + c$ .
329
330     This method just calls :meth:`draw_oblique_line` with ``c`` and ``-c``,
331     and returns True if either call returned True.
332
333     :param QPainter painter: The painter to draw the vectors and grid lines with
334     :param float m: The gradient of the lines to draw
335     :param float c: The y-intercept of the lines to draw. We use the positive and negative versions
336     :returns bool: Whether we were able to draw any lines on the canvas
337     """
338     return any([
339         self.draw_oblique_line(painter, m, c),
340         self.draw_oblique_line(painter, m, -c)
341     ])
342
343 def draw_oblique_line(self, painter: QPainter, m: float, c: float) -> bool:
344     """Draw an oblique line, using the equation  $y = mx + c$ .
345

```

```

346         We only draw the part of the line that fits within the canvas, returning True if
347         we were able to draw a line within the boundaries, and False if we couldn't draw a line
348
349         :param QPainter painter: The painter to draw the vectors and grid lines with
350         :param float m: The gradient of the line to draw
351         :param float c: The y-intercept of the line to draw
352         :returns bool: Whether we were able to draw a line on the canvas
353         """
354         max_x, max_y = self.grid_corner()
355
356         # These variable names are shortened for convenience
357         # myi is max_y_intersection, mmyi is minus_max_y_intersection, etc.
358         myi = (max_y - c) / m
359         mmyi = (-max_y - c) / m
360         mxi = max_x * m + c
361         mmxi = -max_x * m + c
362
363         # The inner list here is a list of coords, or None
364         # If an intersection fits within the bounds, then we keep its coord,
365         # else it is None, and then gets discarded from the points list
366         # By the end, points is a list of two coords, or an empty list
367         points: List[Tuple[float, float]] = [
368             x for x in [
369                 (myi, max_y) if -max_x < myi < max_x else None,
370                 (mmyi, -max_y) if -max_x < mmyi < max_x else None,
371                 (max_x, mxi) if -max_y < mxi < max_y else None,
372                 (-max_x, mmxi) if -max_y < mmxi < max_y else None
373             ] if x is not None
374         ]
375
376         # If no intersections fit on the canvas
377         if len(points) < 2:
378             return False
379
380         # If we can, then draw the line
381         else:
382             painter.drawLine(
383                 *self.canvas_coords(*points[0]),
384                 *self.canvas_coords(*points[1])
385             )
386             return True
387
388     def draw_transformed_grid(self, painter: QPainter) -> None:
389         """Draw the transformed version of the grid, given by the basis vectors.
390
391         .. note:: This method draws the grid, but not the basis vectors. Use :meth:`draw_basis_vectors` to draw
392         ↪ them.
393
394         :param QPainter painter: The painter to draw the grid lines with
395         """
396         # Draw all the parallel lines
397         painter.setPen(QPen(self.colour_i, self.width_transformed_grid))
398         self.draw_parallel_lines(painter, self.point_i, self.point_j)
399         painter.setPen(QPen(self.colour_j, self.width_transformed_grid))
400         self.draw_parallel_lines(painter, self.point_j, self.point_i)
401
402     def draw_arrowhead_away_from_origin(self, painter: QPainter, point: Tuple[float, float]) -> None:
403         """Draw an arrowhead at ``point``, pointing away from the origin.
404
405         :param QPainter painter: The painter to draw the arrowhead with
406         :param point: The point to draw the arrowhead at, given in grid coords
407         :type point: Tuple[float, float]
408         """
409         # This algorithm was adapted from a C# algorithm found at
410         # http://csharpshelper.com/blog/2014/12/draw-lines-with-arrowheads-in-c/
411
412         # Get the x and y coords of the point, and then normalize them
413         # We have to normalize them, or else the size of the arrowhead will
414         # scale with the distance of the point from the origin
415         x, y = point
416         vector_length = np.sqrt(x * x + y * y)
417
418         if vector_length < 1e-12:

```

```

418         return
419
420     nx = x / vector_length
421     ny = y / vector_length
422
423     # We choose a length and find the steps in the x and y directions
424     length = min(
425         self.arrowhead_length * self.default_grid_spacing / self.grid_spacing,
426         vector_length
427     )
428     dx = length * (-nx - ny)
429     dy = length * (nx - ny)
430
431     # Then we just plot those lines
432     painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x + dx, y + dy))
433     painter.drawLine(*self.canvas_coords(x, y), *self.canvas_coords(x - dy, y + dx))
434
435     def draw_position_vector(self, painter: QPainter, point: Tuple[float, float], colour: QColor) -> None:
436         """Draw a vector from the origin to the given point.
437
438         :param QPainter painter: The painter to draw the position vector with
439         :param point: The tip of the position vector in grid coords
440         :type point: Tuple[float, float]
441         :param QColor colour: The colour to draw the position vector in
442         """
443         painter.setPen(QPen(colour, self.width_vector_line))
444         painter.drawLine(*self.canvas_origin, *self.canvas_coords(*point))
445         self.draw_arrowhead_away_from_origin(painter, point)
446
447     def draw_basis_vectors(self, painter: QPainter) -> None:
448         """Draw arrowheads at the tips of the basis vectors.
449
450         :param QPainter painter: The painter to draw the basis vectors with
451         """
452         self.draw_position_vector(painter, self.point_i, self.colour_i)
453         self.draw_position_vector(painter, self.point_j, self.colour_j)
454
455     def draw_determinant_parallelogram(self, painter: QPainter) -> None:
456         """Draw the parallelogram of the determinant of the matrix.
457
458         :param QPainter painter: The painter to draw the parallelogram with
459         """
460         if self.det == 0:
461             return
462
463         path = QPainterPath()
464         path.moveTo(*self.canvas_origin)
465         path.lineTo(*self.canvas_coords(*self.point_i))
466         path.lineTo(*self.canvas_coords(self.point_i[0] + self.point_j[0], self.point_i[1] + self.point_j[1]))
467         path.lineTo(*self.canvas_coords(*self.point_j))
468
469         color = (16, 235, 253) if self.det > 0 else (253, 34, 16)
470         brush = QBrush(QColor(*color, alpha=128), Qt.SolidPattern)
471
472         painter.fillPath(path, brush)
473
474     def draw_determinant_text(self, painter: QPainter) -> None:
475         """Write the string value of the determinant in the middle of the parallelogram.
476
477         :param QPainter painter: The painter to draw the determinant text with
478         """
479         painter.setPen(QPen(self.colour_text, self.width_vector_line))
480
481         # We're building a QRect that encloses the determinant parallelogram
482         # Then we can center the text in this QRect
483         coords: List[Tuple[float, float]] = [
484             (0, 0),
485             self.point_i,
486             self.point_j,
487             (
488                 self.point_i[0] + self.point_j[0],
489                 self.point_i[1] + self.point_j[1]
490             )

```

```

491     ]
492
493     xs = [t[0] for t in coords]
494     ys = [t[1] for t in coords]
495
496     top_left = QPoint(*self.canvas_coords(min(xs), max(ys)))
497     bottom_right = QPoint(*self.canvas_coords(max(xs), min(ys)))
498
499     rect = QRectF(top_left, bottom_right)
500
501     painter.drawText(
502         rect,
503         Qt.AlignHCenter | Qt.AlignVCenter,
504         f'{self.det:.2f}'
505     )
506
507     def draw_eigenvectors(self, painter: QPainter) -> None:
508         """Draw the eigenvectors of the displayed matrix transformation.
509
510         :param QPainter painter: The painter to draw the eigenvectors with
511         """
512         for value, vector in self.eigs:
513             x = value * vector[0]
514             y = value * vector[1]
515
516             if x.imag != 0 or y.imag != 0:
517                 continue
518
519             self.draw_position_vector(painter, (x, y), self.colour_eigen)
520
521             # Now we need to draw the eigenvalue at the tip of the eigenvector
522
523             offset = 3
524             top_left: QPoint
525             bottom_right: QPoint
526             alignment_flags: int
527
528             if x >= 0 and y >= 0: # Q1
529                 top_left = QPoint(self.canvas_x(x) + offset, 0)
530                 bottom_right = QPoint(self.width(), self.canvas_y(y) - offset)
531                 alignment_flags = Qt.AlignLeft | Qt.AlignBottom
532
533             elif x < 0 and y >= 0: # Q2
534                 top_left = QPoint(0, 0)
535                 bottom_right = QPoint(self.canvas_x(x) - offset, self.canvas_y(y) - offset)
536                 alignment_flags = Qt.AlignRight | Qt.AlignBottom
537
538             elif x < 0 and y < 0: # Q3
539                 top_left = QPoint(0, self.canvas_y(y) + offset)
540                 bottom_right = QPoint(self.canvas_x(x) - offset, self.height())
541                 alignment_flags = Qt.AlignRight | Qt.AlignTop
542
543             else: # Q4
544                 top_left = QPoint(self.canvas_x(x) + offset, self.canvas_y(y) + offset)
545                 bottom_right = QPoint(self.width(), self.height())
546                 alignment_flags = Qt.AlignLeft | Qt.AlignTop
547
548             painter.setPen(QPen(self.colour_text, self.width_vector_line))
549             painter.drawText(QRectF(top_left, bottom_right), alignment_flags, f'{value:.2f}')
550
551     def draw_eigenlines(self, painter: QPainter) -> None:
552         """Draw the eigenlines (invariant lines).
553
554         :param QPainter painter: The painter to draw the eigenlines with
555         """
556         painter.setPen(QPen(self.colour_eigen, self.width_transformed_grid))
557
558         for value, vector in self.eigs:
559             if value.imag != 0:
560                 continue
561
562             x, y = vector
563

```

