Gforth Manual

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Preface

This manual documents Gforth. Some introductory material is provided for readers who are unfamiliar with Forth or who are migrating to Gforth from other Forth compilers. However, this manual is primarily a reference manual.

1 Goals of Gforth

The goal of the Gforth Project is to develop a standard model for ANS Forth. This can be split into several subgoals:

- Gforth should conform to the ANS Forth Standard.
- It should be a model, i.e. it should define all the implementation-dependent things.
- It should become standard, i.e. widely accepted and used. This goal is the most difficult one.

To achieve these goals Gforth should be

- Similar to previous models (fig-Forth, F83)
- Powerful. It should provide for all the things that are considered necessary today and even some that are not yet considered necessary.
- Efficient. It should not get the reputation of being exceptionally slow.
- Free.
- Available on many machines/easy to port.

Have we achieved these goals? Gforth conforms to the ANS Forth standard. It may be considered a model, but we have not yet documented which parts of the model are stable and which parts we are likely to change. It certainly has not yet become a de facto standard, but it appears to be quite popular. It has some similarities to and some differences from previous models. It has some powerful features, but not yet everything that we envisioned. We certainly have achieved our execution speed goals (see Section 12.4 [Performance], page 159). It is free and available on many machines.

1.1 Is it a Sin to use Gforth Extensions?

If you've been paying attention, you will have realised that there is an ANS (American National Standard) for Forth. As you read through the rest of this manual, you will see documentation for *Standard* words, and documentation for some appealing Gforth *extensions*. You might ask yourself the question: *"Given that there is a standard, would I be committing a sin to use (non-Standard) Gforth extensions?"*

The answer to that question is somewhat pragmatic and somewhat philosophical. Consider these points:

- A number of the Gforth extensions can be implemented in ANS Forth using files provided in the '`compat/`' directory. These are mentioned in the text in passing.
- Forth has a rich historical precedent for programmers taking advantage of implementation-dependent features of their tools (for example, relying on a knowledge of the dictionary structure). Sometimes these techniques are necessary to extract every last bit of performance from the hardware, sometimes they are just a programming shorthand.
- The best way to break the rules is to know what the rules are. To learn the rules, there is no substitute for studying the text of the Standard itself. In particular, Appendix A of the Standard (*Rationale*) provides a valuable insight into the thought processes of the technical committee.

- The best reason to break a rule is because you have to; because it's more productive to do that, because it makes your code run fast enough or because you can see no Standard way to achieve what you want to achieve.

The tool '`ans-report.fs`' (see Section 6.1 [ANS Report], page 130) makes it easy to analyse your program and determine what non-Standard definitions it relies upon.

2 Gforth Environment

Note: ultimately, the gforth man page will be auto-generated from the material in this chapter.

See Chapter 11 [Image Files], page 149 for related information about the creation of images.

2.1 Invoking Gforth

Gforth is made up of two parts; an executable "engine" (named '`gforth`' or '`gforth-fast`') and an image file. To start it, you will usually just say `gforth` – this automatically loads the default image file '`gforth.fi`'. In many other cases the default Gforth image will be invoked like this:

```
gforth [file | -e forth-code] ...
```

This interprets the contents of the files and the Forth code in the order they are given.

In addition to the '`gforth`' engine, there is also an engine called '`gforth-fast`', which is faster, but gives less informative error messages (see Chapter 5 [Error messages], page 129).

In general, the command line looks like this:

```
gforth[-fast] [engine options] [image options]
```

The engine options must come before the rest of the command line. They are:

`--image-file` *file*
`-i` *file* Loads the Forth image *file* instead of the default '`gforth.fi`' (see Chapter 11 [Image Files], page 149).

`--path` *path*
`-p` *path* Uses *path* for searching the image file and Forth source code files instead of the default in the environment variable `GFORTHPATH` or the path specified at installation time (e.g., '`/usr/local/share/gforth/0.2.0:.`'). A path is given as a list of directories, separated by '`:`' (on Unix) or '`;`' (on other OSs).

`--dictionary-size` *size*
`-m` *size* Allocate *size* space for the Forth dictionary space instead of using the default specified in the image (typically 256K). The *size* specification for this and subsequent options consists of an integer and a unit (e.g., `4M`). The unit can be one of `b` (bytes), `e` (element size, in this case Cells), `k` (kilobytes), `M` (Megabytes), `G` (Gigabytes), and `T` (Terabytes). If no unit is specified, `e` is used.

`--data-stack-size` *size*
`-d` *size* Allocate *size* space for the data stack instead of using the default specified in the image (typically 16K).

`--return-stack-size` *size*
`-r` *size* Allocate *size* space for the return stack instead of using the default specified in the image (typically 15K).

`--fp-stack-size` *size*
`-f` *size* Allocate *size* space for the floating point stack instead of using the default specified in the image (typically 15.5K). In this case the unit specifier `e` refers to floating point numbers.

`--locals-stack-size` *size*
`-l` *size* Allocate *size* space for the locals stack instead of using the default specified in the image (typically 14.5K).

`--help`
`-h` Print a message about the command-line options

`--version`
`-v` Print version and exit

`--debug` Print some information useful for debugging on startup.

`--offset-image`
Start the dictionary at a slightly different position than would be used otherwise (useful for creating data-relocatable images, see Section 11.4 [Data-Relocatable Image Files], page 150).

`--no-offset-im`
Start the dictionary at the normal position.

`--clear-dictionary`
Initialize all bytes in the dictionary to 0 before loading the image (see Section 11.4 [Data-Relocatable Image Files], page 150).

`--die-on-signal`
Normally Gforth handles most signals (e.g., the user interrupt SIGINT, or the segmentation violation SIGSEGV) by translating it into a Forth `THROW`. With this option, Gforth exits if it receives such a signal. This option is useful when the engine and/or the image might be severely broken (such that it causes another signal before recovering from the first); this option avoids endless loops in such cases.

As explained above, the image-specific command-line arguments for the default image '`gforth.fi`' consist of a sequence of filenames and `-e` *forth-code* options that are interpreted in the sequence in which they are given. The `-e` *forth-code* or `--evaluate` *forth-code* option evaluates the Forth code. This option takes only one argument; if you want to evaluate more Forth words, you have to quote them or use `-e` several times. To exit after processing the command line (instead of entering interactive mode) append `-e bye` to the command line.

If you have several versions of Gforth installed, `gforth` will invoke the version that was installed last. `gforth-`*version* invokes a specific version. You may want to use the option `--path`, if your environment contains the variable `GFORTHPATH`.

Not yet implemented: On startup the system first executes the system initialization file (unless the option `--no-init-file` is given; note that the system resulting from using this option may not be ANS Forth conformant). Then the user initialization file '`.gforth.fs`' is executed, unless the option `--no-rc` is given; this file is first searched in '`.`', then in '`~`', then in the normal path (see above).

2.2 Leaving Gforth

You can leave Gforth by typing `bye` or *`Ctrl-d`* (at the start of a line) or (if you invoked Gforth with the `--die-on-signal` option) *`Ctrl-c`*. When you leave Gforth, all of your definitions and data are discarded. See Chapter 11 [Image Files], page 149 for ways of saving the state of the system before leaving Gforth.

