Assignment 2

EXERCISE:
Implementing a multi-user spreadsheet.

Change Log

- Assignment released (2025-04-07)

RSheet

One of the earliest "killer apps" for a computer was VisiCalc. Released on the Apple II in 1979, it was the first spreadsheet program, and it was a huge success. It was so successful that it was the main reason that people bought Apple II computers. In this assignment, you will be implementing a simple spreadsheet program in Rust.

Specifically, you will build a server program which is controlled through simple commands. Those commands will allow you to set and get values within a spreadsheet. Since values in the spreadsheet may be dependent on other values, you will also need to manage cells being calculated and re-calculated.

The goals of this assignment are:

1. To get experience with Rust's constructs for managing concurrency.
2. To design and structure a program capable of correctly and (somewhat) efficiently managing concurrent interactions.
3. To have fun creating an aesthetic and interesting application.

We want to also be explicit about what the goals aren't:

1. To assess your ability to write spreadsheet formulae. Specifically, while we use a particular language to write formulae, you don't need to learn to use it yourself.
2. To assess your ability to write large amounts of useless cruft solely for us to mark you on. Where you're writing code, we have a reason for it. Where you're writing text, it's because we want to genuinely understand your thinking.

Part of this assignment involves submitting a `mark_request.txt` file. This gives you an opportunity to talk about both the highlights and limitations of your design. If you can identify limitations in your design, we'll give you some marks even where we would have otherwise taken them away, since identifying sub-optimal design and learning from it is part of the challenge of the assignment.

An Introduction to Spreadsheets

A spreadsheet is a grid of cells, each of which can contain a value. Cells are addressed using the "A1" method. Each cell has a column and a row. The characters in the column are the column name, and the number is the row number. For example, the cell in the first column and the first row is "A1". The cell in the second column and the first row is "B1". The cell in the first column and the second row is "A2". Importantly, the cell in the 27th column and the 1st row is "AA1". (after AA comes AB, AC, and so on until BA...). Because it is surprisingly difficult to write this logic yourself; we have provided a function called `column_number_to_name` to do this conversion for you. To avoid integer overflow, you will never be asked to write to a cell below or to the right of `ZZZZZZ999999`.

In this program, the logic for spreadsheets will be executed using the Rhai Language. Rhai is a small, fast, safe and embeddable scripting language that feels very similar to Rust. We have provided a type `CellExpr` which manages your interactions with this language for you. You do not need to understand the Rhai language, nor know how to use it. You will only need to use the simple `CellExpr` type in your assignment. You must not parse the Rhai code yourself: you should simply pass it to the CellExpr.

How your program will work

We have provided you with starter code. You **must** use this code as a starting point for your assignment. The starter code manages all the input and output for you, such that you only need to implement the `rsheet` library. That is, you will not have to modify `main.rs`. The starter code explains exactly what you will need to do.

To use the starter code, you have two options:

- To start with, you can run the starter code with no arguments. This will let you enter commands, and see what effect they have. This is the easiest way to run your code, and is generally recommended.
- Alternatively, you can run the starter code with a single argument, which is a network address. This will cause your program to start receiving instructions over a network connection. Running `6991 rsc <address>` will allow you to connect to your program over a command line. This can make it easy to test multiple connections at once, or to use other interfaces to your program. You can use an address like `127.0.0.1:6991`, which means "on my local computer, on port 6991". If you are on CSE (which is a shared machine with many students), there may already be someone using port 6991, so come up with a random number instead (less than 65535).

We have provided a reference solution to check behaviour you are unsure of. You can run the reference solution with the command: `6991 rsheet`.

How We'll Mark Your Code

In this assignment, we won't be providing Design Excellence like in Assignment 1. That's mainly because apart from just "add more features", there wasn't really anything we felt would significantly add to the experience of doing this assignment.

Markers also won't be providing general feedback over your whole assignment. We've done this for a few reasons:

- We've already had an opportunity to give general Rust feedback to you on Assignment 1
- This assignment focusses more on concurrent design than on general design.
- Necessarily, feedback for this assignment will be given after the end of term so we often find students aren't as interested in general feedback.