```

564         if x == 0:
565             x_mid = int(self.width() / 2)
566             painter.drawLine(x_mid, 0, x_mid, self.height())
567
568         elif y == 0:
569             y_mid = int(self.height() / 2)
570             painter.drawLine(0, y_mid, self.width(), y_mid)
571
572         else:
573             self.draw_oblique_line(painter, y / x, 0)

```

A.14 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 numpy import ndarray
21  from nptyping import NDArray, Float
22
23  if version_info >= (3, 10):
24      from typing import TypeGuard
25
26  __all__ = ['is_matrix_type', 'MatrixType', 'MatrixParseList', 'VectorType']
27
28  MatrixType = NDArray[(2, 2), Float]
29  """This type represents a 2x2 matrix as a NumPy array."""
30
31  VectorType = NDArray[(2,), Float]
32  """This type represents a 2D vector as a NumPy array, for use with :attr:`MatrixType`."""
33
34  MatrixParseList = 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[NDArray[(2, 2), Float]]:
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:`lintrans.typing_.MatrixType`.
53         """
54      return isinstance(matrix, ndarray) and matrix.shape == (2, 2)

```

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

```

```

71         string += char
72
73     if paren_depth == 0 and string:
74         sub_expressions.append(string)
75         string = ''
76
77     pointer += 1
78
79     if pointer >= len(expression):
80         break
81
82     if paren_depth != 0:
83         raise MatrixParseError('Unbalanced parentheses in expression')
84
85     return sub_expressions
86
87
88 def validate_matrix_expression(expression: str) -> bool:
89     """Validate the given matrix expression.
90
91     This function simply checks the expression against the BNF schema documented in
92     :ref:`expression-syntax-docs`. It is not aware of which matrices are actually defined
93     in a wrapper. For an aware version of this function, use the
94     :meth:`lintrans.matrices.wrapper.MatrixWrapper.is_valid_expression` method.
95
96     :param str expression: The expression to be validated
97     :returns bool: Whether the expression is valid according to the schema
98     """
99     # Remove all whitespace
100    expression = re.sub(r'\s', '', expression)
101
102    match = naive_expression_pattern.match(expression)
103
104    if match is None:
105        return False
106
107    # Check that the whole expression was matched against
108    if expression != match.group(0):
109        return False
110
111    try:
112        sub_expressions = find_sub_expressions(expression)
113    except MatrixParseError:
114        return False
115
116    if not sub_expressions:
117        return True
118
119    return all(validate_matrix_expression(m) for m in sub_expressions)
120
121
122 @dataclass
123 class MatrixToken:
124     """A simple dataclass to hold information about a matrix token being parsed."""
125
126     multiplier: str = ''
127     identifier: str = ''
128     exponent: str = ''
129
130     @property
131     def tuple(self) -> Tuple[str, str, str]:
132         """Create a tuple of the token for parsing."""
133         return self.multiplier, self.identifier, self.exponent
134
135
136 class ExpressionParser:
137     """A class to hold state during parsing.
138
139     Most of the methods in this class are class-internal and should not be used from outside.
140
141     This class should be used like this:
142
143     >>> ExpressionParser('3A^1B').parse()

```



```

144     [['3', 'A', '-1'), ('', 'B', '')]]
145     >>> ExpressionParser('4(M^TA^2)^-2').parse()
146     [['4', 'M^{T}A^{2}', '-2']]]
147     """
148
149     def __init__(self, expression: str):
150         """Create an instance of the parser with the given expression and initialise variables to use during
151         ↪ parsing."""
152         # Remove all whitespace
153         expression = re.sub(r'\s', '', expression)
154
155         # Check if it's valid
156         if not validate_matrix_expression(expression):
157             raise MatrixParseError('Invalid expression')
158
159         # Wrap all exponents and transposition powers with {}
160         expression = re.sub(r'(<=^)(-?\d+|T)(?=[^}]|$\)', r'{\g<0>}', expression)
161
162         # Remove any standalone minuses
163         expression = re.sub(r'-(?=[A-Z])', '-1', expression)
164
165         # Replace subtractions with additions
166         expression = re.sub(r'-(?=\d+\.?\d*([A-Z]|rot))', '+-', expression)
167
168         # Get rid of a potential leading + introduced by the last step
169         expression = re.sub(r'^\+', '', expression)
170
171         self.expression = expression
172         self.pointer: int = 0
173
174         self.current_token = MatrixToken()
175         self.current_group: List[Tuple[str, str, str]] = []
176
177         self.final_list: MatrixParseList = []
178
179     def __repr__(self) -> str:
180         """Return a simple repr containing the expression."""
181         return f'{self.__class__.__module__}.{self.__class__.__name__}("{self.expression}")'
182
183     @property
184     def char(self) -> str:
185         """Return the char pointed to by the pointer."""
186         return self.expression[self.pointer]
187
188     def parse(self) -> MatrixParseList:
189         """Fully parse the instance's matrix expression and return the :attr:`lintrans.typing.MatrixParseList`.
190
191         This method uses all the private methods of this class to parse the
192         expression in parts. All private methods mutate the instance variables.
193
194         :returns: The parsed expression
195         :rtype: :attr:`lintrans.typing.MatrixParseList`
196         """
197         self._parse_multiplication_group()
198
199         while self.pointer < len(self.expression):
200             if self.expression[self.pointer] != '+':
201                 raise MatrixParseError('Expected "+" between multiplication groups')
202
203             self.pointer += 1
204             self._parse_multiplication_group()
205
206         return self.final_list
207
208     def _parse_multiplication_group(self) -> None:
209         """Parse a group of matrices to be multiplied together.
210
211         This method just parses matrices until we get to a ``+``.
212
213         # This loop continues to parse matrices until we fail to do so
214         while self._parse_matrix():
215             # Once we get to the end of the multiplication group, we add it the final list and reset the group list
216             if self.pointer >= len(self.expression) or self.char == '+':

```

```

216         self.final_list.append(self.current_group)
217         self.current_group = []
218         self.pointer += 1
219
220     def _parse_matrix(self) -> bool:
221         """Parse a full matrix using :meth:`_parse_matrix_part`.
222
223         This method will parse an optional multiplier, an identifier, and an optional exponent. If we
224         do this successfully, we return True. If we fail to parse a matrix (maybe we've reached the
225         end of the current multiplication group and the next char is ``+``), then we return False.
226
227         :returns bool: Success or failure
228         """
229         self.current_token = MatrixToken()
230
231         while self._parse_matrix_part():
232             pass # The actual execution is taken care of in the loop condition
233
234         if self.current_token.identifier == '':
235             return False
236
237         self.current_group.append(self.current_token.tuple)
238         return True
239
240     def _parse_matrix_part(self) -> bool:
241         """Parse part of a matrix (multiplier, identifier, or exponent).
242
243         Which part of the matrix we parse is dependent on the current value of the pointer and the expression.
244         This method will parse whichever part of matrix token that it can. If it can't parse a part of a matrix,
245         or it's reached the next matrix, then we just return False. If we succeeded to parse a matrix part, then
246         we return True.
247
248         :returns bool: Success or failure
249         :raises MatrixParseError: If we fail to parse this part of the matrix
250         """
251         if self.pointer >= len(self.expression):
252             return False
253
254         if self.char.isdigit() or self.char == '-':
255             if self.current_token.multiplier != '' \
256                or (self.current_token.multiplier == '' and self.current_token.identifier != ''):
257                 return False
258
259             self._parse_multiplier()
260
261         elif self.char.isalpha() and self.char.isupper():
262             if self.current_token.identifier != '':
263                 return False
264
265             self.current_token.identifier = self.char
266             self.pointer += 1
267
268         elif self.char == 'r':
269             if self.current_token.identifier != '':
270                 return False
271
272             self._parse_rot_identifier()
273
274         elif self.char == '(':
275             if self.current_token.identifier != '':
276                 return False
277
278             self._parse_sub_expression()
279
280         elif self.char == '^':
281             if self.current_token.exponent != '':
282                 return False
283
284             self._parse_exponent()
285
286         elif self.char == '+':
287             return False
288

```