`bye` – tools-ext "bye"

2.3 Command-line editing

Gforth maintains a history file that records every line that you type to the text interpreter. This file is preserved between sessions, and is used to provide a command-line recall facility; if you type ctrl-P repeatedly you can recall successively older commands from this (or previous) session(s). The full list of command-line editing facilities is:

- *`Ctrl-p`* ("previous") (or up-arrow) to recall successively older commands from the history buffer.
- *`Ctrl-n`* ("next") (or down-arrow) to recall successively newer commands from the history buffer.
- *`Ctrl-f`* (or right-arrow) to move the cursor right, non-destructively.
- *`Ctrl-b`* (or left-arrow) to move the cursor left, non-destructively.
- *`Ctrl-h`* (backspace) to delete the character to the left of the cursor, closing up the line.
- *`Ctrl-k`* to delete ("kill") from the cursor to the end of the line.
- *`Ctrl-a`* to move the cursor to the start of the line.
- *`Ctrl-e`* to move the cursor to the end of the line.
- ⟨RET⟩ (*`Ctrl-m`*) or ⟨LFD⟩ (*`Ctrl-j`*) to submit the current line.
- ⟨TAB⟩ to step through all possible full-word completions of the word currently being typed.
- *`Ctrl-d`* at the start of the line to terminate Gforth (gracefully, using `bye`).

When editing, displayable characters are inserted to the left of the cursor position; the line is always in "insert" (as opposed to "overstrike") mode.

On Unix systems, the history file is '`~/.gforth-history`' by default[1]. You can find out the name and location of your history file using:

```
history-file type \ Unix-class systems

history-file type \ Other systems
history-dir  type
```

If you enter long definitions by hand, you can use a text editor to paste them out of the history file into a Forth source file for reuse at a later time.

Gforth never trims the size of the history file, so you should do this periodically, if necessary.

[1] i.e. it is stored in the user's home directory.

2.4 Upper and lower case

Gforth is case-insensitive, so you can enter definitions and invoke Standard words using upper, lower or mixed case (however, see Section 7.1.1 [Implementation-defined options], page 132).

ANS Forth only *requires* implementations to recognise Standard words when they are typed entirely in upper case. Therefore, a Standard program must use upper case for all Standard words. You can use whatever case you like for words that you define, but in a standard program you have to use the words in the same case that you defined them.

Gforth supports case sensitivity through `tables` (case-sensitive wordlists, see Section 4.11 [Word Lists], page 74).

Two people have asked how to convert Gforth to case sensitivity; while we think this is a bad idea, you can change all wordlists into tables like this:

```
' table-find forth-wordlist wordlist-map !
```

Note that you now have to type the predefined words in the same case that we defined them, which are varying. You may want to convert them to your favourite case before doing this operation (I won't explain how, because if you are even contemplating to do this, you'd better have enough knowledge of Forth systems to know this already).

2.5 Environment variables

Gforth uses these environment variables:

- GFORTHHIST - (Unix systems only) specifies the directory in which to open/create the history file, '`.gforth-history`'. Default: `$HOME`.
- GFORTHPATH - specifies the path used when searching for the gforth image file and for Forth source-code files.
- GFORTH - used by '`gforthmi`' See Section 11.5.1 [gforthmi], page 151.
- GFORTHD - used by '`gforthmi`' See Section 11.5.1 [gforthmi], page 151.
- TMP, TEMP - (non-Unix systems only) used as a potential location for the history file.

All the Gforth environment variables default to sensible values if they are not set.

2.6 Gforth files

When you Gforth on a Unix system in the default places, it installs files in these locations:

- '`/usr/local/bin/gforth`'
- '`/usr/local/bin/gforthmi`'
- '`/usr/local/man/man1/gforth.1`' - man page.
- '`/usr/local/info`' - the Info version of this manual.
- '`/usr/local/lib/gforth/<version>/...`' - Gforth '`.fi`' files.
- '`/usr/local/share/gforth/<version>/TAGS`' - Emacs TAGS file.
- '`/usr/local/share/gforth/<version>/...`' - Gforth source files.

- '`.../emacs/site-lisp/gforth.el`' - Emacs gforth mode.

You can select different places for installation by using `configure` options (listed with `configure --help`).

3 An Introduction to ANS Forth

The primary purpose of this manual is to document Gforth. However, since Forth is not a widely-known language and there is a lack of up-to-date teaching material, it seems worthwhile to provide some introductory material. See Appendix C [Forth-related information], page 165 for other sources of Forth-related information.

The examples in this section should work on any ANS Forth; the output shown was produced using Gforth. Each example attempts to reproduce the exact output that Gforth produces. If you try out the examples (and you should), what you should type is shown *`like this`* and Gforth's response is shown `like this`. The single exception is that, where the example shows ⟨RET⟩ it means that you should press the "carriage return" key. Unfortunately, some output formats for this manual cannot show the difference between *`this`* and `this` which will make trying out the examples harder (but not impossible).

Forth is an unusual language. It provides an interactive development environment which includes both an interpreter and compiler. Forth programming style encourages you to break a problem down into many small fragments (*factoring*), and then to develop and test each fragment interactively. Forth advocates assert that breaking the edit-compile-test cycle used by conventional programming languages can lead to great productivity improvements.

3.1 Introducing the Text Interpreter

When you invoke the Forth image, you will see a startup banner printed and nothing else (if you have Gforth installed on your system, try invoking it now, by typing *`gforth`*⟨RET⟩). Forth is now running its command line interpreter, which is called the *Text Interpreter* (also known as the *Outer Interpreter*). (You will learn a lot about the text interpreter as you read through this chapter, but see Section 4.9 [The Text Interpreter], page 64 for more detail).

Although it's not obvious, Forth is actually waiting for your input. Type a number and press the ⟨RET⟩ key:

```
45⟨RET⟩  ok
```

Rather than give you a prompt to invite you to input something, the text interpreter prints a status message *after* it has processed a line of input. The status message in this case (" `ok`" followed by carriage-return) indicates that the text interpreter was able to process all of your input successfully. Now type something illegal:

```
qwer341⟨RET⟩
:1: Undefined word
qwer341
^^^^^^^
$400D2BA8 Bounce
$400DBDA8 no.extensions
```

The exact text, other than the "Undefined word" may differ slightly on your system, but the effect is the same; when the text interpreter detects an error, it discards any remaining text on a line, resets certain internal state and prints an error message. See Chapter 5 [Error messages], page 129 for a detailed description of error messages.

The text interpreter waits for you to press carriage-return, and then processes your input line. Starting at the beginning of the line, it breaks the line into groups of characters separated by spaces. For each group of characters in turn, it makes two attempts to do something:

- It tries to treat it as a command. It does this by searching a *name dictionary*. If the group of characters matches an entry in the name dictionary, the name dictionary provides the text interpreter with information that allows the text interpreter perform some actions. In Forth jargon, we say that the group of characters names a *word*, that the dictionary search returns an *execution token (xt)* corresponding to the *definition* of the word, and that the text interpreter executes the xt. Often, the terms *word* and *definition* are used interchangeably.
- If the text interpreter fails to find a match in the name dictionary, it tries to treat the group of characters as a number in the current number base (when you start up Forth, the current number base is base 10). If the group of characters legitimately represents a number, the text interpreter pushes the number onto a stack (we'll learn more about that in the next section).

If the text interpreter is unable to do either of these things with any group of characters, it discards the group of characters and the rest of the line, then prints an error message. If the text interpreter reaches the end of the line without error, it prints the status message "`ok`" followed by carriage-return.