Instead, we'll be asking you to answer 5 questions to reflect on your design. In that, you'll point out some particular areas of your code; and where necessary we'll leave feedback on those answers and those bits of code.

Furthermore, if you have particular questions about your design; we encourage you to leave them in the `mark_request.txt` file. Your marker will reply to those questions. Notably, you only need to leave questions if you want to. Also importantly, we've asked markers to be as specific with their answers as you are with your questions. For example, "how could I have done better?" is a pretty general question, we'll give some general answers. "in my Blah struct I returned a `Box`, is there a better way to do that?" is a much more specific question.

The Tasks To Complete

Stage 1. Basic Get and Set (15%)

The basis of this assignment is two commands: `get` and `set`. These allow you to interact with the state of the spreadsheet. You can use the `Manager` trait to receive these commands by calling the `Manager::accept_new_connection` function, which can be called repeatedly to accept new connections. Once `Connect::NoMoreConnections` is received, the server will shutdown/terminate once all existing connections are closed. A connection is made up of a reader and a writer. You will read messages (the get and set input commands) from the reader, and write your responses to the writer as a `rsheet_lib::replies::Reply`, which is an enum with either a cell's value, or an error. A connection is considered closed once a `ReadMessageResult::ConnectionClosed` or `WriteMessageResult::ConnectionClosed` is received from `read_message` or `write_message`. Any errors returned from those two functions can be considered fatal/unrecoverable, i.e. you may terminate your program and output that error. In practice (i.e. in our tests), these unrecoverable errors should never occur.

For now, you will only have one user talking to your code, so you do not need to handle multiple connections.

We have provided you with the `rsheet_lib::command::Command` type, which implements the FromStr trait, so you can use it for parsing the get and set commands (a demonstration on how to do this is provided in the starter code).

The `get` command takes one argument: a cell name/identifier. It returns the value of that cell. By default, all cells are `CellValue::None` until modified. Cells can have one of four types of values: None (the default), an integer (`i64`), a string (`String`), or an error (also represented as a `String`).

The `set` command takes the name of a cell, and then a string (which might contain many spaces!), which is an expression that evaluates to a value. It sets the cell to this value. The `set` command has no output. That said, the set command *must occur atomically*. In other words, if you receive a set command, then a get command; the set command must finish before the get command starts.

For the avoidance of doubt, you **must** evaluate the expression given to you when you receive a `set` command. Some people have suggested implementations that wait until a get happens, and only evaluates the Rhai cell expression then... this is not allowed..

Given a `set` command you can use the `rsheet_lib::cell_expr::CellExpr` struct, and its `evaluate` method to evaluate the expression. This will take the expression, and evaluate it correctly; returning a `CellValue`.

For example, it will take `2 + (4 * 6)` and evaluate that to `26`.

A note on the spreadsheet language

The spreadsheet formula language is Rhai. You do not need to learn any Rhai to be able to complete this assignment, but if you're interested, it's a Rust-like scripting language. All the usual arithmetic operations are supported, as well as string concatenation (`"abc" + "def" == "abcdef"`).

We've also implemented two useful built-in functions for you:

- `sum(arg)` takes a list or list of lists; and returns the sum.
- `sleep_then(time, value)` takes a time (in ms) and a value. It waits the given number of milliseconds, then executes.

Error Handling

- If the `CellExpr::evaluate` function encounters an error while trying to evaluate the cell expression (e.g. it tried to add a string and a number, which is not supported in Rhai), it will return an `Ok(CellValue::Error)`. You should treat this `CellValue::Error` like any other cell value. However, if any of the variable values provided to `CellExpr::evaluate` are `CellValue::Error`s, `CellExpr::evaluate` will return `Err(CellExprEvalError)`, which means that one of the dependency cells is an error. During the set (because we evaluate on set not get), you must figure out a way to represent and store this additional error state of a cell, namely that cell e.g. `A1` depends on another cell with an error. Then, if the user tries to get the value of `A1`, you need to return a `Reply::Error` stating that getting the value of a cell that depends on another cell with an error is not allowed.
- If calling the `parse::()` function returns a parsing error, which could happen if you receive an invalid command (e.g. `frobnicate B1`) or an invalid cell reference (e.g. `get r2d2`), then you should return a `Reply::Error` with that error.

