The Choose-Your-Own-Adventure Calculus (Pearl/Brave New Idea)

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Abstract

Some of the most remarkable results in mathematics reveal surprising connections between different branches of the discipline. The aim of this paper is to point out a modest, but still remarkable, similarity between a range of different interactive programming systems.

use a simple formal mathematical model that we call *the choose-your-own-adventure calculus* to todo

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1 Introduction

Multiple interactive programming systems, ranging from code editors for object-oriented programming languages to data exploration systems and interactive proof assistants, exhibit a remarkably similar pattern of interaction. They offer the user, who can be a programmer, a data scientist or a proof writer, a range of choices that the user can select from in order to complete their program, script or proof. The user can initiate the interaction iteratively, using it to create and refine a larger part of their program.

There are subtle differences between different implementations of the general pattern. In some systems, the resulting source code will contain a trace of the choices made by the user. For example, when choosing an item from a list of class members, the code will contain the member name. In some systems, the interaction results in a block of code that can be included in the source file, but does not include a trace of the interaction. For example, invoking a proof search or case split in Idris [3] constructs a well-typed program, but leaves no trace of the command used to construct it. The nature of the generated options also varies. The list of choices may include all possible options that are valid at a given location, or it may list only a subset of the valid options. In some cases, it may also include incorrect options as, for example, in auto-completion for dynamic languages [4].

The aim of this paper is paper is to formally capture the recurring interaction pattern:

1. We motivate the formalism by reviewing four different systems that implement a variation on the interaction pattern. These include type providers for data access in F# [17], type providers for data exploration in The Gamma [10, 8], AI assistants for semi-automated data wrangling [13] and tooling for interactive proof assistants [2, 3, 18] (Section 2).
2. We introduce the *choose-your-own-adventure calculus*, which is a small formal structure that models an interactive system where a user constructs a program by repeatedly choosing from a list of options offered by the system (Section 3).
3. The calculus allows us to make the aforementioned subtle differences precise. We define the notions of *correctness* and *completeness* for the choose-your-own-adventure calculus. To distinguish the different ways of embedding the interactions in the edited programs, we also formally define *base-level* and *meta-level* integration of the system.
4. We show that various programmer assistance tools, such as search and AI-based recommendations can be built on top of the primitives offered by the calculus, showing how the choose-your-own-adventure calculus supports of transfer of ideas across different kinds of interactive programming systems.

The main contribution of this paper is conceptual rather than technical. We capture a pattern that is perhaps not surprising in retrospect, but that is easy to overlook until it is given a name. We use formal programming language theory methods to precisely describe interesting aspects of the pattern. Moreover, our work also confirms that programming language theory methods can be extremely effective for studying not just *programming languages*, but also interactive *programming systems* [6].

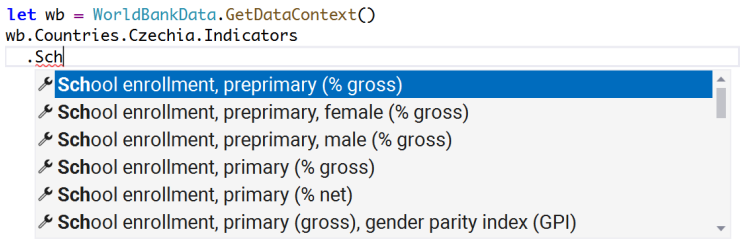


Figure 1 F# code editor showing completions offered by the World Bank type provider.

2 Motivation

Computer scientists studying programming have long focused on programming languages as syntactic entities, sometimes neglecting the interactive environments in which the languages are inevitably embedded [5]. Notably, in many of the motivating examples that we draw from in this section, the interactive aspect of the system is only described in supplementary materials such as tutorial notes [3], workshop papers [17] or user guides [2]. Only recently, programming language theory has been used to look at interactive environments [1, 7]. Our work aims to contribute to this research direction.

The following four sections briefly review four different instances of the choose-your-own-adventure interaction pattern. In all of those, an interactive editor offers the user some kind of a completion list during working with the system.