This is the simplest command we can give to the text interpreter:

⟨RET⟩ `ok`

The text interpreter did everything we asked it to do (nothing) without an error, so it said that everything is "`ok`". Try a slightly longer command:

```
12 dup fred dup⟨RET⟩
:1: Undefined word
12 dup fred dup
       ^^^^
$400D2BA8 Bounce
$400DBDA8 no.extensions
```

When you press the carriage-return key, the text interpreter starts to work its way along the line:

- When it gets to the space after the `2`, it takes the group of characters `12` and looks them up in the name dictionary[1]. There is no match for this group of characters in the name dictionary, so it tries to treat them as a number. It is able to do this successfully, so it puts the number, 12, "on the stack" (whatever that means).
- The text interpreter resumes scanning the line and gets the next group of characters, `dup`. It looks it up in the name dictionary and (you'll have to take my word for this) finds it, and executes the word `dup` (whatever that means).
- Once again, the text interpreter resumes scanning the line and gets the group of characters `fred`. It looks them up in the name dictionary, but can't find them. It tries to treat them as a number, but they don't represent any legal number.

[1] We can't tell if it found them or not, but assume for now that it did not

At this point, the text interpreter gives up and prints an error message. The error message shows exactly how far the text interpreter got in processing the line. In particular, it shows that the text interpreter made no attempt to do anything with the final character group, `dup`, even though we have good reason to believe that the text interpreter would have no problem looking that word up and executing it a second time.

3.2 Stacks, postfix notation and parameter passing

In procedural programming languages (like C and Pascal), the building-block of programs is the *function* or *procedure*. These functions or procedures are called with *explicit parameters*. For example, in C we might write:

```
total = total + new_volume(length,height,depth);
```

where new_volume is a function-call to another piece of code, and total, length, height and depth are all variables. length, height and depth are parameters to the function-call.

In Forth, the equivalent of the function or procedure is the *definition* and parameters are implicitly passed between definitions using a shared stack that is visible to the programmer. Although Forth does support variables, the existence of the stack means that they are used far less often than in most other programming languages. When the text interpreter encounters a number, it will place (*push*) it on the stack. There are several stacks (the actual number is implementation-dependent ...) and the particular stack used for any operation is implied unambiguously by the operation being performed. The stack used for all integer operations is called the *data stack* and, since this is the stack used most commonly, references to "the data stack" are often abbreviated to "the stack".

The stacks have a last-in, first-out (LIFO) organisation. If you type:

```
1 2 3⟨RET⟩  ok
```

Then this instructs the text interpreter to placed three numbers on the (data) stack. An analogy for the behaviour of the stack is to take a pack of playing cards and deal out the ace (1), 2 and 3 into a pile on the table. The 3 was the last card onto the pile ("last-in") and if you take a card off the pile then, unless you're prepared to fiddle a bit, the card that you take off will be the 3 ("first-out"). The number that will be first-out of the stack is called the *top of stack*, which is often abbreviated to *TOS*.

To understand how parameters are passed in Forth, consider the behaviour of the definition `+` (pronounced "plus"). You will not be surprised to learn that this definition performs addition. More precisely, it adds two number together and produces a result. Where does it get the two numbers from? It takes the top two numbers off the stack. Where does it place the result? On the stack. You can act-out the behaviour of `+` with your playing cards like this:

- Pick up two cards from the stack on the table
- Stare at them intently and ask yourself "what *is* the sum of these two numbers"
- Decide that the answer is 5
- Shuffle the two cards back into the pack and find a 5
- Put a 5 on the remaining ace that's on the table.

If you don't have a pack of cards handy but you do have Forth running, you can use the definition `.s` to show the current state of the stack, without affecting the stack. Type:

```
clearstack 1 2 3⟨RET⟩ ok
.s⟨RET⟩ <3> 1 2 3  ok
```

The text interpreter looks up the word `clearstack` and executes it; it tidies up the stack and removes any entries that may have been left on it by earlier examples. The text interpreter pushes each of the three numbers in turn onto the stack. Finally, the text interpreter looks up the word `.s` and executes it. The effect of executing `.s` is to print the "<3>" (the total number of items on the stack) followed by a list of all the items on the stack; the item on the far right-hand side is the TOS.

You can now type:

```
+ .s⟨RET⟩ <2> 1 5  ok
```

which is correct; there are now 2 items on the stack and the result of the addition is 5.

If you're playing with cards, try doing a second addition: pick up the two cards, work out that their sum is 6, shuffle them into the pack, look for a 6 and place that on the table. You now have just one item on the stack. What happens if you try to do a third addition? Pick up the first card, pick up the second card – ah! There is no second card. This is called a *stack underflow* and consitutes an error. If you try to do the same thing with Forth it will report an error (probably a Stack Underflow or an Invalid Memory Address error).

The opposite situation to a stack underflow is a *stack overflow*, which simply accepts that there is a finite amount of storage space reserved for the stack. To stretch the playing card analogy, if you had enough packs of cards and you piled the cards up on the table, you would eventually be unable to add another card; you'd hit the ceiling. Gforth allows you to set the maximum size of the stacks. In general, the only time that you will get a stack overflow is because a definition has a bug in it and is generating data on the stack uncontrollably.

There's one final use for the playing card analogy. If you model your stack using a pack of playing cards, the maximum number of items on your stack will be 52 (I assume you didn't use the Joker). The maximum *value* of any item on the stack is 13 (the King). In fact, the only possible numbers are positive integer numbers 1 through 13; you can't have (for example) 0 or 27 or 3.52 or -2. If you change the way you think about some of the cards, you can accommodate different numbers. For example, you could think of the Jack as representing 0, the Queen as representing -1 and the King as representing -2. Your *range* remains unchanged (you can still only represent a total of 13 numbers) but the numbers that you can represent are -2 through 10.

In that analogy, the limit was the amount of information that a single stack entry could hold, and Forth has a similar limit. In Forth, the size of a stack entry is called a *cell*. The actual size of a cell is implementation dependent and affects the maximum value that a stack entry can hold. A Standard Forth provides a cell size of at least 16-bits, and most desktop systems use a cell size of 32-bits.

Forth does not do any type checking for you, so you are free to manipulate and combine stack items in any way you wish. A convenient way of treating stack items is as 2's complement signed integers, and that is what Standard words like `+` do. Therefore you can type:

```
-5 12 + .s⟨RET⟩ <1> 7  ok
```

If you use numbers and definitions like `+` in order to turn Forth into a great big pocket calculator, you will realise that it's rather different from a normal calculator. Rather than typing 2 + 3 = you had to type 2 3 + (ignore the fact that you had to use `.s` to see the result). The terminology used to describe this difference is to say that your calculator uses *Infix Notation* (parameters and operators are mixed) whilst Forth uses *Postfix Notation* (parameters and operators are separate), also called *Reverse Polish Notation*.

Whilst postfix notation might look confusing to begin with, it has several important advantages:

- it is unambiguous
- it is more concise
- it fits naturally with a stack-based system

To examine these claims in more detail, consider these sums:

```
6 + 5 * 4 =
4 * 5 + 6 =
```

If you're just learning maths or your maths is very rusty, you will probably come up with the answer 44 for the first and 26 for the second. If you are a bit of a whizz at maths you will remember the *convention* that multiplication takes precendence over addition, and you'd come up with the answer 26 both times. To explain the answer 26 to someone who got the answer 44, you'd probably rewrite the first sum like this:

```
6 + (5 * 4) =
```

If what you really wanted was to perform the addition before the multiplication, you would have to use parentheses to force it.