```

289         else:
290             raise MatrixParseError(f'Unrecognised character "{self.char}" in matrix expression')
291
292         return True
293
294     def _parse_multiplier(self) -> None:
295         """Parse a multiplier from the expression and pointer.
296
297         This method just parses a numerical multiplier, which can include
298         zero or one ``.`` character and optionally a ``-`` at the start.
299
300         :raises MatrixParseError: If we fail to parse this part of the matrix
301         """
302         multiplier = ''
303
304         while self.char.isdigit() or self.char in ('.', '-'):
305             multiplier += self.char
306             self.pointer += 1
307
308         try:
309             float(multiplier)
310         except ValueError as e:
311             raise MatrixParseError(f'Invalid multiplier "{multiplier}"') from e
312
313         self.current_token.multiplier = multiplier
314
315     def _parse_rot_identifier(self) -> None:
316         """Parse a ``rot()``-style identifier from the expression and pointer.
317
318         This method will just parse something like ``rot(12.5)``. The angle number must be a real number.
319
320         :raises MatrixParseError: If we fail to parse this part of the matrix
321         """
322         if match := re.match(r'rot\(([\d.-]+\))', self.expression[self.pointer:]):
323             # Ensure that the number in brackets is a valid float
324             try:
325                 float(match.group(1))
326             except ValueError as e:
327                 raise MatrixParseError(f'Invalid angle number "{match.group(1)}" in rot-identifier') from e
328
329             self.current_token.identifier = match.group(0)
330             self.pointer += len(match.group(0))
331         else:
332             raise MatrixParseError(f'Invalid rot-identifier "{self.expression[self.pointer:self.pointer + 15]}'
333 }..."')
334
335     def _parse_sub_expression(self) -> None:
336         """Parse a parenthesized sub-expression as the identifier.
337
338         This method will also validate the expression in the parentheses.
339
340         :raises MatrixParseError: If we fail to parse this part of the matrix
341         """
342         if self.char != '(':
343             raise MatrixParseError('Sub-expression must start with "("')
344
345         self.pointer += 1
346         paren_depth = 1
347         identifier = ''
348
349         while paren_depth > 0:
350             if self.char == '(':
351                 paren_depth += 1
352             elif self.char == ')':
353                 paren_depth -= 1
354
355             if paren_depth == 0:
356                 self.pointer += 1
357                 break
358
359             identifier += self.char
360             self.pointer += 1

```

```

361         if not validate_matrix_expression(identifier):
362             raise MatrixParseError(f'Invalid sub-expression identifier "{identifier}"')
363
364         self.current_token.identifier = identifier
365
366     def _parse_exponent(self) -> None:
367         """Parse a matrix exponent from the expression and pointer.
368
369         The exponent must be an integer or ``T`` for transpose.
370
371         :raises MatrixParseError: If we fail to parse this part of the token
372         """
373         if match := re.match(r'\^((-?\d+|T)\s)', self.expression[self.pointer:]):
374             exponent = match.group(1)
375
376             try:
377                 if exponent != 'T':
378                     int(exponent)
379             except ValueError as e:
380                 raise MatrixParseError(f'Invalid exponent "{match.group(1)}"') from e
381
382             self.current_token.exponent = exponent
383             self.pointer += len(match.group(0))
384         else:
385             raise MatrixParseError(f'Invalid exponent "{self.expression[self.pointer:self.pointer + 10]}..."')
386
387
388     def parse_matrix_expression(expression: str) -> MatrixParseList:
389         """Parse the matrix expression and return a :data:`lintrans.typing_.MatrixParseList`.
390
391         :Example:
392
393         >>> parse_matrix_expression('A')
394         [[(' ', 'A', ' ')]]
395         >>> parse_matrix_expression('-3M^2')
396         [[(' ', 'M', '2')]]
397         >>> parse_matrix_expression('1.2rot(12)^{3}2B^T')
398         [[('1.2', 'rot(12)', '3'), ('2', 'B', 'T')]]
399         >>> parse_matrix_expression('A^2 + 3B')
400         [[(' ', 'A', '2')], [('3', 'B', ' ')]]
401         >>> parse_matrix_expression('-3A^{-1}3B^T - 45M^2')
402         [[(' ', 'A', '-1'), ('3', 'B', 'T')], [(' ', 'M', '2')]]
403         >>> parse_matrix_expression('5.3A^{4} 2.6B^{-2} + 4.6D^T 8.9E^{-1}')
404         [[('5.3', 'A', '4'), ('2.6', 'B', '-2')], [('4.6', 'D', 'T'), ('8.9', 'E', '-1')]]
405         >>> parse_matrix_expression('2(A+B^TC)^2D')
406         [[('2', 'A+B^TC', '2'), (' ', 'D', ' ')]]
407
408         :param str expression: The expression to be parsed
409         :returns: A list of parsed components
410         :rtype: :data:`lintrans.typing_.MatrixParseList`
411         """
412         return ExpressionParser(expression).parse()

```

A.16 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.17 matrices/utility.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  """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 [0, 2pi)
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:].rstrip('0')
116
117     else:
118         return string

```

A.18 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, Tuple, Union
16
17 import numpy as np
18
19 from lintrans.typing import is_matrix_type, MatrixType

```

```

20 from .parse import parse_matrix_expression, validate_matrix_expression
21 from .utility import create_rotation_matrix
22
23
24 class MatrixWrapper:
25     """A wrapper class to hold all possible matrices and allow access to them.
26
27     .. note::
28         When defining a custom matrix, its name must be a capital letter and cannot be ``I``.
29
30     The contained matrices can be accessed and assigned to using square bracket notation.
31
32     :Example:
33
34     >>> wrapper = MatrixWrapper()
35     >>> wrapper['I']
36     array([[1., 0.],
37            [0., 1.]])
38     >>> wrapper['M'] # Returns None
39     >>> wrapper['M'] = np.array([[1, 2], [3, 4]])
40     >>> wrapper['M']
41     array([[1., 2.],
42            [3., 4.]])
43     """
44
45     def __init__(self):
46         """Initialize a :class:`MatrixWrapper` object with a dictionary of matrices which can be accessed."""
47         self._matrices: Dict[str, Optional[Union[MatrixType, str]]] = {
48             'A': None, 'B': None, 'C': None, 'D': None,
49             'E': None, 'F': None, 'G': None, 'H': None,
50             'I': np.eye(2), # I is always defined as the identity matrix
51             'J': None, 'K': None, 'L': None, 'M': None,
52             'N': None, 'O': None, 'P': None, 'Q': None,
53             'R': None, 'S': None, 'T': None, 'U': None,
54             'V': None, 'W': None, 'X': None, 'Y': None,
55             'Z': None
56         }
57
58     def __repr__(self) -> str:
59         """Return a nice string repr of the :class:`MatrixWrapper` for debugging."""
60         defined_matrices = ''.join([k for k, v in self._matrices.items() if v is not None])
61         return f'<{self.__class__.__module__}.{self.__class__.__name__} object with ' \
62             f'{len(defined_matrices)} defined matrices: '{defined_matrices}'>'
63
64     def __eq__(self, other: Any) -> bool:
65         """Check for equality in wrappers by comparing dictionaries.
66
67         :param Any other: The object to compare this wrapper to
68         """
69         if not isinstance(other, self.__class__):
70             return NotImplemented
71
72         # We loop over every matrix and check if every value is equal in each
73         for name in self._matrices:
74             s_matrix = self[name]
75             o_matrix = other[name]
76
77             if s_matrix is None and o_matrix is None:
78                 continue
79
80             elif (s_matrix is None and o_matrix is not None) or \
81                 (s_matrix is not None and o_matrix is None):
82                 return False
83
84             # This is mainly to satisfy mypy, because we know these must be matrices
85             elif not is_matrix_type(s_matrix) or not is_matrix_type(o_matrix):
86                 return False
87
88             # Now we know they're both NumPy arrays
89             elif np.array_equal(s_matrix, o_matrix):
90                 continue
91
92         else:

```