Type providers F# type providers [17] are a mechanism that make it possible to integrate external data sources into the F# type system. A type provider is a compiler extension, loaded and executed at compile-time and at edit-time. It can run arbitrary code to read the structure of external data and use it to generate a suitable statically-typed representation of the external data, typically as objects with members. Type providers can, for example, infer the type from a sample JSON [12] or read a database schema.

The example in Figure 1 shows a simple type provider for accessing information from the World Development Indicators database. The provided wb object allows the programmer to access any indicator of any country in the database by choosing an appropriate [Country] and an [Indicator] in a chain of members wb.Countries.[Country].Indicator.[Indicator]. The result is a time series with values of the given indicator and country. More generally, the example can be seen as a special case of a type provider for slicing n-dimensional data cube [10]. Here, we choose a fixed value for two of the three dimensions (country, indicator, time).

When using the type provider, the user types the first line of code and trigger auto-completion by typing wb followed by the dot. The rest of the code is constructed by choosing an option from a list and typing another dot.[1]

[1] This interaction pattern has been lightheartedly called *dot-driven development* by Phil Trelford [15].

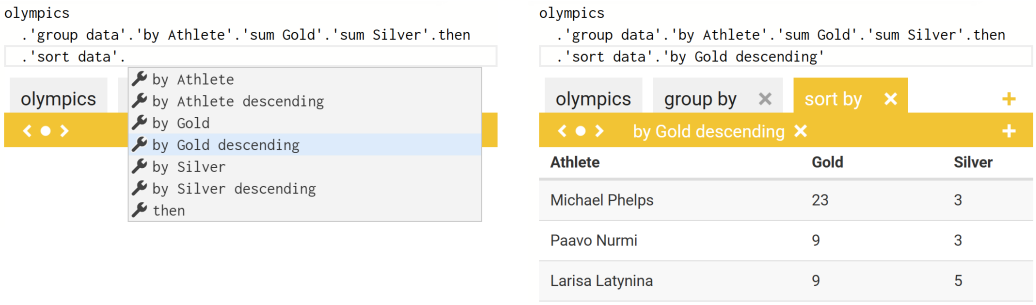


Figure 2 Constructing a query in The Gamma. We count the number of gold and silver medals for each athlete and sort the data by the number of gold medals.

Data exploration The Gamma [10] is a web-based programmatic data exploration environment for non-programmers. In The Gamma, type providers are the primary programming mechanism and they are used not just for data access, but also for constructing queries.

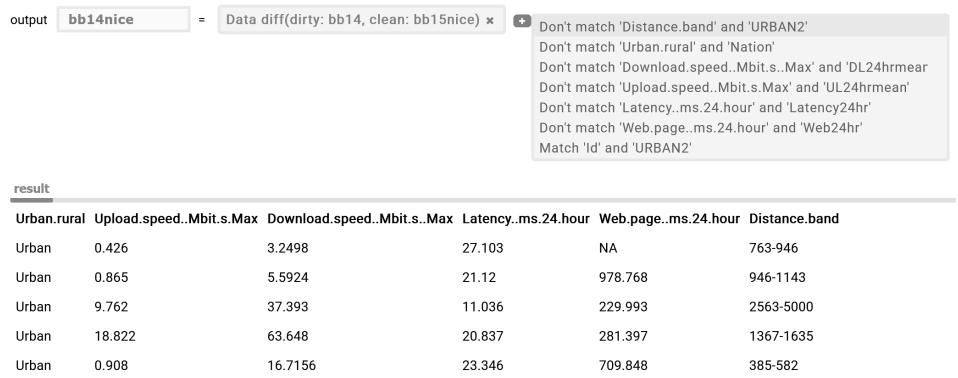
The type provider shown in Figure 2 lets the user construct an SQL-like query by repeatedly choosing operations and their parameters [8]. It keeps track of the data schema and uses the schema to generate all possible valid parameters. When sorting data, it generates an object with two members for each columns – one for ascending and one for descending sort. Similarly, grouping first offers all columns as possible sorting keys and then lets the user choose from a range of pre-defined aggregations (sum, count, average, concatenate). The system evaluates the query on the fly, providing a live preview during editing [9].