If you did the first two sums on a pocket calculator you would probably get the right answers, unless you were very cautious and entered them using these keystroke sequences:

6 + 5 = * 4 = 4 * 5 = + 6 =

Postfix notation is unambiguous because the order that the operators are applied is always explicit; that also means that parentheses are never required. The operators are *active* (the act of quoting the operator makes the operation occur) which removes the need for "=".

The sum 6 + 5 * 4 can be written (in postfix notation) in two equivalent ways:

```
6 5 4 * +       or:
5 4 * 6 +
```

An important thing that you should notice about this notation is that the *order* of the numbers does not change; if you want to subtract 2 from 10 you type `10 2 -`.

The reason that Forth uses postfix notation is very simple to explain: it makes the implementation extremely simple, and it follows naturally from using the stack as a mechanism for passing parameters. Another way of thinking about this is to realise that all Forth definitions are *active*; they execute as they are encountered by the text interpreter. The result of this is that the syntax of Forth is trivially simple.

3.3 Your first Forth definition

Until now, the examples we've seen have been trivial; we've just been using Forth as a bigger-than-pocket calculator. Also, each calculation we've shown has been a "one-off" – to repeat it we'd need to type it in again[2] In this section we'll see how to add new words to Forth's vocabulary.

The easiest way to create a new word is to use a *colon definition*. We'll define a few and try them out before worrying too much about how they work. Try typing in these examples; be careful to copy the spaces accurately:

```
: add-two 2 + . ;
: greet ." Hello and welcome" ;
: demo 5 add-two ;
```

Now try them out:

```
greet⟨RET⟩ Hello and welcome  ok
greet greet⟨RET⟩ Hello and welcomeHello and welcome  ok
4 add-two⟨RET⟩ 6  ok
demo⟨RET⟩ 7  ok
9 greet demo add-two⟨RET⟩ Hello and welcome7 11  ok
```

The first new thing that we've introduced here is the pair of words `:` and `;`. These are used to start and terminate a new definition, respectively. The first word after the `:` is the name for the new definition.

As you can see from the examples, a definition is built up of words that have already been defined; Forth makes no distinction between definitions that existed when you started the system up, and those that you define yourself.

The examples also introduce the words `.` (dot), `."` (dot-quote) and `dup` (dewp). Dot takes the value from the top of the stack and displays it. It's like `.s` except that it only displays the top item of the stack and it is destructive; after it has executed, the number is no longer on the stack. There is always one space printed after the number, and no spaces before it. Dot-quote defines a string (a sequence of characters) that will be printed when the word is executed. The string can contain any printable characters except ". A " has a special function; it is not a Forth word but it acts as a delimiter (the way that delimiters work is described in the next section). Finally, `dup` duplicates the value at the top of the stack. Try typing `5 dup .s` to see what it does.

We already know that the text interpreter searches through the dictionary to locate names. If you've followed the examples earlier, you will already have a definition called `add-two`. Lets try modifying it by typing in a new definition:

```
: add-two dup . ." + 2 =" 2 + . ;⟨RET⟩ redefined add-two  ok
```

Forth recognised that we were defining a word that already exists, and printed a message to warn us of that fact. Let's try out the new definition:

```
9 add-two⟨RET⟩ 9 + 2 =11  ok
```

All that we've actually done here, though, is to create a new definition, with a particular name. The fact that there was already a definition with the same name did not make

[2] That's not quite true. If you press the up-arrow key on your keyboard you should be able to scroll back to any earlier command, edit it and re-enter it.

any difference to the way that the new definition was created (except that Forth printed a warning message). The old definition of add-two still exists (try `demo` again to see that this is true). Any new definition will use the new definition of `add-two`, but old definitions continue to use the version that already existed at the time that they were `compiled`.

Before you go on to the next section, try defining and redefining some words of your own.

3.4 How does that work?

Now we're going to take another look at the definition of `add-two` from the previous section. From our knowledge of the way that the text interpreter works, we would have expected this result when we tried to define `add-two`:

```
: add-two 2 + . " ;⟨RET⟩
  ^^^^^^^
Error: Undefined word
```

The reason that this didn't happen is bound up in the way that : works. The word : does two special things. The first special thing that it does prevents the text interpreter from ever seeing the characters `add-two`. The text interpreter uses a variable called `>IN` (pronounced "to-in") to keep track of where it is in the input line. When it encounters the word : it behaves in exactly the same way as it does for any other word; it looks it up in the name dictionary, finds its xt and executes it. When : executes, it looks at the input buffer, finds the word `add-two` and advances the value of `>IN` to point past it. It then does some other stuff associated with creating the new definition (including creating an entry for `add-two` in the name dictionary). When the execution of : completes, control returns to the text interpreter, which is oblivious to the fact that it has been tricked into ignoring part of the input line.

Words like : – words that advance the value of `>IN` and so prevent the text interpreter from acting on the whole of the input line – are called *parsing words*.

The second special thing that : does is change the value of a variable called `state`, which affects the way that the text interpreter behaves. When Gforth starts up, `state` has the value 0, and the text interpreter is said to be *interpreting*. During a colon definition (started with :), `state` is set to -1 and the text interpreter is said to be *compiling*. The word ; ends the definition – one of the things that it does is to change the value of `state` back to 0.

We have already seen how the text interpreter behaves when it is interpreting; it looks for each character sequence in the dictionary, finds its xt and executes it, or it converts it to a number and pushes it onto the stack, or it fails to do either and generates an error.

When the text interpreter is compiling, its behaviour is slightly different; it still looks for each character sequence in the dictionary and finds it, or converts it to a number, or fails to do either and generates an error. But instead of the execution token of a word it finds and executes the compilation token. For most words executing the compilation token results in laying down (*compiling*) the execution token, i.e., some magic to make that xt or number get executed or pushed at a later time; at the time that `add-two` is *executed*. Therefore, when you execute `add-two` its *run-time effect* is exactly the same as if you had typed `2 + .` outside of a definition, and pressed carriage-return.

In Forth, every word or number can be described in terms of two properties:

- Its *interpretation semantics*, represented by the execution token.
- Its *compilation semantics*, represented by the compilation token.

The value of `state` determines whether the text interpreter will use the compilation or interpretation semantics of a word or number that it encounters.

- When the text interpreter encounters a word or number in *interpret* state, it performs the *interpretation semantics* of the word or number.
- When the text interpreter encounters a word or number in *compile* state, it performs the *compilation semantics* of the word or number.

Numbers are always treated in a fixed way:

- When the number is *interpreted*, its behaviour is to push the number onto the stack.
- When the number is *compiled*, a piece of code is appended to the current definition that pushes the number when it runs. (In other words, the compilation semantics of a number are to postpone its interpretation semantics until the run-time of the definition that it is being compiled into.)

The behaviour of a word is not so regular, but most have *default compilation semantics* which means that they behave like this:

- The *interpretation semantics* of the word are to do something useful.
- The *compilation semantics* of the word are to append its *interpretation semantics* to the current definition (so that its run-time behaviour is to do something useful).