Examples

A simple example:

```
get A1
A1 = None
set A1 3 + 5
get A1
A1 = 8
```

A more complex example:

```
set ASDF a
Error: Invalid Key Provided
set A1 this-isn't-code
get A1
A1 = Error: "'this' can only be used in functions (line 1, position 1)"
```

A note on `--mark-mode`

The starter code includes a variable, `--mark-mode`. In this mode, any errors you send back to the user are replaced with a standard error message. You should write descriptive error messages in your program, and they can be completely different to the reference solution. During marking, only the fact you've sent back an error message will be checked, not the contents of the error.

Stage 2. Using Variables in Calculations (15%)

A spreadsheet isn't very useful unless it can actually use variables. In this stage, you will add support for variables into rsheet.

Variables can be used in the `set` command simply by referencing them. For example, `set A2 A1 + 1` means "set the A2 cell to be equal to A1 + 1". To make this work, you should use the `cell_expr::CellExpr::find_variable_names` function to find the names of variables referenced inside a command, and then pass them to the `cell_expr::CellExpr::evaluate` function.

An important note, **which only applies until Stage 4** (at which point you will lose this guarantee) is that you can assume that the cells on which other cells depend will never change.

```
set A1 1
set A2 A1 + 1
get A2
A2 = 2
set A1 3  # <---- this will never happen
get A2    # <---- this will never happen
A2 = 4
```

This means you don't need to handle the dependencies changing, and updating them until stage 5.

There are three types of variables you should support:

- *Scalar Variables*: these are individual cells; like `A1`. They will contain a single value, either a string or an integer.
- *Vector Variables*: these are a vertical or horizontal list of cells; spelled `A1_A3` or `A1_C1`. These are represented by a 1-dimensional list.
- *Matrix Variables*: these are rectangular selections of cells; like `A1_B3`. They will contain a list of lists; where each sub-list corresponds to a **row** (not a column) in the spreadsheet.

The main place we will use these vector and matrix variables is with the `sum` command that we've built into the spreadsheet language (i.e. Rhai)

```
set A1 1
set A1 1
set A2 1
set A3 sum(A1_A2)
get A3
A3 = 2
```

You will always receive the top-left variable and the bottom-right variable in a vector or matrix, in that order. This means you'll always get `A1_B3` and never `B3_A1` or `B1_A3`. Similarly, you'll always get `A1_C1` and never `C1_A1` or `A3_A1`. You don't need to test for this case.

You will never receive vector / matrix variables that contain exactly one value, like `A1_A1` or `B3_B3`. You do not need to test for this case.

Here is an example of what certain variables would equate to if the sheet was:

	A	B	C
1	1	2	3
2	4	5	6
3	7	8	9

In the image, the blue outline is `A1_C1` and the green outline is `A1_B3`. These would be represented as `[1, 2, 3]` and `[[1, 2], [4, 5], [7, 8]]` respectively.

Stage 3. Multiple Readers and Writers (20%)

In this section, you will support more than one reader/writer accessing your spreadsheet simultaneously. Because you're using a terminal to interact with the spreadsheet, we have a special syntax that will allow you to pretend to be from multiple clients at once. This syntax is *already implemented*, you do not need to do anything to get it to work.

To use this special syntax, you'll do something like this:

```
snd1: get A1
A1 = None
snd2: set A2 42
snd2: get A2
A2 = 42
```

The part before the `:` uniquely indicates a "sender". If you type a new sender, a new connection will be made to your sheet. If you reuse an existing sender, it will send another command over the same connection.

To clarify, when you type something into the terminal, rsheet_lib reads the line. It will split the line by the first colon, and then use the part before the colon as the "sender". If no colon is found, the sender will just be the empty string. If the sender has never been seen before, a new "connection" will be made to the sheet. If the sender has been seen before, the command will be sent over the existing connection.

In order to correctly implement this assignment, you will need to implement it such that each connection to the sheet is processed in its own thread. This is the first stage that requires multithreading.

One important part of this assignment is that interactions with the sheet from a single observer must happen in order. For example, from `snd2`'s point of view, the set must happen before the get.