```

93         return False
94
95     return True
96
97     def __hash__(self) -> int:
98         """Return the hash of the matrices dictionary."""
99         return hash(self._matrices)
100
101     def __getitem__(self, name: str) -> Optional[MatrixType]:
102         """Get the matrix with the given name.
103
104         If it is a simple name, it will just be fetched from the dictionary. If the name is ``rot(x)`, with
105         a given angle in degrees, then we return a new matrix representing a rotation by that angle.
106
107         .. note::
108             If the named matrix is defined as an expression, then this method will return its evaluation.
109             If you want the expression itself, use :meth:`get_expression`.
110
111         :param str name: The name of the matrix to get
112         :returns Optional[MatrixType]: The value of the matrix (could be None)
113
114         :raises NameError: If there is no matrix with the given name
115         """
116         # Return a new rotation matrix
117         if (match := re.match(r'^rot\((-?\d*\.\d*)\)$', name)) is not None:
118             return create_rotation_matrix(float(match.group(1)))
119
120         if name not in self._matrices:
121             if validate_matrix_expression(name):
122                 return self.evaluate_expression(name)
123
124             raise NameError(f'Unrecognised matrix name "{name}"')
125
126         # We copy the matrix before we return it so the user can't accidentally mutate the matrix
127         matrix = copy(self._matrices[name])
128
129         if isinstance(matrix, str):
130             return self.evaluate_expression(matrix)
131
132         return matrix
133
134     def __setitem__(self, name: str, new_matrix: Optional[Union[MatrixType, str]]) -> None:
135         """Set the value of matrix ``name`` with the new_matrix.
136
137         The new matrix may be a simple 2x2 NumPy array, or it could be a string, representing an
138         expression in terms of other, previously defined matrices.
139
140         :param str name: The name of the matrix to set the value of
141         :param Optional[Union[MatrixType, str]] new_matrix: The value of the new matrix (could be None)
142
143         :raises NameError: If the name isn't a legal matrix name
144         :raises TypeError: If the matrix isn't a valid 2x2 NumPy array or expression in terms of other defined
145         ↪ matrices
146         :raises ValueError: If you attempt to define a matrix in terms of itself
147         """
148         if not (name in self._matrices and name != 'I'):
149             raise NameError('Matrix name is illegal')
150
151         if new_matrix is None:
152             self._matrices[name] = None
153             return
154
155         if isinstance(new_matrix, str):
156             if self.is_valid_expression(new_matrix):
157                 if name not in self._matrices:
158                     self._matrices[name] = new_matrix
159                     return
160             else:
161                 raise ValueError('Cannot define a matrix recursively')
162
163         if not is_matrix_type(new_matrix):
164             raise TypeError('Matrix must be a 2x2 NumPy array')

```



```

165     # All matrices must have float entries
166     a = float(new_matrix[0][0])
167     b = float(new_matrix[0][1])
168     c = float(new_matrix[1][0])
169     d = float(new_matrix[1][1])
170
171     self._matrices[name] = np.array([[a, b], [c, d]])
172
173 def get_expression(self, name: str) -> Optional[str]:
174     """If the named matrix is defined as an expression, return that expression, else return None.
175
176     :param str name: The name of the matrix
177     :returns Optional[str]: The expression that the matrix is defined as, or None
178
179     :raises NameError: If the name is invalid
180     """
181     if name not in self._matrices:
182         raise NameError('Matrix must have a legal name')
183
184     matrix = self._matrices[name]
185     if isinstance(matrix, str):
186         return matrix
187
188     return None
189
190 def is_valid_expression(self, expression: str) -> bool:
191     """Check if the given expression is valid, using the context of the wrapper.
192
193     This method calls :func:`lintrans.matrices.parse.validate_matrix_expression`, but also
194     ensures that all the matrices in the expression are defined in the wrapper.
195
196     :param str expression: The expression to validate
197     :returns bool: Whether the expression is valid in this wrapper
198
199     :raises LinAlgError: If a matrix is defined in terms of the inverse of a singular matrix
200     """
201     # Get rid of the transposes to check all capital letters
202     new_expression = expression.replace('^T', '').replace('^T}', '')
203
204     # Make sure all the referenced matrices are defined
205     for matrix in [x for x in new_expression if re.match('[A-Z]', x)]:
206         if self[matrix] is None:
207             return False
208
209         if (expr := self.get_expression(matrix)) is not None:
210             if not self.is_valid_expression(expr):
211                 return False
212
213     return validate_matrix_expression(expression)
214
215 def evaluate_expression(self, expression: str) -> MatrixType:
216     """Evaluate a given expression and return the matrix evaluation.
217
218     :param str expression: The expression to be parsed
219     :returns MatrixType: The matrix result of the expression
220
221     :raises ValueError: If the expression is invalid
222     """
223     if not self.is_valid_expression(expression):
224         raise ValueError('The expression is invalid')
225
226     parsed_result = parse_matrix_expression(expression)
227     final_groups: List[List[MatrixType]] = []
228
229     for group in parsed_result:
230         f_group: List[MatrixType] = []
231
232         for multiplier, identifier, index in group:
233             if index == 'T':
234                 m = self[identifier]
235
236             # This assertion is just so mypy doesn't complain
237             # We know this won't be None, because we know that this matrix is defined in this wrapper

```

```
238         assert m is not None
239         matrix_value = m.T
240
241     else:
242         matrix_value = np.linalg.matrix_power(self[identifier], 1 if index == '' else int(index))
243
244         matrix_value *= 1 if multiplier == '' else float(multiplier)
245         f_group.append(matrix_value)
246
247     final_groups.append(f_group)
248
249     return reduce(add, [reduce(matmul, group) for group in final_groups])
250
251 def get_defined_matrices(self) -> List[Tuple[str, Union[MatrixType, str]]]:
252     """Return a list of tuples containing the name and value of all defined matrices in the wrapper.
253
254     :returns: A list of tuples where the first element is the name, and the second element is the value
255     :rtype: List[Tuple[str, Union[MatrixType, str]]]
256     """
257     matrices = []
258
259     for name, value in self._matrices.items():
260         if value is not None:
261             matrices.append((name, value))
262
263     return matrices
```

B Testing code

B.1 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 (
14      MatrixParseError, find_sub_expressions, parse_matrix_expression, validate_matrix_expression
15  )
16  from lintrans.typing_ import MatrixParseList
17
18  expected_sub_expressions: List[Tuple[str, List[str]]] = [
19      ('2(AB)^-1', ['AB']),
20      ('-3(A+B)^2-C(B^TA)^-1', ['A+B', 'B^TA']),
21      ('rot(45)', []),
22      ('()', []),
23      ('(()', ['()']),
24      ('2.3A^-1(AB)^-1+(BC)^2', ['AB', 'BC']),
25      ('(2.3A^-1(AB)^-1+(BC)^2)', ['2.3A^-1(AB)^-1+(BC)^2']),
26  ]
27
28
29  def test_find_sub_expressions() -> None:
30      """Test the :func:`lintrans.matrices.parse.find_sub_expressions` function."""
31      for inp, output in expected_sub_expressions:
32          assert find_sub_expressions(inp) == output
33
34
35  valid_inputs: List[str] = [
36      'A', 'AB', '3A', '1.2A', '-3.4A', 'A^2', 'A^-1', 'A^{-1}',
37      'A^12', 'A^T', 'A^{5}', 'A^{T}', '4.3A^7', '9.2A^{18}', '0.1A'
38
39      'rot(45)', 'rot(12.5)', '3rot(90)',
40      'rot(135)^3', 'rot(51)^T', 'rot(-34)^-1',
41
42      'A+B', 'A+2B', '4.3A+9B', 'A^2+B^T', '3A^7+0.8B^{16}',
43      'A-B', '3A-4B', '3.2A^3-16.79B^T', '4.752A^{17}-3.32B^{36}',
44      'A-1B', '-A', '-1A'
45
46      '3A4B', 'A^TB', 'A^{T}B', '4A^6B^3',
47      '2A^{3}4B^5', '4rot(90)^3', 'rot(45)rot(13)',
48      'Arot(90)', 'AB^2', 'A^2B^2', '8.36A^T3.4B^12',
49
50      '3.5A^{4}5.6rot(19.2)^T-B^{-1}4.1C^5',
51
52      '(A)', '(AB)^-1', '2.3(3B^TA)^2', '-3.4(9D^{2}3F^{-1})^T+C', '(AB)(C)',
53      '3(rot(34)^-7A)^-1+B', '3A^2B+4A(B+C)^-1D^T-A(C(D+E)B)'
54  ]
55
56  invalid_inputs: List[str] = [
57      '', 'rot()', 'A^', 'A^1.2', 'A^{3.4}', '1,2A', 'ro(12)', '5', '12^2', '^T', '^12}', '.1A',
58      'A^{13}', 'A^3}', 'A^A', '^2', 'A--B', '--A', '+A', '--1A', 'A--B', 'A--1B', '.A', '1.A',
59      '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))',
60      '3)^2', '4(your mum)^T', 'rot()', 'rot(10.1.1)', 'rot(--2)',
61
62      'This is 100% a valid matrix expression, I swear'
63  ]
64
65
66  @pytest.mark.parametrize('inputs,output', [(valid_inputs, True), (invalid_inputs, False)])
67  def test_validate_matrix_expression(inputs: List[str], output: bool) -> None:

```

```

68     """Test the validate_matrix_expression() function."""
69     for inp in inputs:
70         assert validate_matrix_expression(inp) == output
71
72
73 expressions_and_parsed_expressions: List[Tuple[str, MatrixParseList]] = [
74     # Simple expressions
75     ('A', [((' ', 'A', ' ')]]),
76     ('A^2', [((' ', 'A', '2')]]),
77     ('A^{2}', [((' ', 'A', '2')]]),
78     ('3A', [(('3', 'A', ' ')]]),
79     ('1.4A^3', [(('1.4', 'A', '3')]]),
80     ('0.1A', [(('0.1', 'A', ' ')]]),
81     ('0.1A', [(('0.1', 'A', ' ')]]),
82     ('A^{12}', [((' ', 'A', '12')]]),
83     ('A^{234}', [((' ', 'A', '234')]]),
84
85     # Multiplications
86     ('A 0.1B', [((' ', 'A', ' '), ('0.1', 'B', ' ')]]),
87     ('A^2 3B', [((' ', 'A', '23'), (' ', 'B', ' ')]]),
88     ('4A{3} 6B^2', [(('4', 'A', '3'), ('6', 'B', '2')]]),
89     ('4.2A^{T} 6.1B^{-1}', [(('4.2', 'A', 'T'), ('6.1', 'B', '-1')]]),
90     ('-1.2A^2 rot(45)^2', [(('1.2', 'A', '2'), (' ', 'rot(45)', '2')]]),
91     ('3.2A^T 4.5B^{5} 9.6rot(121.3)', [(('3.2', 'A', 'T'), ('4.5', 'B', '5'), ('9.6', 'rot(121.3)', ' ')]]),
92     ('-1.18A^{-2} 0.1B^{2} 9rot(-34.6)^{-1}', [(('1.18', 'A', '-2'), ('0.1', 'B', '2'), ('9', 'rot(-34.6)', '-1')]]),
93
94     # Additions
95     ('A + B', [((' ', 'A', ' '), (' ', 'B', ' ')]]),
96     ('A + B - C', [((' ', 'A', ' '), (' ', 'B', ' '), ('-1', 'C', ' ')]]),
97     ('A^2 + 0.5B', [((' ', 'A', '2'), ('0.5', 'B', ' ')]]),
98     ('2A^3 + 8B^T - 3C^{-1}', [(('2', 'A', '3'), ('8', 'B', 'T'), ('-3', 'C', '-1')]]),
99     ('4.9A^2 - 3rot(134.2)^{-1} + 7.6B^8', [(('4.9', 'A', '2'), ('-3', 'rot(134.2)', '-1'), ('7.6', 'B', '8')]]),
100
101     # Additions with multiplication
102     ('2.14A{3} 4.5rot(14.5)^{-1} + 8B^T - 3C^{-1}', [(('2.14', 'A', '3'), ('4.5', 'rot(14.5)', '-1'), ('8', 'B', 'T'), ('-3', 'C', '-1')]]),
103     ('2.14A{3} 4.5rot(14.5)^{-1} + 8.5B^T 5.97C^{14} - 3.14D^{-1} 6.7E^T', [(('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')]]),
104
105     # Parenthesized expressions
106     ('(AB)^{-1}', [((' ', 'AB', '-1')]]),
107     ('-3(A+B)^2-C(B^TA)^{-1}', [(('3', 'A+B', '2'), ('-1', 'C', ' '), (' ', 'B^{T}A', '-1')]]),
108     ('2.3(3B^TA)^2', [(('2.3', '3B^{T}A', '2')]]),
109     ('-3.4(9D^{2}3F^{-1})^T+C', [(('3.4', '9D^{2}3F^{-1}', 'T'), (' ', 'C', ' ')]]),
110     ('2.39(3.1A^{-1}2.3B(CD)^{-1})^T + (AB^T)^{-1}', [(('2.39', '3.1A^{-1}2.3B(CD)^{-1}', 'T'), (' ', 'AB^{T}', '-1')]]),
111     ('-1')]]
112 ]
113
114
115
116
117 def test_parse_matrix_expression() -> None:
118     """Test the parse_matrix_expression() function."""
119     for expression, parsed_expression in expressions_and_parsed_expressions:
120         # Test it with and without whitespace
121         assert parse_matrix_expression(expression) == parsed_expression
122         assert parse_matrix_expression(expression.replace(' ', '')) == parsed_expression
123
124
125 def test_parse_error() -> None:
126     """Test that parse_matrix_expression() raises a MatrixParseError."""
127     for expression in invalid_inputs:
128         with pytest.raises(MatrixParseError):
129             parse_matrix_expression(expression)

```

B.2 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.3 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.4 matrices/utility/test_float_utility_functions.py

```

1  # lintrans - The linear transformation visualizer
2  # Copyright (C) 2021-2022 D. Dyson (DoctorDalek1963)

```

```

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

```

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

```

```

26     assert test_wrapper.get_expression('E') is None
27     assert test_wrapper.get_expression('F') is None
28     assert test_wrapper.get_expression('G') is None
29
30     assert test_wrapper.get_expression('N') == 'A^2'
31     assert test_wrapper.get_expression('O') == '4B'
32     assert test_wrapper.get_expression('P') == 'A+C'
33
34     assert test_wrapper.get_expression('Q') == 'N^-1'
35     assert test_wrapper.get_expression('R') == 'P-40'
36     assert test_wrapper.get_expression('S') == 'NOP'

```

B.6 matrices/matrix_wrapper/test_setitem_and_getitem.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, List
10
11  import numpy as np
12  import pytest
13  from numpy import linalg as la
14
15  from lintrans.matrices import MatrixWrapper
16  from lintrans.typing_ import MatrixType
17
18  valid_matrix_names = 'ABCDEFGHJKLMNOPQRSTUVWXYZ'
19  invalid_matrix_names = ['bad name', '123456', 'Th15 Is an 1nV@l1D n@m3', 'abc', 'a']
20
21  test_matrix: MatrixType = np.array([[1, 2], [4, 3]])
22
23
24  def test_basic_get_matrix(new_wrapper: MatrixWrapper) -> None:
25      """Test MatrixWrapper().__getitem__()."""
26      for name in valid_matrix_names:
27          assert new_wrapper[name] is None
28
29      assert (new_wrapper['I'] == np.array([[1, 0], [0, 1]])).all()
30
31
32  def test_get_name_error(new_wrapper: MatrixWrapper) -> None:
33      """Test that MatrixWrapper().__getitem__() raises a NameError if called with an invalid name."""
34      for name in invalid_matrix_names:
35          with pytest.raises(NameError):
36              _ = new_wrapper[name]
37
38
39  def test_basic_set_matrix(new_wrapper: MatrixWrapper) -> None:
40      """Test MatrixWrapper().__setitem__()."""
41      for name in valid_matrix_names:
42          new_wrapper[name] = test_matrix
43          assert (new_wrapper[name] == test_matrix).all()
44
45      new_wrapper[name] = None
46      assert new_wrapper[name] is None
47
48
49  def test_set_expression(test_wrapper: MatrixWrapper) -> None:
50      """Test that MatrixWrapper.__setitem__() can accept a valid expression."""
51      test_wrapper['N'] = 'A^2'
52      test_wrapper['O'] = 'BA+2C'
53      test_wrapper['P'] = 'E^T'
54      test_wrapper['Q'] = 'C^-1B'
55      test_wrapper['R'] = 'A^{2}3B'
56      test_wrapper['S'] = 'N^-1'