The actual behaviour of any particular word depends upon the way in which it was defined. When the text interpreter finds the word in the name dictionary, it not only retrieves the xt for the word, it also retrieves some flags: the *compile-only* flag and the *immediate flag*. The compile-only flag indicates that the word has no interpretation semantics (the run-time behaviour for the default compilation semantics is not affected by this flag, however); any attempt to interpret a word that has the compile-only flag set will generate an error (for example, `IF` has no interpretation semantics). The immediate flag changes the compilation semantics of the word; if it is set, the compilation semantics are equal to the interpretation semantics (again ignoring the compile-only flag). it. In other words, these so-called *immediate* words behave like this:

- The *interpretation semantics* of the word are to do something useful.
- The *compilation semantics* of the word are to do something useful (and actually the same thing); i.e., it is executed during compilation.

This example shows the difference between an immediate and a non-immediate word:

```
: show-state state @ . ;
: show-state-now show-state ; immediate
: word1 show-state ;
: word2 show-state-now ;
```

The word `immediate` after the definition of `show-state-now` makes that word an immediate word. These definitions introduce a new word: `@` (pronounced "fetch"). This word fetches the value of a variable, and leaves it on the stack. Therefore, the behaviour of `show-state` is to print a number that represents the current value of `state`.

When you execute `word1`, it prints the number 0, indicating that the system is interpreting. When the text interpreter compiled the definition of `word1`, it encountered `show-state` whose compilation semantics are to append its interpretation semantics to the current definition. When you execute `word1`, it performs the interpretation semantics of `show-state`. At the time that `word1` (and therefore `show-state`) are executed, the system is interpreting.

When you pressed ⟨RET⟩ after entering the definition of `word2`, you should have seen the number -1 printed, followed by " `ok`". When the text interpreter compiled the definition of `word2`, it encountered `show-state-now`, an immediate word, whose compilation semantics are therefore to perform its interpretation semantics. It is executed straight away (even before the text interpreter has moved on to process another group of characters; the `;` in this example). The effect of executing it are to display the value of `state` *at the time that the definition of* `word2` *is being defined.* Printing -1 demonstrates that the system is compiling at this time. If you execute `word2` it does nothing at all.

Before leaving the subject of immediate words, consider the behaviour of `."` in the definition of `greet`, in the previous section. This word is both a parsing word and an immediate word. Notice that there is a space between `."` and the start of the text `Hello and welcome`, but that there is no space between the last letter of `welcome` and the `"` character. The reason for this is that `."` is a Forth word; it must have a space after it so that the text interpreter can identify it. The `"` is not a Forth word; it is a *delimiter*. The examples earlier show that, when the string is displayed, there is neither a space before the `H` nor after the `e`. Since `."` is an immediate word, it executes at the time that `greet` is defined. When it executes, its behaviour is to search forward in the input line looking for the delimiter. When it finds the delimiter, it updates `>IN` to point past the delimiter. It also compiles some magic code into the definition of `greet`; the xt of a run-time routine that prints a text string. It compiles the string `Hello and welcome` into memory so that it is available to be printed later. When the text interpreter gains control, the next word it finds in the input stream is `;` and so it terminates the definition of `greet`.

3.5 Forth is written in Forth

When you start up a Forth compiler, a large number of definitions already exist. In Forth, you develop a new application using bottom-up programming techniques to create new definitions that are defined in terms of existing definitions. As you create each definition you can test and debug it interactively.

If you have tried out the examples in this section, you will probably have typed them in by hand; when you leave Gforth, your definitions will be lost. You can avoid this by using a text editor to enter Forth source code into a file, and then loading code from the file using `include` (See Section 4.13.1 [Forth source files], page 78). A Forth source file is processed by the text interpreter, just as though you had typed it in by hand[3].

Gforth also supports the traditional Forth alternative to using text files for program entry (See Section 4.14 [Blocks], page 81).

[3] Actually, there are some subtle differences – see Section 4.9 [The Text Interpreter], page 64.

In common with many, if not most, Forth compilers, most of Gforth is actually written in Forth. All of the '`.fs`' files in the installation directory[4] are Forth source files, which you can study to see examples of Forth programming.

Gforth maintains a history file that records every line that you type to the text interpreter. This file is preserved between sessions, and is used to provide a command-line recall facility. If you enter long definitions by hand, you can use a text editor to paste them out of the history file into a Forth source file for reuse at a later time (see Section 2.3 [Command-line editing], page 13 for more information).

3.6 Review - elements of a Forth system

To summarise this chapter:

- Forth programs use *factoring* to break a problem down into small fragments called *words* or *definitions*.
- Forth program development is an interactive process.
- The main command loop that accepts input, and controls both interpretation and compilation, is called the *text interpreter* (also known as the *outer interpreter*).
- Forth has a very simple syntax, consisting of words and numbers separated by spaces or carriage-return characters. Any additional syntax is imposed by *parsing words*.
- Forth uses a stack to pass parameters between words. As a result, it uses postfix notation.
- To use a word that has previously been defined, the text interpreter searches for the word in the *name dictionary*.
- Words have *interpretation semantics* and *compilation semantics*.
- The text interpreter uses the value of `state` to select between the use of the *interpretation semantics* and the *compilation semantics* of a word that it encounters.
- The relationship between the *interpretation semantics* and *compilation semantics* for a word depend upon the way in which the word was defined (for example, whether it is an *immediate* word).
- Forth definitions can be implemented in Forth (called *high-level definitions*) or in some other way (usually a lower-level language and as a result often called *low-level definitions*, *code definitions* or *primitives*).
- Many Forth systems are implemented mainly in Forth.

3.7 Where To Go Next

Amazing as it may seem, if you have read (and understood) this far, you know almost all the fundamentals about the inner workings of a Forth system. You certainly know enough to be able to read and understand the rest of this manual and the ANS Forth document, to learn more about the facilities that Forth in general and Gforth in particular provide. Even scarier, you know almost enough to implement your own Forth system. However, that's not a good idea just yet... better to try writing some programs in Gforth.

[4] For example, '`/usr/local/share/gforth...`'

Forth has such a rich vocabulary that it can be hard to know where to start in learning it. This section suggests a few sets of words that are enough to write small but useful programs. Use the word index in this document to learn more about each word, then try it out and try to write small definitions using it. Start by experimenting with these words:

- Arithmetic: `+ - * / /MOD */ ABS INVERT`
- Comparison: `MIN MAX =`
- Logic: `AND OR XOR NOT`
- Stack manipulation: `DUP DROP SWAP OVER`
- Loops and decisions: `IF ELSE ENDIF ?DO I LOOP`
- Input/Output: `. ." EMIT CR KEY`
- Defining words: `: ; CREATE`
- Memory allocation words: `ALLOT ,`
- Tools: `SEE WORDS .S MARKER`

When you have mastered those, go on to:

- More defining words: `VARIABLE CONSTANT VALUE TO CREATE DOES>`
- Memory access: `@ !`

When you have mastered these, there's nothing for it but to read through the whole of this manual and find out what you've missed.

3.8 Exercises

TODO: provide a set of programming excercises linked into the stuff done already and into other sections of the manual. Provide solutions to all the exercises in a .fs file in the distribution.

4 Forth Words

4.1 Notation

The Forth words are described in this section in the glossary notation that has become a de-facto standard for Forth texts, i.e.,

word *Stack effect* *wordset* *pronunciation*

Description

word The name of the word.

