

fn make_count

Sílvia Casacuberta, Grace Tian, Connor Wagaman

Proves soundness of `make_count` in `mod.rs` at commit `f5bb719` (outdated¹).

`make_count` returns a Transformation that computes a count of the number of records in a vector. The length of the vector, of type `usize`, is exactly casted to a user specified output type `T0`. If the length is too large to be represented exactly by `T0`, the cast saturates at the maximum value of type `T0`.

1 Hoare Triple

Precondition

Compiler-verified

- Generic TIA (atomic input type) is a type with trait `Primitive`.
- Generic T0 (output type) is a type with trait `Number`.
- Argument `input_domain` is of type `VectorDomain<AtomDomain<TIA>>`.
- Argument `input_metric` is of type `SymmetricDistance`.

Caller-verified

None

Pseudocode

```
1 def make_count(  
2     input_domain: VectorDomain[AtomDomain[TIA]],  
3     input_metric: SymmetricDistance  
4 ):  
5     output_domain = AtomDomain.default(T0) #  
6  
7     def function(arg: Vec[TIA]) -> T0: #  
8         size = arg.len() #  
9         try: #  
10            return T0.exact_int_cast(size) #  
11        except FailedCast:  
12            return T0.MAX_CONSECUTIVE #  
13  
14     output_metric = AbsoluteDistance(T0)  
15  
16     stability_map = StabilityMap.new_from_constant(T0.one()) #  
17  
18     return Transformation(  
19         input_domain, output_domain, function,  
20         input_metric, output_metric, stability_map)
```

¹See new changes with `git diff f5bb719..eb0a360 rust/src/transformations/count/mod.rs`

Postcondition

Theorem 1.1. For every setting of the input parameters (`input_domain`, `input_metric`, `TIA`, `T0`) to `make_count` such that the given preconditions hold, `make_count` 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). The `output_domain` is `AtomDomain(T0)`, so it is sufficient to show that `function` always returns non-null values of type `T0`. By the definition of the `ExactIntCast` trait, `T0.exact_int_cast` always returns a non-null value of type `T0` or raises an exception. If an exception is raised, the function returns `T0.MAXIMUM_CONSECUTIVE`, which is also a non-null value of type `T0`. Thus, in all cases, the function (from line 9) returns a non-null value of type `T0`. \square

Before proceeding with proving the validity of the stability map, we provide a couple lemmas.

Lemma 2.1. $|\text{function}(x) - \text{function}(x')| \leq |\text{len}(x) - \text{len}(x')|$, where `len` is an alias for `input_domain.size`.

Proof. As `arg` has type `Vec<TIA>`, it supports the Rust standard library function `len` that returns the number of elements in the `arg` as type `usize` on line 8. By the definition of `ExactIntCast`, the invocation of `T0.exact_int_cast` on line 10 can only fail if the argument is greater than `T0.MAX_CONSECUTIVE`. In this case, the value is replaced with `T0.MAX_CONSECUTIVE`. Therefore, $\text{function}(x) = \min(\text{len}(x), c)$, where $c = \text{T0.MAX_CONSECUTIVE}$. We use this equality to prove the lemma:

$$\begin{aligned} |\text{function}(x) - \text{function}(x')| &= |\min(\text{len}(x), c) - \min(\text{len}(x'), c)| \\ &\leq |\text{len}(x) - \text{len}(x')| \end{aligned} \quad \text{since clamping is stable}$$

\square

Lemma 2.2. For vector x with each element $\ell \in x$ drawn from domain \mathcal{X} , $\text{len}(x) = \sum_{z \in \mathcal{X}} h_x(z)$.

Proof. Every element $\ell \in x$ is drawn from domain \mathcal{X} , so summing over all $z \in \mathcal{X}$ will sum over every element $\ell \in x$. Recall that the definition of `SymmetricDistance` states that $h_x(z)$ will return the number of occurrences of value z in vector x . Therefore, $\sum_{z \in \mathcal{X}} h_x(z)$ is the sum of the number of occurrences of each unique value; this is equivalent to the total number of items in the vector.

By the postcondition of `Vec.len` in the Rust standard library, the variable `size` is of type `usize` containing the number of elements in `arg`. Therefore, $\sum_{z \in \mathcal{X}} h_x(z)$ is equivalent to `size`. \square

Proof. (Part 2 – stability map). Take any two elements x, x' 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 x, x' are `d_in`-close under `input_metric` and that `stability_map(d_in) ≤ d_out`. These assumptions are used to establish the following inequality:

$$\begin{aligned}
|\text{function}(x) - \text{function}(x')| &\leq |\text{len}(x) - \text{len}(x')| && \text{by 2.1} \\
&= \left| \sum_{z \in \mathcal{X}} h_x(z) - \sum_{z \in \mathcal{X}} h_{x'}(z) \right| && \text{by 2.2} \\
&= \left| \sum_{z \in \mathcal{X}} (h_x(z) - h_{x'}(z)) \right| && \text{by algebra} \\
&\leq \sum_{z \in \mathcal{X}} |h_x(z) - h_{x'}(z)| && \text{by triangle inequality} \\
&= d_{Sym}(x, x') && \text{by SymmetricDistance} \\
&\leq d_in && \text{by the first assumption} \\
&\leq T0.\text{inf_cast}(d_in) && \text{by InfCast} \\
&\leq T0.\text{one}().\text{inf_mul}(T0.\text{inf_cast}(d_in)) && \text{by InfMul} \\
&= \text{stability_map}(d_in) && \text{by line 16, see StabilityMap} \\
&\leq d_out && \text{by the second assumption}
\end{aligned}$$

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