```



```

57     test_wrapper['T'] = 'PQP^-1'
58
59     with pytest.raises(TypeError):
60         test_wrapper['U'] = 'A+1'
61
62     with pytest.raises(TypeError):
63         test_wrapper['V'] = 'K'
64
65     with pytest.raises(TypeError):
66         test_wrapper['W'] = 'L^2'
67
68     with pytest.raises(TypeError):
69         test_wrapper['X'] = 'M^-1'
70
71
72 def test_simple_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
73     """Test that expression-defined matrices are evaluated dynamically."""
74     test_wrapper['N'] = 'A^2'
75     test_wrapper['O'] = '4B'
76     test_wrapper['P'] = 'A+C'
77
78     assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
79     assert (test_wrapper['O'] == test_wrapper.evaluate_expression('4B')).all()
80     assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
81
82     assert (test_wrapper.evaluate_expression('N^2 + 3O') ==
83             la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
84             3 * test_wrapper.evaluate_expression('4B')
85             ).all()
86     assert (test_wrapper.evaluate_expression('P^-1 - 3N0^2') ==
87             la.inv(test_wrapper.evaluate_expression('A+C')) -
88             (3 * test_wrapper.evaluate_expression('A^2')) @
89             la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
90             ).all()
91
92     test_wrapper['A'] = np.array([
93         [19, -21.5],
94         [84, 96.572]
95     ])
96     test_wrapper['B'] = np.array([
97         [-0.993, 2.52],
98         [1e10, 0]
99     ])
100    test_wrapper['C'] = np.array([
101        [0, 19512],
102        [1.414, 19]
103    ])
104
105    assert (test_wrapper['N'] == test_wrapper.evaluate_expression('A^2')).all()
106    assert (test_wrapper['O'] == test_wrapper.evaluate_expression('4B')).all()
107    assert (test_wrapper['P'] == test_wrapper.evaluate_expression('A+C')).all()
108
109    assert (test_wrapper.evaluate_expression('N^2 + 3O') ==
110            la.matrix_power(test_wrapper.evaluate_expression('A^2'), 2) +
111            3 * test_wrapper.evaluate_expression('4B')
112            ).all()
113    assert (test_wrapper.evaluate_expression('P^-1 - 3N0^2') ==
114            la.inv(test_wrapper.evaluate_expression('A+C')) -
115            (3 * test_wrapper.evaluate_expression('A^2')) @
116            la.matrix_power(test_wrapper.evaluate_expression('4B'), 2)
117            ).all()
118
119
120 def test_recursive_dynamic_evaluation(test_wrapper: MatrixWrapper) -> None:
121     """Test that dynamic evaluation works recursively."""
122     test_wrapper['N'] = 'A^2'
123     test_wrapper['O'] = '4B'
124     test_wrapper['P'] = 'A+C'
125
126     test_wrapper['Q'] = 'N^-1'
127     test_wrapper['R'] = 'P-4O'
128     test_wrapper['S'] = 'NOP'
129

```

```

130     assert test_wrapper['Q'] == pytest.approx(test_wrapper.evaluate_expression('A^-2'))
131     assert test_wrapper['R'] == pytest.approx(test_wrapper.evaluate_expression('A + C - 16B'))
132     assert test_wrapper['S'] == pytest.approx(test_wrapper.evaluate_expression('A^{2}4BA + A^{2}4BC'))
133
134
135 def test_set_identity_error(new_wrapper: MatrixWrapper) -> None:
136     """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to the identity matrix."""
137     with pytest.raises(NameError):
138         new_wrapper['I'] = test_matrix
139
140
141 def test_set_name_error(new_wrapper: MatrixWrapper) -> None:
142     """Test that MatrixWrapper().__setitem__() raises a NameError when trying to assign to an invalid name."""
143     for name in invalid_matrix_names:
144         with pytest.raises(NameError):
145             new_wrapper[name] = test_matrix
146
147
148 def test_set_type_error(new_wrapper: MatrixWrapper) -> None:
149     """Test that MatrixWrapper().__setitem__() raises a TypeError when trying to set a non-matrix."""
150     invalid_values: List[Any] = [
151         12,
152         [1, 2, 3, 4, 5],
153         [[1, 2], [3, 4]],
154         True,
155         24.3222,
156         'This is totally a matrix, I swear',
157         MatrixWrapper,
158         MatrixWrapper(),
159         np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]]),
160         np.eye(100)
161     ]
162
163     for value in invalid_values:
164         with pytest.raises(TypeError):
165             new_wrapper['M'] = value

```

B.7 matrices/matrix_wrapper/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."""
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.8 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 from numpy import linalg as la
11 import pytest
12 from pytest import approx
13
14 from lintrans.matrices import MatrixWrapper, create_rotation_matrix
15 from lintrans.typing import MatrixType
16
17 from confest import get_test_wrapper
18
19
20 def test_simple_matrix_addition(test_wrapper: MatrixWrapper) -> None:
21     """Test simple addition and subtraction of two matrices."""
22
23     # NOTE: We assert that all of these values are not None just to stop mypy complaining
24     # These values will never actually be None because they're set in the wrapper() fixture
25     # There's probably a better way do this, because this method is a bit of a bodge, but this works for now
26     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
27         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
28         test_wrapper['G'] is not None
29
30     assert (test_wrapper.evaluate_expression('A+B') == test_wrapper['A'] + test_wrapper['B']).all()
31     assert (test_wrapper.evaluate_expression('E+F') == test_wrapper['E'] + test_wrapper['F']).all()
32     assert (test_wrapper.evaluate_expression('G+D') == test_wrapper['G'] + test_wrapper['D']).all()
33     assert (test_wrapper.evaluate_expression('C+C') == test_wrapper['C'] + test_wrapper['C']).all()
34     assert (test_wrapper.evaluate_expression('D+A') == test_wrapper['D'] + test_wrapper['A']).all()
35     assert (test_wrapper.evaluate_expression('B+C') == test_wrapper['B'] + test_wrapper['C']).all()
36
37     assert test_wrapper == get_test_wrapper()
38
39
40 def test_simple_two_matrix_multiplication(test_wrapper: MatrixWrapper) -> None:
41     """Test simple multiplication of two matrices."""
42     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
43         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
44         test_wrapper['G'] is not None
45
46     assert (test_wrapper.evaluate_expression('AB') == test_wrapper['A'] @ test_wrapper['B']).all()
47     assert (test_wrapper.evaluate_expression('BA') == test_wrapper['B'] @ test_wrapper['A']).all()
48     assert (test_wrapper.evaluate_expression('AC') == test_wrapper['A'] @ test_wrapper['C']).all()
49     assert (test_wrapper.evaluate_expression('DA') == test_wrapper['D'] @ test_wrapper['A']).all()
50     assert (test_wrapper.evaluate_expression('ED') == test_wrapper['E'] @ test_wrapper['D']).all()
51     assert (test_wrapper.evaluate_expression('FD') == test_wrapper['F'] @ test_wrapper['D']).all()
52     assert (test_wrapper.evaluate_expression('GA') == test_wrapper['G'] @ test_wrapper['A']).all()
53     assert (test_wrapper.evaluate_expression('CF') == test_wrapper['C'] @ test_wrapper['F']).all()
54     assert (test_wrapper.evaluate_expression('AG') == test_wrapper['A'] @ test_wrapper['G']).all()

```

