fn make_row_by_row_fallible

Michael Shoemate

This proof resides in **"contrib"** because it has not completed the vetting process.

Proves soundness of `make_row_by_row_fallible` in `mod.rs` at commit f5bb719 (outdated[1]).

`make_row_by_row_fallible` returns a Transformation that applies a user-specified function to each record in the input dataset. The function is permitted to return a data-independent error.

Vetting History

- Pull Request #562

1 Hoare Triple

Precondition

- `DI` (input domain) is a type with trait `RowByRowDomain<DO>`. This trait provides a way to apply a map function to each record in the input dataset to retrieve a dataset that is a member of the output domain, of type `DO`. The trait further implies that `DatasetDomain` is also implemented for `DI`.
- `DO` (output domain) is a type with trait `DatasetDomain`. `DatasetDomain` is used to define the type of the row domain.
- `M` (metric) is a type with trait `DatasetMetric`. `DatasetMetric` is used to restrict the set of valid metrics to those which measure distances between datasets.
- `MetricSpace` is implemented for `(DI, M)`. Therefore `M` is a valid metric on `DI`.
- `MetricSpace` is implemented for `(DO, M)`.
- `row_function` has no side-effects.
- If the input to `row_function` is a member of `input_domain`'s row domain, then the output is a member of `output_row_domain`, or a data-independent error.

Pseudocode

```python
def make_row_by_row_fallible(
    input_domain: DI,
    input_metric: M,
    output_row_domain: DO,
    # a function from input domain's row type to output domain's row type
    row_function: Callable([[DI_RowDomain_Carrier], DO_RowDomain_Carrier])
) -> Transformation:

```

[1] See new changes with `git diff f5bb719..33f2250 rust/src/transformations/manipulation/mod.rs`

```python
    # where .translate is defined by the RowByRowDomain trait
    output_domain = input_domain.translate(output_row_domain)

    def function(data: DI_Carrier) -> DO_Carrier:
        # where .apply_rows is defined by the RowByRowDomain trait
        return DI.apply_rows(data, row_function)

    stability_map = new_stability_map_from_constant(1) #

    return Transformation(
        input_domain, output_domain, function,
        input_metric, input_metric, stability_map)
```

Postcondition

Theorem 1.1. For every setting of the input parameters `(input_domain, input_metric, output_domain, row_function, DI, DO, M)` to `make_row_by_row` such that the given preconditions hold, `make_row_by_row` raises an error (at compile time or run time) or returns a valid transformation. A valid transformation has the following properties:

1. (Data-independent runtime errors). For every pair of members x and x' in `input_domain`, `invoke`(x) and `invoke`(x') either both return the same error or neither return an error.

2. (Appropriate output domain). For every member x in `input_domain`, `function`(x) is in `output_domain` or raises a data-independent runtime error.

3. (Stability guarantee). For every pair of members x and x' in `input_domain` and for every pair (`d_in`, `d_out`), where `d_in` has the associated type for `input_metric` and `d_out` has the associated type for
`output_metric`, if x, x' are `d_in`-close under `input_metric`, `stability_map(d_in)` does not raise an error, and `stability_map(d_in)` = `d_out`, then `function`(x), `function`(x') are `d_out`-close under `output_metric`.

2 Proofs

Proof. **(Part 1 – appropriate output domain).** By the definition of `RowByRowDomain`, `DI.apply_rows(data, row_function)` returns a dataset in `input_domain.translate(output_row_domain)`, if `row_function` is a mapping between `input_domain`'s row domain to `output_row_domain`. This is satisfied by the precondition on `row_function`. Thus, for all settings of input arguments, the function returns a dataset in the output domain. □

Before proceeding with proving the validity of the stability map, we first provide a lemma.

Lemma 2.1. Let f denote the `row_function`. For any choice u, v of input arguments in the input domain, and any choice `M` for which `DatasetMetric` is implemented for, $d_M([f(u_1), f(u_2), ...], [f(v_1), f(v_2), ...]) \leq d_M([u_1, u_2, ...], [v_1, v_2, ...])$.

Proof. Assume WLOG that any source of randomness is fixed when f is computed on u vs v. Given this assumption, and the precondition that f has no side-effects, if $u_i = v_i$, then $f(u_i) = f(v_i)$. That is, the row function cannot increase the distance between corresponding rows in any adjacent dataset. On the other hand, it is possible for $f(u_i) = f(v_i)$, even if $u_i \neq v_i$. For example, if f is a constant function, then $f(u_i) = f(v_i)$ for all i. Therefore, by any of the metrics that `DatasetMetric` is implemented for, f can only make datasets more similar. □

Proof. **(Part 2 – stability map).** Take any two elements u, v in the
`input_domain` and any pair (`d_in`, `d_out`), where `d_in` has the associated type for `input_metric` and `d_out`

has the associated type for `output_metric`. Assume u, v are `d_in`-close under `input_metric` and that `stability_map`(`d_in`) $\leq$ `d_out`.

$$
\begin{aligned}
d_M(\texttt{function}(u), \texttt{function}(v)) &= d_M([f(u_1), f(u_2), ...], [f(v_1), f(v_2), ...]) && \text{since } \texttt{DO} \text{ is a } \texttt{DatasetDomain} \\
&\leq d_M([u_1, u_2, ...], [v_1, v_2, ...]) && \texttt{by } 2.1 \\
&= d_M(u, v) && \text{since } \texttt{DI} \text{ is a } \texttt{DatasetDomain} \\
&= \texttt{d\_in} && \text{by the first assumption} \\
&\leq \texttt{TO.inf\_cast(d\_in)} && \text{by } \texttt{InfCast} \\
&\leq \texttt{TO.one().inf\_mul(TO.inf\_cast(d\_in))} && \text{by } \texttt{InfMul} \\
&= \texttt{stability\_map(d\_in)} && \text{by pseudocode line } 16 \\
&\leq \texttt{d\_out} && \text{by the second assumption}
\end{aligned}
$$

It is shown that `function`(u), `function`(v) are `d_out`-close under `output_metric`. □