3 THE DATA STACK

Factor is also a stack-based programming language. This means that all data in the program is loaded onto a shared data stack. Words that use this data pop off the stack and push back the results of the operation. Concatenated words, then, work together through the use of the shared stack to morph the input data into the desired output. It is worth noting that the shared data stack is entirely unrelated to the traditional concept of the runtime stack used in function calls and memory allocation [1]. Furthermore, the data stack itself is not directly related to a typical stack data structure, as the data stack does not encapsulate any methods like push or pop. Instead, the data stack is fully managed by the words used in the program.

3.1 Stack Shuffling and Combinators

One of the greater learning curves that comes with studying Factor is understanding how to properly manipulate the data stack. There are multiple words that are readily available to the programmer, such as swap (which swaps the two topmost elements), drop (which throws away the top element), and dup (which duplicates the top element). These words are vital to the success of more complicated Factor programs but make the code bulky and less readable. As a result, the programmer is encouraged to adopt more powerful higher-order functions that abstract some of the busy work associated with the language. Words in Factor that achieve this goal, such as reduce and fold, are called combinators.

One commonly used combinator is the word bi, which takes a single value off of the stack and applies two separate functions to the value, leaving two results on the stack. For example, 12 [ 1 + ] [ 1 - ] bi will leave the two separate values 13 and 11 on the top of the stack. The word bi may also be used for the evaluation of an or word as in the program [ even? ] [ odd? ] bi or. Other useful combinators include cleave (which applies an arbitrary number of words to a given value), each (which applies a word to all items of a list), filter (which returns the elements of a list that pass a given filter), and map (which applies a word to a list to receive a new list). Fig. 1 illustrates some of these common stack shuffling and combinator words in action.

3.2 Stack Effect and the Stack Checker

Another challenge with programming in a stack-based language comes from the large amount of bugs that can arise when words that manipulate the stack leave a varying number of items on to the stack after completion. As a result, words defined in Factor are accompanied with an explicit declaration that shows how many items are taken from and placed on the stack. This declaration, called a stack effect, is noted with ( a -- b ), where the words a

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and b are representative of the effect that the word has on the stack. Stack effect declarations serve both a documentation purpose as well as a crucial part of compilation—words can only be compiled if they strictly follow the notation of their corresponding stack effect. Stack effects, in general, perform a simple role that is similar to pattern matching in other languages, such as Haskell. However, unlike Haskell, the words used to represent items on the stack are purely symbolic, meaning that they cannot be referenced in the body of the word like a lexically-scoped variable.

The stack checker is the name given to the tool that acts similar to a type system in Factor [3]. The stack checker performs a brief simulation of the program before passing it to the compiler—checking that each branch of control in the program leaves the stack at equal heights. If the word does not leave the stack with a consistent height, then a compile-time error is raised and the program is rejected. However, Factor does make some exceptions to this rule, specifically with regards to row polymorphism. In some situations the programmer may wish to use a combinator with sets of words that have different stack effects. Row polymorphism in Factor permits this, so long as the quotations are only operating on data below itself on the stack—resulting in the same stack height as the other words used in control flow.

4 QUOTATIONS AND VOCABULARIES

As mentioned above, functions in Factor are idiomatically called words. Words can be anonymously constructed from the composition of other words. Anonymous words are called quotations and are wrapped in the [ and ] parsing words that enclose the quotation. Table 1 illustrates some of the most common parsing words encountered in Factor code. Some words, such as 1 f, take a quotation as an argument and use that quotation to transform the stack. Quotations can also be constructed using values already on the stack when using a pair of alternate words. For instance, 10 ' [ _ = ] results in the equality quotation [ 10 = ].

Words can also be defined with formal names. New words are defined with a sequence of the beginning : parsing word, the given name to the word, the word’s stack effect, the body of the word, and the enclosing ; parsing word that marks the end of a definition. For example, consider the following word product which multiplies the contents of a sequence:

: product ( seq ← p ) 1 [ * ] reduce ;

Multiple words like product above can be defined in a collection known as a vocabulary—the Factor analog of a library. Vocabularies are stored within a source code file that rests in a hierarchal subdirectory structure within the Factor installation directory. Each vocabulary has to explicitly reference the vocabularies that it relies upon for operation. For example, a separate vocabulary that wishes to use the product word above would need to include the vocabulary in which product is defined. Explicit declaration of necessary vocabularies allow Factor’s compiler to ensure minimization of the compiled code. Compiled Factor programs only include the bare minimum code needed for successful program execution.

5 OBJECT-ORIENTED IMPLEMENTATION

Factor is a purely object oriented programming language. This means that every value used is an object. Classes are divided into three primary types: primitive classes, tuple classes, and derived classes [3]. Primitive classes cannot be subclassed and are used for primitive classes like strings, numbers, and words. Tuple classes are more advanced and may contain instance variables that, unlike generic words, are owned by the class. Derived classes are built from other preexisting classes and can take multiple forms. For example, predicate, union, and intersection classes can be created in the same way one might interpret sets from set theory. A special example is a mixin class that is used often in Factor to collect groups of classes under a common interface [3].