Stack effect

The stack effect is written in the notation *before* `--` *after*, where *before* and *after* describe the top of stack entries before and after the execution of the word. The rest of the stack is not touched by the word. The top of stack is rightmost, i.e., a stack sequence is written as it is typed in. Note that Gforth uses a separate floating point stack, but a unified stack notation. Also, return stack effects are not shown in *stack effect*, but in *Description*. The name of a stack item describes the type and/or the function of the item. See below for a discussion of the types.

All words have two stack effects: A compile-time stack effect and a run-time stack effect. The compile-time stack-effect of most words is *–*. If the compile-time stack-effect of a word deviates from this standard behaviour, or the word does other unusual things at compile time, both stack effects are shown; otherwise only the run-time stack effect is shown.

pronunciation

How the word is pronounced.

wordset The ANS Forth standard is divided into several word sets. A standard system need not support all of them. Therefore, in theory, the fewer word sets your program uses the more portable it will be. However, we suspect that most ANS Forth systems on personal machines will feature all word sets. Words that are not defined in ANS Forth have `gforth` or `gforth-internal` as word set. `gforth` describes words that will work in future releases of Gforth; `gforth-internal` words are more volatile. Environmental query strings are also displayed like words; you can recognize them by the `environment` in the word set field.

Description

A description of the behaviour of the word.

The type of a stack item is specified by the character(s) the name starts with:

`f` Boolean flags, i.e. `false` or `true`.

`c` Char

`w` Cell, can contain an integer or an address

`n` signed integer

`u`	unsigned integer
`d`	double sized signed integer
`ud`	double sized unsigned integer
`r`	Float (on the FP stack)
`a-`	Cell-aligned address
`c-`	Char-aligned address (note that a Char may have two bytes in Windows NT)
`f-`	Float-aligned address
`df-`	Address aligned for IEEE double precision float
`sf-`	Address aligned for IEEE single precision float
`xt`	Execution token, same size as Cell
`wid`	Word list ID, same size as Cell
`f83name`	Pointer to a name structure
`"`	string in the input stream (not on the stack). The terminating character is a blank by default. If it is not a blank, it is shown in `<>` quotes.

4.2 Comments

Forth supports two styles of comment; the traditional *in-line* comment, `(` and its modern cousin, the *comment to end of line*; `\`.

`(` *compilation 'ccc<close-paren>' – ; run-time* – core,file "paren"

Comment, usually till the next `):` parse and discard all subsequent characters in the parse area until `")"` is encountered. During interactive input, an end-of-line also acts as a comment terminator. For file input, it does not; if the end-of-file is encountered whilst parsing for the `")"` delimiter, Gforth will generate a warning.

`\` – core-ext,block-ext "backslash"

Comment till the end of the line if `BLK` contains 0 (i.e., while not loading a block), parse and discard the remainder of the parse area. Otherwise, parse and discard all subsequent characters in the parse area corresponding to the current line.

`\G` – gforth "backslash-gee"

Equivalent to `\` but used as a tag to annotate definition comments into documentation.

4.3 Boolean Flags

A Boolean flag is cell-sized. A cell with all bits clear represents the flag `false` and a flag with all bits set represents the flag `true`. Words that check a flag (for example, `IF`) will treat a cell that has *any* bit set as `true`.

`true` – *f* core-ext "true"

CONSTANT: *f* is a cell with all bits set.

`false` – *f* core-ext "false"

CONSTANT: *f* is a cell with all bits clear.

`on` *a-addr* – gforth "on"

Set the (value of the) variable at *a-addr* to `true`.

`off` *a-addr* – gforth "off"

Set the (value of the) variable at *a-addr* to `false`.

4.4 Arithmetic

Forth arithmetic is not checked, i.e., you will not hear about integer overflow on addition or multiplication, you may hear about division by zero if you are lucky. The operator is written after the operands, but the operands are still in the original order. I.e., the infix `2-1` corresponds to `2 1 -`. Forth offers a variety of division operators. If you perform division with potentially negative operands, you do not want to use `/` or `/mod` with its undefined behaviour, but rather `fm/mod` or `sm/mod` (probably the former, see Section 4.4.5 [Mixed precision], page 31).

4.4.1 Single precision

By default, numbers in Forth are single-precision integers that are 1 cell in size. They can be signed or unsigned, depending upon how you treat them. See Section 4.9.2 [Number Conversion], page 67 for the rules used by the text interpreter for recognising single-precision integers.

`+` *n1 n2* – *n* core "plus"

`1+` *n1* – *n2* core "one-plus"

`-` *n1 n2* – *n* core "minus"

`1-` *n1* – *n2* core "one-minus"

`*` *n1 n2* – *n* core "star"

`/` *n1 n2* – *n* core "slash"

`mod` *n1 n2* – *n* core "mod"

`/mod` *n1 n2* – *n3 n4* core "slash-mod"

`negate` *n1* – *n2* core "negate"

`abs` *n1* – *n2* core "abs"

`min` *n1 n2* – *n* core "min"

`max` *n1 n2* – *n* core "max"

`d>s` *d* – *n* double "d-to-s"

`FLOORED` – *f* environment "FLOORED"

True if division is floored by default.

4.4.2 Bitwise operations

`and` *w1 w2 – w* core "and"
`or` *w1 w2 – w* core "or"
`xor` *w1 w2 – w* core "xor"
`invert` *w1 – w2* core "invert"
`lshift` *u1 n – u2* core "lshift"
`rshift` *u1 n – u2* core "rshift"
`2*` *n1 – n2* core "two-star"
`d2*` *d1 – d2* double "d-two-star"
`2/` *n1 – n2* core "two-slash"
`d2/` *d1 – d2* double "d-two-slash"

4.4.3 Double precision

See Section 4.9.2 [Number Conversion], page 67 for the rules used by the text interpreter for recognising double-precision integers.

A double precision number is represented by a cell pair, with the most significant cell at the TOS. It is trivial to convert an unsigned single to an (unsigned) double; simply push a `0` onto the TOS. Since numbers are represented by Gforth using 2's complement arithmetic, converting a signed single to a (signed) double requires sign-extension across the most significant cell. This can be achieved using `s>d`. The moral of the story is that you cannot convert a number without knowing whether it represents an unsigned or a signed number.

`s>d` *n – d* core "s-to-d"
`d+` *d1 d2 – d* double "d-plus"
`d-` *d1 d2 – d* double "d-minus"
`dnegate` *d1 – d2* double "dnegate"
`dabs` *d1 – d2* double "dabs"
`dmin` *d1 d2 – d* double "dmin"
`dmax` *d1 d2 – d* double "dmax"

4.4.4 Numeric comparison

`<` *n1 n2 – f* core "less"
`<=` *n1 n2 – f* gforth "less-or-equal"
`<>` *n1 n2 – f* core-ext "different"
`=` *n1 n2 – f* core "equals"
`>` *n1 n2 – f* core "greater"
`>=` *n1 n2 – f* gforth "greater-or-equal"
`0<` *n – f* core "zero-less"
`0<=` *n – f* gforth "zero-less-or-equal"
`0<>` *n – f* core-ext "zero-different"

`0=` *n – f* core "zero-equals"
`0>` *n – f* core-ext "zero-greater"
`0>=` *n – f* gforth "zero-greater-or-equal"
`u<` *u1 u2 – f* core "u-less"
`u<=` *u1 u2 – f* gforth "u-less-or-equal"
`u>` *u1 u2 – f* core-ext "u-greater"
`u>=` *u1 u2 – f* gforth "u-greater-or-equal"
`within` *u1 u2 u3 – f* core-ext "within"

u2=<u1<u3 or: u3=<u2 and u1 is not in [u3,u2). This works for unsigned and signed numbers (but not a mixture). Another way to think about this word is to consider the numbers as a circle (wrapping around from `max-u` to 0 for unsigned, and from `max-n` to min-n for signed numbers); now consider the range from u2 towards increasing numbers up to and excluding u3 (giving an empty range if u2=u3; if u1 is in this range, `within` returns true.