Of course, with multiple readers and writers, it's not guaranteed that two different senders's actions will happen in any particular order. To deal with this in testing, we've added a utility for marking called `sleep`, which ensures a gap of a certain number of milliseconds between commands. Thus:

```
snd1: set A1 1
snd2: get A1
A1 = ???
```

isn't guaranteed to say that `A1` is set; but the following will.

```
snd1: set A1 1
snd2: sleep 50     # <--- this is implemented for you as part of rsheet_lib.
snd2: get A1
A1 = 1
```

We've designed all the test cases so that there should be one correct ordering of outputs. There are many other inputs to your program that could have multiple correct orderings, depending on exactly how the threads behave. For example, the following code block could set A1 to 1 or 2.

```
snd1: set A1 1
snd2: set A1 2
snd1: get A1
A1 = ???
```

We will not test you on any of these cases.

Stage 4. Simple Dependency Changes (20%)

In this stage, you will start to deal with simple dependencies. This means, for example, that you'll `set B1 A1 * 2` (i.e. `B1 = (A1 * 2)`). Then, we might change `A1`. If `A1` is set to 3, then `B1` must be set to 6. If `A1` is set to `"blah"`, then `B1` will be an

error (since `"blah" * 2` causes an error in Rhai).

It is important that these dependency changes happen *asynchronously*. In other words, say that you've run the following commands:

```
set A1 1
set B1 A1 + 1
```

Because of the guarantee that `set`s occur atomically, you're assured that `A1` will be equal to 1 by the time that we set `B1`. However, let's say you now run `set A1 2`. `A1` will be equal to `2` immediately. However, `B1` will not yet be equal to `3`. That should happen separately, and not necessarily atomically.

Specifically, you **must** have a single worker thread which processes all the updates to other cells in the spreadsheet that are not directly caused by an update (i.e. set) command. This worker thread will call the `CellExpr::evaluate` function for each cell whose dependency has been updated.

Importantly, because these updates are happening in the background on the worker thread, this code is not guaranteed to have `B1` be `3` straight away, since the worked thread may need some time to process.

```
set A1 1
set B1 A1 + 1
set A1 2
get B1  # <-- potentially B1 is still 2
```

For that reason, we'll usually put a sleep that gives your extra thread enough time to process `B1` before we check it.

It's also important to note that for this section, we will *only* test dependency chains exactly one-cell long. You'll never end up in a situation where `C1` depends on `B1`, and `B1` depends on `A1` (in this stage). You'll also never be given a circular dependency or self-referential dependency (in this stage).

Note that if you receive a command which gets a cell which depends on an error, you should return a `Reply::Error`. For example, if `A1` is set to `bad-code`, and `B1` is set to `A1 + 1`, then `get B1` should fail with an error stating that it depends on a cell with an error.

A Complex Edge Case

As part of completing this stage, there is a complex edge case which you will need to decide how to handle. This edge case involves the fact that dependencies can be updated in strange orders.

In particular, some cell updates might take some time (emulated using the `sleep_then` function). Say user A makes an update to a cell that takes 5 seconds to compute. User B then makes an update to that same cell 1 second later, but that update only takes 2 seconds to compute. In `rsheet`, we want to make sure a more recent update is never wiped out by an older one. Since user B's update was more recent, once user A's update finishes computing (at T=5 seconds), it **should not** override the value produced by user B.

Here is an example in `rsheet` code:

```
snd1: set B1 A1 + 1
snd1: set A1 sleep_then(5000, 5)
snd2: sleep 1000
snd2: set A1 sleep_then(2000, 10)
```

> **HINT:**
>
> The `sleep_then` function can be located in the `rsheet_lib::cell_expr` module inside the `evaluate` function.
>
> It's a simple function that sleeps for a given number of milliseconds, then returns the value given to it.

It's clear that `A1` should be equal to `10` here (since it was the more recent update). That means that `B1` should be equal to `11`. However, this could be (incorrectly) written out like this:

- 0 seconds in: B1 got set,
- 0 seconds in: snd1 sleeps for 5 seconds, waiting to update A1
- 0 seconds in: snd2 sleeps for 1 second.
- 1 second in: snd2 sleeps for 2 seconds, waiting to update A1
- 3 seconds in: snd2 updates `A1 = 10`
- 3.001 seconds in: `B1` updates to `11`
- 5 seconds in: `A1` is (incorrectly!) updated to `5`
- 5.001 seconds in: `B1` is (incorrectly) updates to `6`.

