Dimensions and functions as values

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Abstract

We introduce dimension and function identifiers as first class values in the Lucid language. We illustrate the need for such values through examples, and show that their semantics simplifies the presentation of Lucid.

1 Introduction

In Indexical Lucid, dimensions can be passed as parameters to functions, but they are not real values: for example, one cannot create a stream of dimensions. However, this possibility is necessary whenever one wishes to build functions that work over a variable number of dimensions.

For example, consider the runningSum function defined below:

\[
\text{runningSum}(N) = M
\text{where}
M = N \text{ fby } M + \text{ next } N;
\text{end;}
\]

Suppose that the running sum of an integer stream \( A \) is supposed to take place in two dimensions, \( da \) and \( db \), where \( A \) is (dimension \( da \) goes horizontally rightwards and dimen-
sion db goes vertically downwards):

\[
\begin{array}{cccccc}
1 & 3 & 4 & 2 & 7 & \\
3 & 1 & 6 & 7 & 9 & \\
1 & 9 & 2 & 1 & 4 & \\
\vdots & \vdots & \vdots & \vdots & \vdots & \\
\end{array}
\]

Then \texttt{runningSum.da(runningSum.db(A))} gives:

\[
\begin{array}{cccccc}
1 & 4 & 8 & 10 & 17 & \\
4 & 8 & 18 & 27 & 43 & \\
5 & 18 & 30 & 40 & 60 & \\
\vdots & \vdots & \vdots & \vdots & \vdots & \\
\end{array}
\]

Suppose that integer stream \textit{B} varied in three dimensions, \textit{da}, \textit{db} and \textit{dc}; to compute the running sum in three dimensions, one would have to write:

\[
\texttt{runningSum.da(runningSum.db(runningSum.dc(B)))}
\]

But without dimensions as values, it is impossible to compute the general running sum for an \textit{n}-dimensional stream, where \textit{n} is arbitrary.

A dimension stream is simply a stream whose values are dimensions. We define the general running sum program:

\[
\texttt{RunningSum.d(D,N) = M asa.d iseod(D)}
\]

\[
\text{where}
\]

\[
M = N \texttt{ fby.d runningSum.D(M)};
\]

end;

where it is supposed that \textit{D} is a stream of dimensions varying in dimension \textit{d}. \texttt{RunningSum} calls \texttt{runningSum}, in turn, for each dimension in which \textit{N} varies.

For the example with stream \textit{A}, the expression becomes:

\[
\texttt{RunningSum.dA(da fby.dA db fby.dA eod, A)}
\]

For stream \textit{B}, the expression becomes:

\[
\texttt{RunningSum.dA(da fby.dA db fby.dA dc fby.dA eod, B)}
\]

In each case, dimension \textit{dA} is a local dimension.

A second example is for testing the equality of \textit{n}-dimensional finite rectangular arrays:
Figure 1: Behavior of equal function

\[
\text{equal.d,D}(E_0, E_1) = s \text{ asa.d iseod(D)}
\]
where
\[
s = E_0 \text{ eq E1 fby.d collection.D s;}
collection.c E = (\text{iseod(E) or E}) \text{ asa.c}
\]
\[
(\text{iseod(E) or not E});
\]
end;

The behavior of equal is illustrated by Figure 1.

As we can see, defining a function that acts over an arbitrary stream of dimensions is quite useful. With function identifiers as values, we can do more. Here we have a general-use function that applies a function iteratively to a stream of dimensions:

\[
\text{applydim.d}(D, \text{fid}, A) = \text{result asa.d iseod(D)}
\]
where
\[
\text{result} = \text{fid.D(A) fby.d fid.(next.d D)(result)};
\]
end;

Note that we are only manipulating function identifiers, not actual functions, so we only allow Pascal-like higher-order functions, with no partial application.
2 Syntax of Lucid

Now that dimension and function identifiers have become values, the abstract syntax for Lucid programs is greatly simplified. In the following syntax, identifiers \( id \) can be constants (type const), data operations (op), variables (var), functions (func) or dimensions (dim). Lucid's operations are function application, intensional query and intensional navigation.

\[
E ::= \begin{align*}
    & id \\
    | & E(E_1, \ldots, E_n) \\
    | & \text{if } E \text{ then } E' \text{ else } E'' \\
    | & \#E \\
    | & E \circ E' \ E'' \\
    | & E \text{ where } Q
\end{align*}
\]

\[
Q ::= \begin{align*}
    & \text{dimension } id \\
    | & id = E \\
    | & id(id_1, \ldots, id_n) = E \\
    | & Q \ Q
\end{align*}
\]