`d<` *d1 d2 – f* double "d-less"
`d<=` *d1 d2 – f* gforth "d-less-or-equal"
`d<>` *d1 d2 – f* gforth "d-different"
`d=` *d1 d2 – f* double "d-equals"
`d>` *d1 d2 – f* gforth "d-greater"
`d>=` *d1 d2 – f* gforth "d-greater-or-equal"
`d0<` *d – f* double "d-zero-less"
`d0<=` *d – f* gforth "d-zero-less-or-equal"
`d0<>` *d – f* gforth "d-zero-different"
`d0=` *d – f* double "d-zero-equals"
`d0>` *d – f* gforth "d-zero-greater"
`d0>=` *d – f* gforth "d-zero-greater-or-equal"
`du<` *ud1 ud2 – f* double-ext "d-u-less"
`du<=` *ud1 ud2 – f* gforth "d-u-less-or-equal"
`du>` *ud1 ud2 – f* gforth "d-u-greater"
`du>=` *ud1 ud2 – f* gforth "d-u-greater-or-equal"

4.4.5 Mixed precision

`m+` *d1 n – d2* double "m-plus"
`*/` *n1 n2 n3 – n4* core "star-slash"
`*/mod` *n1 n2 n3 – n4 n5* core "star-slash-mod"
`m*` *n1 n2 – d* core "m-star"
`um*` *u1 u2 – ud* core "u-m-star"
`m*/` *d1 n2 u3 – dqout* double "m-star-slash"
`um/mod` *ud u1 – u2 u3* core "u-m-slash-mod"

ud=u3*u1+u2, u1>u2>=0

`fm/mod` *d1 n1 – n2 n3* core "f-m-slash-mod"

Floored division: *d1* = *n3***n1*+*n2*, *n1*>*n2*>=0 or 0>=*n2*>*n1*.

`sm/rem` *d1 n1 – n2 n3* core "s-m-slash-rem"

Symmetric division: *d1* = *n3***n1*+*n2*, sign(*n2*)=sign(*d1*) or 0.

4.4.6 Floating Point

See Section 4.9.2 [Number Conversion], page 67 for the rules used by the text interpreter for recognising floating-point numbers.

Gforth has a separate floating point stack, but the documentation uses the unified notation.

Floating point numbers have a number of unpleasant surprises for the unwary (e.g., floating point addition is not associative) and even a few for the wary. You should not use them unless you know what you are doing or you don't care that the results you get are totally bogus. If you want to learn about the problems of floating point numbers (and how to avoid them), you might start with *David Goldberg, What Every Computer Scientist Should Know About Floating-Point Arithmetic, ACM Computing Surveys 23(1):5–48, March 1991* (`http://www.validgh.com/goldberg/paper.ps`).

`d>f` *d – r* float "d-to-f"

`f>d` *r – d* float "f-to-d"

`f+` *r1 r2 – r3* float "f-plus"

`f-` *r1 r2 – r3* float "f-minus"

`f*` *r1 r2 – r3* float "f-star"

`f/` *r1 r2 – r3* float "f-slash"

`fnegate` *r1 – r2* float "fnegate"

`fabs` *r1 – r2* float-ext "fabs"

`fmax` *r1 r2 – r3* float "fmax"

`fmin` *r1 r2 – r3* float "fmin"

`floor` *r1 – r2* float "floor"

Round towards the next smaller integral value, i.e., round toward negative infinity.

`fround` *r1 – r2* float "fround"

Round to the nearest integral value.

`f**` *r1 r2 – r3* float-ext "f-star-star"

r3 is *r1* raised to the *r2*th power.

`fsqrt` *r1 – r2* float-ext "fsqrt"

`fexp` *r1 – r2* float-ext "fexp"

`fexpm1` *r1 – r2* float-ext "fexpm1"

r2=*e****r1*−1

`fln` *r1 – r2* float-ext "fln"

`flnp1` *r1 – r2* float-ext "flnp1"

r2=ln(*r1*+1)

`flog` *r1 – r2* float-ext "flog"

The decimal logarithm.

`falog` *r1 – r2* float-ext "falog"

r2=10**r1*

`f2*` *r1 – r2* gforth "f2*"

Multiply *r1* by 2.0e0

`f2/` *r1 – r2* gforth "f2/"

Multiply *r1* by 0.5e0

`1/f` *r1 – r2* gforth "1/f"

Divide 1.0e0 by *r1*.

`precision` *– u* floating-ext "precision"

u is the number of significant digits currently used by `F.` `FE.` and `FS.`

`set-precision` *u –* floating-ext "set-precision"

Set the number of significant digits currently used by `F.` `FE.` and `FS.` to *u*.

Angles in floating point operations are given in radians (a full circle has 2 pi radians).

`fsin` *r1 – r2* float-ext "fsin"

`fcos` *r1 – r2* float-ext "fcos"

`fsincos` *r1 – r2 r3* float-ext "fsincos"

r2=sin(*r1*), *r3*=cos(*r1*)

`ftan` *r1 – r2* float-ext "ftan"

`fasin` *r1 – r2* float-ext "fasin"

`facos` *r1 – r2* float-ext "facos"

`fatan` *r1 – r2* float-ext "fatan"

`fatan2` *r1 r2 – r3* float-ext "fatan2"

r1/r2=tan(*r3*). ANS Forth does not require, but probably intends this to be the inverse of `fsincos`. In gforth it is.

`fsinh` *r1 – r2* float-ext "fsinh"

`fcosh` *r1 – r2* float-ext "fcosh"

`ftanh` *r1 – r2* float-ext "ftanh"

`fasinh` *r1 – r2* float-ext "fasinh"

`facosh` *r1 – r2* float-ext "facosh"

`fatanh` *r1 – r2* float-ext "fatanh"

`pi` *– r* gforth "pi"

FCONSTANT: *r* is the value pi; the ratio of a circle's area to its diameter.

One particular problem with floating-point arithmetic is that comparison for equality often fails when you would expect it to succeed. For this reason approximate equality is often preferred (but you still have to know what you are doing). The comparison words are:

`f~rel` *r1 r2 r3 – flag* gforth "f~rel"

Approximate equality with relative error: `|r1-r2|<r3*|r1+r2|`.

`f~abs` *r1 r2 r3 – flag* gforth "f~abs"

Approximate equality with absolute error: `|`r1-r2`|<`r3.

`f=` *r1 r2 – f* gforth "f-equals"

`f~` *r1 r2 r3 – flag* float-ext "f~"

ANS Forth medley: r3>0: `f~abs`; r3=0: r1=r2; r3<0: `fnegate f~abs`.