```

55
56     assert test_wrapper.evaluate_expression('A2B') == approx(test_wrapper['A'] @ (2 * test_wrapper['B']))
57     assert test_wrapper.evaluate_expression('2AB') == approx((2 * test_wrapper['A']) @ test_wrapper['B'])
58     assert test_wrapper.evaluate_expression('C3D') == approx(test_wrapper['C'] @ (3 * test_wrapper['D']))
59     assert test_wrapper.evaluate_expression('4.2E1.2A') == approx((4.2 * test_wrapper['E']) @ (1.2 *
    ↪ test_wrapper['A']))
60
61     assert test_wrapper == get_test_wrapper()
62
63
64 def test_identity_multiplication(test_wrapper: MatrixWrapper) -> None:
65     """Test that multiplying by the identity doesn't change the value of a matrix."""
66     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
67         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
68         test_wrapper['G'] is not None
69
70     assert (test_wrapper.evaluate_expression('I') == test_wrapper['I']).all()
71     assert (test_wrapper.evaluate_expression('AI') == test_wrapper['A']).all()
72     assert (test_wrapper.evaluate_expression('IA') == test_wrapper['A']).all()
73     assert (test_wrapper.evaluate_expression('GI') == test_wrapper['G']).all()
74     assert (test_wrapper.evaluate_expression('IG') == test_wrapper['G']).all()
75
76     assert (test_wrapper.evaluate_expression('EID') == test_wrapper['E'] @ test_wrapper['D']).all()
77     assert (test_wrapper.evaluate_expression('IED') == test_wrapper['E'] @ test_wrapper['D']).all()
78     assert (test_wrapper.evaluate_expression('EDI') == test_wrapper['E'] @ test_wrapper['D']).all()
79     assert (test_wrapper.evaluate_expression('IEIDI') == test_wrapper['E'] @ test_wrapper['D']).all()
80     assert (test_wrapper.evaluate_expression('EI^3D') == test_wrapper['E'] @ test_wrapper['D']).all()
81
82     assert test_wrapper == get_test_wrapper()
83
84
85 def test_simple_three_matrix_multiplication(test_wrapper: MatrixWrapper) -> None:
86     """Test simple multiplication of two matrices."""
87     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
88         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
89         test_wrapper['G'] is not None
90
91     assert (test_wrapper.evaluate_expression('ABC') == test_wrapper['A'] @ test_wrapper['B'] @
    ↪ test_wrapper['C']).all()
92     assert (test_wrapper.evaluate_expression('ACB') == test_wrapper['A'] @ test_wrapper['C'] @
    ↪ test_wrapper['B']).all()
93     assert (test_wrapper.evaluate_expression('BAC') == test_wrapper['B'] @ test_wrapper['A'] @
    ↪ test_wrapper['C']).all()
94     assert (test_wrapper.evaluate_expression('EFG') == test_wrapper['E'] @ test_wrapper['F'] @
    ↪ test_wrapper['G']).all()
95     assert (test_wrapper.evaluate_expression('DAC') == test_wrapper['D'] @ test_wrapper['A'] @
    ↪ test_wrapper['C']).all()
96     assert (test_wrapper.evaluate_expression('GAE') == test_wrapper['G'] @ test_wrapper['A'] @
    ↪ test_wrapper['E']).all()
97     assert (test_wrapper.evaluate_expression('FAG') == test_wrapper['F'] @ test_wrapper['A'] @
    ↪ test_wrapper['G']).all()
98     assert (test_wrapper.evaluate_expression('GAF') == test_wrapper['G'] @ test_wrapper['A'] @
    ↪ test_wrapper['F']).all()
99
100     assert test_wrapper == get_test_wrapper()
101
102
103 def test_matrix_inverses(test_wrapper: MatrixWrapper) -> None:
104     """Test the inverses of single matrices."""
105     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
106         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
107         test_wrapper['G'] is not None
108
109     assert (test_wrapper.evaluate_expression('A^-1') == la.inv(test_wrapper['A'])).all()
110     assert (test_wrapper.evaluate_expression('B^-1') == la.inv(test_wrapper['B'])).all()
111     assert (test_wrapper.evaluate_expression('C^-1') == la.inv(test_wrapper['C'])).all()
112     assert (test_wrapper.evaluate_expression('D^-1') == la.inv(test_wrapper['D'])).all()
113     assert (test_wrapper.evaluate_expression('E^-1') == la.inv(test_wrapper['E'])).all()
114     assert (test_wrapper.evaluate_expression('F^-1') == la.inv(test_wrapper['F'])).all()
115     assert (test_wrapper.evaluate_expression('G^-1') == la.inv(test_wrapper['G'])).all()
116
117     assert (test_wrapper.evaluate_expression('A^-1') == la.inv(test_wrapper['A'])).all()
118     assert (test_wrapper.evaluate_expression('B^-1') == la.inv(test_wrapper['B'])).all()

```

```

119     assert (test_wrapper.evaluate_expression('C^-1') == la.inv(test_wrapper['C'])).all()
120     assert (test_wrapper.evaluate_expression('D^-1') == la.inv(test_wrapper['D'])).all()
121     assert (test_wrapper.evaluate_expression('E^-1') == la.inv(test_wrapper['E'])).all()
122     assert (test_wrapper.evaluate_expression('F^-1') == la.inv(test_wrapper['F'])).all()
123     assert (test_wrapper.evaluate_expression('G^-1') == la.inv(test_wrapper['G'])).all()
124
125     assert test_wrapper == get_test_wrapper()
126
127
128 def test_matrix_powers(test_wrapper: MatrixWrapper) -> None:
129     """Test that matrices can be raised to integer powers."""
130     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
131         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
132         test_wrapper['G'] is not None
133
134     assert (test_wrapper.evaluate_expression('A^2') == la.matrix_power(test_wrapper['A'], 2)).all()
135     assert (test_wrapper.evaluate_expression('B^4') == la.matrix_power(test_wrapper['B'], 4)).all()
136     assert (test_wrapper.evaluate_expression('C^{12}') == la.matrix_power(test_wrapper['C'], 12)).all()
137     assert (test_wrapper.evaluate_expression('D^{12}') == la.matrix_power(test_wrapper['D'], 12)).all()
138     assert (test_wrapper.evaluate_expression('E^8') == la.matrix_power(test_wrapper['E'], 8)).all()
139     assert (test_wrapper.evaluate_expression('F^{-6}') == la.matrix_power(test_wrapper['F'], -6)).all()
140     assert (test_wrapper.evaluate_expression('G^{-2}') == la.matrix_power(test_wrapper['G'], -2)).all()
141
142     assert test_wrapper == get_test_wrapper()
143
144
145 def test_matrix_transpose(test_wrapper: MatrixWrapper) -> None:
146     """Test matrix transpositions."""
147     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
148         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
149         test_wrapper['G'] is not None
150
151     assert (test_wrapper.evaluate_expression('A^T') == test_wrapper['A'].T).all()
152     assert (test_wrapper.evaluate_expression('B^T') == test_wrapper['B'].T).all()
153     assert (test_wrapper.evaluate_expression('C^T') == test_wrapper['C'].T).all()
154     assert (test_wrapper.evaluate_expression('D^T') == test_wrapper['D'].T).all()
155     assert (test_wrapper.evaluate_expression('E^T') == test_wrapper['E'].T).all()
156     assert (test_wrapper.evaluate_expression('F^T') == test_wrapper['F'].T).all()
157     assert (test_wrapper.evaluate_expression('G^T') == test_wrapper['G'].T).all()
158
159     assert (test_wrapper.evaluate_expression('A^T') == test_wrapper['A'].T).all()
160     assert (test_wrapper.evaluate_expression('B^T') == test_wrapper['B'].T).all()
161     assert (test_wrapper.evaluate_expression('C^T') == test_wrapper['C'].T).all()
162     assert (test_wrapper.evaluate_expression('D^T') == test_wrapper['D'].T).all()
163     assert (test_wrapper.evaluate_expression('E^T') == test_wrapper['E'].T).all()
164     assert (test_wrapper.evaluate_expression('F^T') == test_wrapper['F'].T).all()
165     assert (test_wrapper.evaluate_expression('G^T') == test_wrapper['G'].T).all()
166
167     assert test_wrapper == get_test_wrapper()
168
169
170 def test_rotation_matrices(test_wrapper: MatrixWrapper) -> None:
171     """Test that 'rot(angle)' can be used in an expression."""
172     assert (test_wrapper.evaluate_expression('rot(90)') == create_rotation_matrix(90)).all()
173     assert (test_wrapper.evaluate_expression('rot(180)') == create_rotation_matrix(180)).all()
174     assert (test_wrapper.evaluate_expression('rot(270)') == create_rotation_matrix(270)).all()
175     assert (test_wrapper.evaluate_expression('rot(360)') == create_rotation_matrix(360)).all()
176     assert (test_wrapper.evaluate_expression('rot(45)') == create_rotation_matrix(45)).all()
177     assert (test_wrapper.evaluate_expression('rot(30)') == create_rotation_matrix(30)).all()
178
179     assert (test_wrapper.evaluate_expression('rot(13.43)') == create_rotation_matrix(13.43)).all()
180     assert (test_wrapper.evaluate_expression('rot(49.4)') == create_rotation_matrix(49.4)).all()
181     assert (test_wrapper.evaluate_expression('rot(-123.456)') == create_rotation_matrix(-123.456)).all()
182     assert (test_wrapper.evaluate_expression('rot(963.245)') == create_rotation_matrix(963.245)).all()
183     assert (test_wrapper.evaluate_expression('rot(-235.24)') == create_rotation_matrix(-235.24)).all()
184
185     assert test_wrapper == get_test_wrapper()
186
187
188 def test_multiplication_and_addition(test_wrapper: MatrixWrapper) -> None:
189     """Test multiplication and addition of matrices together."""
190     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
191         test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \

```