3 Semantics of Lucid

Semantic expressions for Lucid expressions are of the form \( D, P \vdash E : v \). In definition environment \( D \) and in context \( P \), expression \( E \) evaluates to value \( v \). Identifiers of type op, func and dim evaluate to themselves. They can only be used in the appropriate situations.

\[
\begin{align*}
\text{D}(id) &= (\text{const}, c) \\
D, P \vdash id : c
\end{align*}
\]

\[
\begin{align*}
\text{D}(id) &= (\text{op}, f) \\
D, P \vdash id : id
\end{align*}
\]

\[
\begin{align*}
\text{D}(id) &= (\text{dim}) \\
D, P \vdash id : id
\end{align*}
\]

\[
\begin{align*}
\text{D}(id) &= (\text{func}, id, E) \\
D, P \vdash id : id
\end{align*}
\]

\[
\begin{align*}
\text{D}(id) &= (\text{var}, E) \\
D, P \vdash E : v \\
D, P \vdash id : v
\end{align*}
\]
\[ \begin{align*}
\mathcal{D}, \mathcal{P} \vdash E : \text{id} & \quad \mathcal{D}(\text{id}) = (\text{op}, f) \quad \mathcal{D}, \mathcal{P} \vdash E_i : v_i \\
\mathcal{D}, \mathcal{P} \vdash E(E_1, \ldots, E_n) : f(v_1, \ldots, v_n) \\
\mathcal{D}, \mathcal{P} \vdash E : \text{id} & \quad \mathcal{D}(\text{id}) = (\text{func}, \text{id}_i, E') \quad \mathcal{D}, \mathcal{P} \vdash E'[\text{id}_i \leftarrow E_i] : v \\
\mathcal{D}, \mathcal{P} \vdash E(E_1, \ldots, E_n) : v \\
\mathcal{D}, \mathcal{P} \vdash E : \text{true} & \quad \mathcal{D}, \mathcal{P} \vdash E' : v' \\
\mathcal{D}, \mathcal{P} \vdash E : \text{false} & \quad \mathcal{D}, \mathcal{P} \vdash E' : v'' \\
\mathcal{D}, \mathcal{P} \vdash \text{if } E \text{ then } E' \text{ else } E'' : v'' \\
\mathcal{D}, \mathcal{P} \vdash E : \text{id} & \quad \mathcal{D}(\text{id}) = (\text{dim}) \\
\mathcal{D}, \mathcal{P} \vdash \#E : \mathcal{P}(\text{id}) \\
\mathcal{D}, \mathcal{P} \vdash E' : \text{id} & \quad \mathcal{D}(\text{id}) = (\text{dim}) \quad \mathcal{D}, \mathcal{P} \vdash E'' : v'' \quad \mathcal{D}, \mathcal{P}[\text{id} \mapsto v''] \vdash E : v \\
\mathcal{D}, \mathcal{P} \vdash \#E \oplus E' \oplus E'' : v \\
\mathcal{D}, \mathcal{P} \vdash Q : \mathcal{D}', \mathcal{P}' \quad \mathcal{D}', \mathcal{P}' \vdash E : v \\
\mathcal{D}, \mathcal{P} \vdash E \text{ where } Q : v \\
\mathcal{D}, \mathcal{P} \vdash \text{dimension } \text{id} : \mathcal{D}[\text{id} \mapsto (\text{dim})], \mathcal{P}[\text{id} \mapsto 0] \\
\mathcal{D}, \mathcal{P} \vdash \text{id} = E : \mathcal{D}[\text{id} \mapsto (\text{var}, E)], \mathcal{P} \\
\mathcal{D}, \mathcal{P} \vdash \text{id}(\text{id}_1, \ldots, \text{id}_n) = E : \mathcal{D}[\text{id} \mapsto (\text{func}, \text{id}_i, E)], \mathcal{P} \\
\mathcal{D}, \mathcal{P} \vdash Q : \mathcal{D}', \mathcal{P}' \quad \mathcal{D}', \mathcal{P}' \vdash Q' : \mathcal{D}'', \mathcal{P}'' \\
\mathcal{D}, \mathcal{P} \vdash Q Q' : \mathcal{D}'', \mathcal{P}'' 
\end{align*} \]

4 Conclusions

We have shown that dimension and function identifiers can be write easily treated as first-class values with little change to the semantics of the language. It is now time to have a working implementation of these and to use them in different applications.