The interaction pattern is the same as above. The user triggers auto-completion by entering a data source and typing dot. They can then repeatedly select an operation and its parameters to construct a query. One notable difference is that the structure of the generated types is potentially infinite (the user can keep adding further operations) and so the types are generated lazily.

AI assistants The third instance of the choose-your-own-adventure interaction pattern comes from work on semi-automatic data wrangling tools known as AI assistants [13]. An AI assistant guides the analyst through a data wrangling problem such as reconciling mismatched datasets, filling missing values or inferring data format and types. An AI assistant tries to solve the problem automatically and suggests an initial data transformation, but it also generates a number of constraints that the user can choose from to refine the initial solution. If the initial solution is not correct, the user chooses a constraint and the AI assistant runs again, suggesting a new data transformation that respects the constraint.

Figure 3 shows an example. It uses the datadiff [16] AI assistant, running in a Wrattler notebook [11], to merge broadband quality data published by Ofcom for two subsequent years. The format of the CSV files differs. Some columns were added, some removed, all were renamed and their order has changed. In the example, we selected 6 columns from the year 2015 and want to find matching data from 2014.

When the AI assistants runs automatically, it incorrectly maps the Urban.rural (2014) column to Nation (2015). This happens because both columns are categorical and have three values with similar distribution, but a data analyst can easily spot the mistake. To correct the error, they click the "+" button to add a constraint and choose Don't match Urban.rural and Nation to specify that the two columns should not be matched. Datadiff then runs again and finds the correct matching.



Urban.rural	Upload.speed..Mbit.s.Max	Download.speed..Mbit.s..Max	Latency..ms.24.hour	Web.page..ms.24.hour	Distance.band
Urban	0.426	3.2498	27.103	NA	763-946
Urban	0.865	5.5924	21.12	978.768	946-1143
Urban	9.762	37.393	11.036	229.993	2563-5000
Urban	18.822	63.648	20.837	281.397	1367-1635
Urban	0.908	16.7156	23.346	709.848	385-582

Figure 3 aia

The interaction patter is the same as in the previous two cases. The analyst constructs the correct data transformation by repeatedly choosing from a list of options, until they obtain the desired result. However, the way the interaction pattern is used in this case differs. First, in the case of type providers, we are constructing a program (adding operations to a method chain). Now, we are collecting constraints and the AI assistant then synthesizes a data transformation (a script) based on those constraints. Second, in the case of type providers, the completion list offered all possible members of the object. Now, the list offers a choice of constraints that are recommended by the AI assistant, which may not be complete.

Interactive theorem provers yo

3 Formal model

4 Examples

5 Properties

6 Applications

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A Styles of lists, enumerations, and descriptions

List of different predefined enumeration styles:

- `\begin{itemize}...\end{itemize}`
- ...
- ...

1. `\begin{enumerate}...\end{enumerate}`
2. ...
3. ...

(a) `\begin{alphaenumerate}...\end{alphaenumerate}`
(b) ...
(c) ...

(i) `\begin{romanenumerate}...\end{romanenumerate}`

(ii) ...
(iii) ...

(1) `\begin{bracketenumerate}...\end{bracketenumerate}`
(2) ...
(3) ...

Description 1 `\begin{description} \item[Description 1] ...\end{description}`
Description 2 Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.
Description 3 ...

Proposition 10 and Proposition 10 ...

B Theorem-like environments

List of different predefined enumeration styles:

▶ **Theorem 7.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Lemma 8.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Corollary 9.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Proposition 10.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Conjecture 11.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Observation 12.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Exercise 13.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Definition 14.** *Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.*

▶ **Example 15.** Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▶ Note 16. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▶ Note. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▶ Remark 17. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▶ Remark. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▷ Claim 18. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

▷ Claim. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque.

Proof. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque. ◀

Proof. Fusce eu leo nisi. Cras eget orci neque, eleifend dapibus felis. Duis et leo dui. Nam vulputate, velit et laoreet porttitor, quam arcu facilisis dui, sed malesuada risus massa sit amet neque. ◁