Another unique feature of Factor is the way in which objects and object-specific words interact. In many object-oriented languages a given object has direct access to methods that are intrinsic to that object. Factor instead uses generic words that are redefined as needed to handle a given object-specific implementation—serving a purpose similar to template class functions in other languages, but with less restrictive implementation due to the absence of the concept of ownership.

6 FACTOR’S DEVELOPMENT WORKFLOW

Programming in Factor necessitates familiarity with Factor’s interactive development environment—the Factor Listener. The Listener provides an interpretive playground for the programmer to test new ideas and words on the fly without the use of dedicated source code. When the programmer is ready to commit to a source file, they can create a new vocabulary using the scaffold tool vocabulary and the scaffold-work word. A new directory is created with an empty source file and ready for the programmer. Once the file has been successfully edited, the programmer can update Factor automatically with the new vocabulary by using either the F2 key or the refresh-all word.
Other convenient features are provided by the Factor IDE. Unit tests can be defined and automatically evaluated with the use of the unit-test vocabulary. Documentation files can be created with the use of the scaffold-docs vocabulary and multiple words from the auto-included help vocabulary. In addition to user documentation all of the Factor documentation is available from within the IDE through the help button at the top of the interface. Word execution can be benchmarked at any time with the use of either the CTRL + T keystroke or the use of the time word. Because Factor uses an image-based compilation system, the save-image word can be used to save the state of the current Factor instance to a file. Images can then be loaded when the IDE is launched, resulting in a faster development experience without the need of reloading key vocabularies for every launch. Factor is also capable of deployment as a standalone executable with support for Windows, Linux, and Mac OS, through the use of the deploy word. Moreover, Factor itself also has many capable vocabularies that implement concepts from foreign function interfaces and UI toolkits to direct OS and support [3].

7 EXERCISES

The following are some programming exercises that incorporate some essential Factor concepts:

(1) Define a word caesar in a vocabulary homework that takes a string of alphabetical characters and an integer and applies the integer to each character in the string. Your solution must handle both positive and negative offset values. Only include uppercase and lowercase alphabetical characters in the output. For example, ABCD with an offset of 4 should produce EFGH. Factor your solution into a primary word caesar and set any helper words as private. This problem can be solved in less than 10 lines of code.

Examples:

```
> "SEESPOTRUN" 26 caesar .
"seespotrun"

> "SEESPOTRUN" -26 caesar .
"seespotrun"

> "ABCDDEFG" 7 caesar .
"HIJKLMN"
```

(2) Define a new tuple class novel that represents a fictional literary work. Include member variables that correspond to the novel’s title, author, genre, publisher, year of publication, and an identification number. Use strings for the first four variables and integers for the last pair. Include a constructor <novel> that takes values for each variable as arguments and sets them automatically. Also include a word book-print that takes a novel as an argument and prints the novel’s details in a simple format.

Examples:

```
> "Narnia" "C. S. Lewis" "Fantasy" "Geoffrey Bles" 1952 1 <novel>
```

--- Data stack:

```
T{ novel f "The Lion, the Witch, and the Wardrobe" "C. S. Lewis"
  "Fantasy" "Geoffrey Bles" 1950...`

> book-print
Class: Novel
Title: The Lion, the Witch, and the Wardrobe
Author: C. S. Lewis
Genre: Fantasy
Publisher: Geoffrey Bles
Year: 1950
ID: 1
```

(3) Extend the solution to problem 2 to two new classes of books—textbook and article. For textbooks, change the genre field to subject. For article, change the genre field to discipline and add journal and volume fields. Then, with the three classes, define a mixin class called library that will represent the union of different types of books. Adjust the book-print word from before to be generic with templates for each type of book. Publish the library and each class in a library vocabulary.

Examples:

```
> USE: library
> "The C Programming Language"
  "Ritchie, D. and Kernighan, B."
  "Computer Science" "Prentice Hall" 1988 2 <textbook>
```

--- Data stack:

```
T{ textbook f "The C Programming Language"...`

> book-print
Class: Novel
Title: The C Programming Language
Author: Ritchie, D. and Kernighan, B.
Subject: Computer Science
Publisher: Prentice Hall
Year: 1988
ID: 2
```

```
> "Factor: A Dynamic Stack-based Programming Language"
  "Pestov, S." "Computer Science"
  "ACM SIGPLAN Notices" 45 "ACM Press" 2010 3 <article>
```

--- Data stack:

```
T{ article f...`
8 CONCLUSION

The strengths of both object-oriented and functional languages are blended in Factor. Abstract classes, higher-order functions, and Factor’s expressive syntax give the programmer the flexibility needed to solve many complex problems in an elegant way. Factor’s wide set of mature vocabularies and features allow the programmer to focus on the greater details of a given problem. If the curious programmer is able to overcome the learning curve that comes with writing concatenatively they will find a rich and rewarding language awaits them. In summary, or if you will, in a word:

: Factor ( -- is ) "Object Oriented" "Functional Execution" + ;

REFERENCES