```

192         test_wrapper['G'] is not None
193
194     assert (test_wrapper.evaluate_expression('AB+C') ==
195             test_wrapper['A'] @ test_wrapper['B'] + test_wrapper['C']).all()
196     assert (test_wrapper.evaluate_expression('DE-D') ==
197             test_wrapper['D'] @ test_wrapper['E'] - test_wrapper['D']).all()
198     assert (test_wrapper.evaluate_expression('FD+AB') ==
199             test_wrapper['F'] @ test_wrapper['D'] + test_wrapper['A'] @ test_wrapper['B']).all()
200     assert (test_wrapper.evaluate_expression('BA-DE') ==
201             test_wrapper['B'] @ test_wrapper['A'] - test_wrapper['D'] @ test_wrapper['E']).all()
202
203     assert (test_wrapper.evaluate_expression('2AB+3C') ==
204             (2 * test_wrapper['A']) @ test_wrapper['B'] + (3 * test_wrapper['C'])).all()
205     assert (test_wrapper.evaluate_expression('4D7.9E-1.2A') ==
206             (4 * test_wrapper['D']) @ (7.9 * test_wrapper['E']) - (1.2 * test_wrapper['A'])).all()
207
208     assert test_wrapper == get_test_wrapper()
209
210
211 def test_complicated_expressions(test_wrapper: MatrixWrapper) -> None:
212     """Test evaluation of complicated expressions."""
213     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
214            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
215            test_wrapper['G'] is not None
216
217     assert (test_wrapper.evaluate_expression('-3.2A^T 4B^{-1} 6C^{-1} + 8.1D^{2} 3.2E^4') ==
218             (-3.2 * test_wrapper['A'].T) @ (4 * la.inv(test_wrapper['B'])) @ (6 * la.inv(test_wrapper['C']))
219             + (8.1 * la.matrix_power(test_wrapper['D'], 2)) @ (3.2 * la.matrix_power(test_wrapper['E'], 4))).all()
220
221     assert (test_wrapper.evaluate_expression('53.6D^{2} 3B^T - 4.9F^{2} 2D + A^3 B^{-1}') ==
222             (53.6 * la.matrix_power(test_wrapper['D'], 2)) @ (3 * test_wrapper['B'].T)
223             - (4.9 * la.matrix_power(test_wrapper['F'], 2)) @ (2 * test_wrapper['D'])
224             + la.matrix_power(test_wrapper['A'], 3) @ la.inv(test_wrapper['B'])).all()
225
226     assert test_wrapper == get_test_wrapper()
227
228
229 def test_parenthesized_expressions(test_wrapper: MatrixWrapper) -> None:
230     """Test evaluation of parenthesized expressions."""
231     assert test_wrapper['A'] is not None and test_wrapper['B'] is not None and test_wrapper['C'] is not None and \
232            test_wrapper['D'] is not None and test_wrapper['E'] is not None and test_wrapper['F'] is not None and \
233            test_wrapper['G'] is not None
234
235     assert (test_wrapper.evaluate_expression('(A^T)^2') == la.matrix_power(test_wrapper['A'].T, 2)).all()
236     assert (test_wrapper.evaluate_expression('(B^T)^3') == la.matrix_power(test_wrapper['B'].T, 3)).all()
237     assert (test_wrapper.evaluate_expression('(C^T)^4') == la.matrix_power(test_wrapper['C'].T, 4)).all()
238     assert (test_wrapper.evaluate_expression('(D^T)^5') == la.matrix_power(test_wrapper['D'].T, 5)).all()
239     assert (test_wrapper.evaluate_expression('(E^T)^6') == la.matrix_power(test_wrapper['E'].T, 6)).all()
240     assert (test_wrapper.evaluate_expression('(F^T)^7') == la.matrix_power(test_wrapper['F'].T, 7)).all()
241     assert (test_wrapper.evaluate_expression('(G^T)^8') == la.matrix_power(test_wrapper['G'].T, 8)).all()
242
243     assert (test_wrapper.evaluate_expression('(rot(45)^1)^T') == create_rotation_matrix(45).T).all()
244     assert (test_wrapper.evaluate_expression('(rot(45)^2)^T') == la.matrix_power(create_rotation_matrix(45),
245                                         ↪ 2).T).all()
246     assert (test_wrapper.evaluate_expression('(rot(45)^3)^T') == la.matrix_power(create_rotation_matrix(45),
247                                         ↪ 3).T).all()
248     assert (test_wrapper.evaluate_expression('(rot(45)^4)^T') == la.matrix_power(create_rotation_matrix(45),
249                                         ↪ 4).T).all()
250     assert (test_wrapper.evaluate_expression('(rot(45)^5)^T') == la.matrix_power(create_rotation_matrix(45),
251                                         ↪ 5).T).all()
252
253     assert (test_wrapper.evaluate_expression('D^3(A+6.2F-0.397G^TE)^{-2+A}') ==
254             la.matrix_power(test_wrapper['D'], 3) @ la.matrix_power(
255                 test_wrapper['A'] + 6.2 * test_wrapper['F'] - 0.397 * test_wrapper['G'].T @ test_wrapper['E'],
256                 -2
257             ) + test_wrapper['A']).all()
258
259     assert (test_wrapper.evaluate_expression('-1.2F^{3}4.9D^T(A^2(B+3E^TF)^{-1})^2') ==
260             -1.2 * la.matrix_power(test_wrapper['F'], 3) @ (4.9 * test_wrapper['D'].T) @
261             la.matrix_power(
262                 la.matrix_power(test_wrapper['A'], 2) @ la.matrix_power(
263                     test_wrapper['B'] + 3 * test_wrapper['E'].T @ test_wrapper['F'],
264                     -1

```

```
261         ),
262         2
263     ).all()
264
265
266 def test_value_errors(test_wrapper: MatrixWrapper) -> None:
267     """Test that evaluate_expression() raises a ValueError for any malformed input."""
268     invalid_expressions = ['', '+', '-', 'This is not a valid expression', '3+4',
269                           'A+2', 'A^', '^2', 'A^-', 'At', 'A^t', '3^2']
270
271     for expression in invalid_expressions:
272         with pytest.raises(ValueError):
273             test_wrapper.evaluate_expression(expression)
274
275
276 def test_linalgerror() -> None:
277     """Test that certain expressions raise np.linalg.LinAlgError."""
278     matrix_a: MatrixType = np.array([
279         [0, 0],
280         [0, 0]
281     ])
282
283     matrix_b: MatrixType = np.array([
284         [1, 2],
285         [1, 2]
286     ])
287
288     wrapper = MatrixWrapper()
289     wrapper['A'] = matrix_a
290     wrapper['B'] = matrix_b
291
292     assert (wrapper.evaluate_expression('A') == matrix_a).all()
293     assert (wrapper.evaluate_expression('B') == matrix_b).all()
294
295     with pytest.raises(np.linalg.LinAlgError):
296         wrapper.evaluate_expression('A^-1')
297
298     with pytest.raises(np.linalg.LinAlgError):
299         wrapper.evaluate_expression('B^-1')
300
301     assert (wrapper['A'] == matrix_a).all()
302     assert (wrapper['B'] == matrix_b).all()
```