Even though the user more recently set `A1` to `10`, it gets set *back* to `5`, because it was slower to compute. Furthermore, any dependencies are also incorrectly set as a result of this mistake.

You will need to account for this edge case in your code.

Stage 5. Multi-Layered Dependencies (30%)

In this stage, you will expand your implementation of Stage 5 so that it works for dependency chains of any length. In other words, you might have a situation where `C1` depends on `B1`, and `B1` depends on `A1`. You might also have tricker dependencies, like where `C1` depends on `A1_B1`, and `B1` depends on `A1`.

You are guaranteed that you will never be asked to calculate a circular dependency, or self-referential dependency. That is, there will never be a chain of dependencies such that a cell depends on itself, like `set A2 A2` or `set A1 A2; set A2 A1`.

Autotests

The normal `6991 autotest` command will provide you some automated tests to check your code.

These tests are set to be **very slow**. This is what we'll mark your code with, however it will make iterating on your code very slow. You can run the tests with the `--fast` flag to activate a faster version of the tests. These tests are semantically identical, they just run faster. If you see failures in these tests occasionally, you should check with the slow tests to make sure your program is correct.

Design Questions

These questions are worth 15% of your final mark for this assignment. You should answer them in the `mark_request.txt` file. Questions which talk about code require **specific** references to lines of code (like "src/main.rs:123"). You must not write more than 150 words for each question (the autotests check this).

1. In the provided starter code, we provide a `Command` struct, and implement the `FromStr` trait for it. Here are three alternate ways we could have implemented this code. For each one, make a judgement on whether it would be better or worse than the current implementation, with a brief explanation.
   - Rather than building a separate struct and parser, we could have parsed the string from the user directly.
   - Rather than implementing the `FromStr`, we could have written a separate function `parse`.
   - Rather than defining named fields on the enum (e.g. `cell_identifier` on the `get` variant), we could have made seperate `GetCommand` and `SetCommand` structs.
2. (Requires attempting stage 2) Identify the three lines of code where you handle Scalar, Vector and Matrix variables.
   - Describe how much code is shared between the three types of variables, versus how much requires seperate handling. Could you have improved this at all?
   - Imagine the assignment added a new type of variable, `MatrixList` (a list of matricies of the same size): how would you need to change your code to support this?

   (Requires attempting stage 3)
3. Identify two specific lines that have required the use of different concurrency utilities, datastructures or synchronization primitives (e.g. mutex, channels, threads, scopes). For each one, explain a possible concurrency bug which Rust's type system has helped you avoid.
4. (Requires attempting stage 4) What line/lines of code show how you deal with the "complex edge case" in part 4. Justify how your solution ensures you'll never have the problem described.
5. (Requires attempting stage 5) Your program is given the following input:

   ```
   set A1 5
   set B1 A1
   set C1 B1
   set A1 7
   sleep 100
   get C1
   ```

   At the point where the `set A1 7` command is issued, describe how your solution reads that command, and updates each cell from A1 to B1 to C1. In your answer, specifically identify every line of code where a data is passed between your program's threads.

Other Information

Submission

See the instructions down the bottom of the page.

Using Other Crates

We are happy for you to use any crate that has been published on crates.io under three conditions:

> The crate must not have been authored by anyone else in the course.
> The crate must have at least 1000 downloads, excluding the last 30 days.
> The crate must not impose license restrictions which require you to share your own code.

If you are in doubt (or think these restrictions unfairly constrain you from using a reasonable crate), ask on the course forum.

Marking Scheme

There are 3 things on which you will be marked:

- Mechanical Style (10% of the total marks for this assignment)
- Functional Correctness (75% of the total marks for this assignment)
- Design Questions (15% of the total marks for this assignment)

And a detailed analysis is shown below:

1. Mechanical Style (10%):

We will look at your crates, and make sure they:

- Compile, with no warnings or errors.
- Raise no issues with `6991 cargo clippy`.
- Are formatted with `rustfmt` (you can run `6991 cargo fmt` to auto-format your crate).
- Have any tests written for them pass.

If they do all of the above, you get full marks. Otherwise, we will award partial marks. This is meant to be the "easy marks" of programming.

2. Functional Correctness (75%):

You should pass the provided test cases. We will vary the test case very slightly during marking, to ensure you haven't just hard-coded things; but we're not going to do anything that's not just changing around some commands and re-ordering things.

3. Design Questions (15%):

You should answer the 5 design questions from above. You will be marked based on your response to these questions, and the relevant code and design that you reference as part of your answers.

IMPORTANT: your marks for the assignment **are not** the percentage of tests which you pass. We'll scale the tests to fit in with the weights described above.

You should complete the questions of the `mark_request` faithfully. If you do not answer the questions in the file, you will not receive design question marks. The "Questions to the Marker" do not count towards any marks and are entirely optional.

Note that the following penalties apply to your total mark for plagiarism:

0 for the assignment	Knowingly providing your work to anyone and it is subsequently submitted (by anyone).
0 for the assignment	Submitting any other persons work. This includes joint work.
0 FL for COMP6991	Paying another person to complete work. Submitting another persons work without their consent.

Formal Stuff

Assignment Conditions

- **Joint work** is **not permitted** on this assignment.

  This is an individual assignment.

  The work you submit must be entirely your own work. Submission of any work even partly written by any other person is not permitted.

  The only exception being if you use small amounts (< 10 lines) of general purpose code (not specific to the assignment) obtained from a site such as Stack Overflow or other publicly available resources. You should attribute the source of this code clearly in an accompanying comment.

  Assignment submissions will be examined, both automatically and manually for work written by others.

  Do not request help from anyone other than the teaching staff of COMP6991.

  Do not post your assignment code to the course forum.

  Rationale: this assignment is an individual piece of work. It is designed to develop the skills needed to produce an entire working program. Using code written by or taken from other people will stop you learning these skills.

- The use of **code-synthesis tools** is permitted on this assignment, however beware -- the code it creates can be subtly broken or introduce design flaws. It is your job to figure out what code is good. Your code is your responsibility. If your AI assistant blatantly plagiarises code from another author which you then submit, you will be held accountable.

  Rationale: this assignment is intended to mimic the real world. These tools are available in the real world. However, you must be careful to use these tools cautiously and ethically.

- **Sharing, publishing, distributing** your assignment work is **not permitted**.

  Do not provide or show your assignment work to any other person, other than the teaching staff of COMP6991. For example, do not share your work with friends.

  Do not publish your assignment code via the internet. For example, do not place your assignment in a public GitHub repository. You can publish Workshops or Labs (after they are due), but assignments are large investments for the course and worth a significant amount; so publishing them makes it harder for us and tempts future students.

  Rationale: by publishing or sharing your work you are facilitating other students to use your work, which is not permitted. If they submit your work, you may become involved in an academic integrity investigation.

- **Sharing, publishing, distributing your assignment work after the completion of COMP6991** is **not permitted** .

  For example, do not place your assignment in a public GitHub repository after COMP6991 is over.

  Rationale: COMP6991 sometimes reuses assignment themes, using similar concepts and content. If students in future terms can find your code and use it, which is not permitted, you may become involved in an academic integrity investigation.

Violation of the above conditions may result in an academic integrity investigation with possible penalties, up to and including a mark of 0 in COMP6991 and exclusion from UNSW.

Relevant scholarship authorities will be informed if students holding scholarships are involved in an incident of plagiarism or other misconduct. If you knowingly provide or show your assignment work to another person for any reason, and work derived from it is submitted - you may be penalised, even if the work was submitted without your knowledge or consent. This may apply even if your work is submitted by a third party unknown to you.

If you have not shared your assignment, you will not be penalised if your work is taken without your consent or knowledge.

For more information, read the UNSW Student Code, or contact the course account.

When you are finished working on this exercise, you must submit your work by running `give`:

```
$ 6991 give-crate
```

The due date for this exercise is **Week 10 Friday 17:00:00**.

Note that this is an individual exercise; the work you submit with `give` must be entirely your own.