`f<>` *r1 r2 – f* gforth "f-different"

`f<` *r1 r2 – f* float "f-less"

`f<=` *r1 r2 – f* gforth "f-less-or-equal"

`f>` *r1 r2 – f* gforth "f-greater"

`f>=` *r1 r2 – f* gforth "f-greater-or-equal"

`f0<` *r – f* float "f-zero-less"

`f0<=` *r – f* gforth "f-zero-less-or-equal"

`f0<>` *r – f* gforth "f-zero-different"

`f0=` *r – f* float "f-zero-equals"

`f0>` *r – f* gforth "f-zero-greater"

`f0>=` *r – f* gforth "f-zero-greater-or-equal"

4.5 Stack Manipulation

Gforth maintains a number of separate stacks:

- A data stack (also known as the *parameter stack*) – for characters, cells, addresses, and double cells.
- A floating point stack – for floating point numbers.
- A return stack – for storing the return addresses of colon definitions and other (non-FP) data.
- A locals stack for storing local variables.

4.5.1 Data stack

`drop` *w –* core "drop"

`nip` *w1 w2 – w2* core-ext "nip"

`dup` *w – w w* core "dup"

`over` *w1 w2 – w1 w2 w1* core "over"

`tuck` *w1 w2 – w2 w1 w2* core-ext "tuck"

`swap` *w1 w2 – w2 w1* core "swap"

`pick` *u – w* core-ext "pick"

`rot` *w1 w2 w3 – w2 w3 w1* core "rote"

`-rot` *w1 w2 w3 – w3 w1 w2* gforth "not-rote"

`?dup` *w – w* core "question-dupe"

`roll` *x0 x1 .. xn n – x1 .. xn x0* core-ext "roll"

`2drop` *w1 w2 –* core "two-drop"

`2nip` *w1 w2 w3 w4 – w3 w4* gforth "two-nip"
`2dup` *w1 w2 – w1 w2 w1 w2* core "two-dupe"
`2over` *w1 w2 w3 w4 – w1 w2 w3 w4 w1 w2* core "two-over"
`2tuck` *w1 w2 w3 w4 – w3 w4 w1 w2 w3 w4* gforth "two-tuck"
`2swap` *w1 w2 w3 w4 – w3 w4 w1 w2* core "two-swap"
`2rot` *w1 w2 w3 w4 w5 w6 – w3 w4 w5 w6 w1 w2* double-ext "two-rote"

4.5.2 Floating point stack

Whilst every sane Forth has a separate floating-point stack, it is not strictly required; an ANS Forth system could theoretically keep floating-point numbers on the data stack. As an additional difficulty, you don't know how many cells a floating-point number takes. It is reportedly possible to write words in a way that they work also for a unified stack model, but we do not recommend trying it. Instead, just say that your program has an environmental dependency on a separate floating-point stack.

`floating-stack` *– n* environment "floating-stack"

n is non-zero, showing that Gforth maintains a separate floating-point stack of depth *n*.

`fdrop` *r –* float "fdrop"
`fnip` *r1 r2 – r2* gforth "fnip"
`fdup` *r – r r* float "fdup"
`fover` *r1 r2 – r1 r2 r1* float "fover"
`ftuck` *r1 r2 – r2 r1 r2* gforth "ftuck"
`fswap` *r1 r2 – r2 r1* float "fswap"
`fpick` *u – r* gforth "fpick"
`frot` *r1 r2 r3 – r2 r3 r1* float "frot"

4.5.3 Return stack

A Forth system is allowed to keep local variables on the return stack. This is reasonable, as local variables usually eliminate the need to use the return stack explicitly. So, if you want to produce a standard compliant program and you are using local variables in a word, forget about return stack manipulations in that word (refer to the standard document for the exact rules).

`>r` *w –* core "to-r"
`r>` *– w* core "r-from"
`r@` *– w ; R: w – w* core "r-fetch"

Copy *w* from the return stack to the data stack.

`rdrop` *–* gforth "rdrop"
`2>r` *w1 w2 –* core-ext "two-to-r"
`2r>` *– w1 w2* core-ext "two-r-from"
`2r@` *– w1 w2* core-ext "two-r-fetch"
`2rdrop` *–* gforth "two-r-drop"

4.5.4 Locals stack

4.5.5 Stack pointer manipulation

`sp0` – *a-addr* gforth "sp0"

USER VARIABLE: Initial value of the data stack pointer.

`sp@` – *a-addr* gforth "sp-fetch"

`sp!` *a-addr* – gforth "sp-store"

`fp0` – *a-addr* gforth "fp0"

USER VARIABLE: Initial value of the floating-point stack pointer.

`fp@` – *f-addr* gforth "fp-fetch"

`fp!` *f-addr* – gforth "fp-store"

`rp0` – *a-addr* gforth "rp0"

USER VARIABLE: Initial value of the return stack pointer.

`rp@` – *a-addr* gforth "rp-fetch"

`rp!` *a-addr* – gforth "rp-store"

`lp0` – *a-addr* gforth "lp0"

USER VARIABLE: Initial value of the locals stack pointer.

`lp@` – *addr* gforth "lp-fetch"

`lp!` *c-addr* – gforth "lp-store"

4.6 Memory

4.6.1 ANS Forth and Gforth memory models

ANS Forth considers a Forth system as consisting of several memories, of which only *data space* is managed and accessible with the memory words. Memory not necessarily in data space includes the stacks, the code (called code space) and the headers (called name space). In Gforth everything is in data space, but the code for the primitives is usually read-only.

Data space is divided into a number of areas: The (data space portion of the) dictionary[1], the heap, and a number of system-allocated buffers.

In ANS Forth data space is also divided into contiguous regions. You can only use address arithmetic within a contiguous region, not between them. Usually each allocation gives you one contiguous region, but the dictionary allocation words have additional rules (see Section 4.6.2 [Dictionary allocation], page 38).

Gforth provides one big address space, and address arithmetic can be performed between any addresses. However, in the dictionary headers or code are interleaved with data, so

[1] Sometimes, the term *dictionary* is used to refer to the search data structure embodied in word lists and headers, because it is used for looking up names, just as you would in a conventional dictionary.

almost the only contiguous data space regions there are those described by ANS Forth as contiguous; but you can be sure that the dictionary is allocated towards increasing addresses even between contiguous regions. The memory order of allocations in the heap is platform-dependent (and possibly different from one run to the next).

4.6.1.1 ANS Forth dictionary details

This section is just informative, you can skip it if you are in a hurry.

When you create a colon definition, the text interpreter compiles the code for the definition into the code space and compiles the name of the definition into the header space, together with other information about the definition (such as its execution token).

When you create a variable, the execution of `variable` will compile some code, assign one cell in data space, and compile the name of the variable into the header space.

ANS Forth does not specify the relationship between the three memory regions, and specifies that a Standard program must not access code or data space directly – it may only access data space directly. In addition, the Standard defines what relationships you may and may not rely on when allocating regions in data space. These constraints are simply a reflection of the many diverse techniques that are used to implement Forth systems; understanding and following the requirements of the Standard allows you to write portable programs – programs that run in the same way on any of these diverse systems. Another way of looking at this is to say that ANS Forth was designed to permit compliant Forth systems to be implemented in many diverse ways.

Here are some examples of ways in which name, code and data spaces might be assigned in different Forth implementations:

- For a Forth system that runs from RAM under a general-purpose operating system, it can be convenient to interleave name, code and data spaces in a single contiguous memory region. This organisation can be memory-efficient (for example, because the relationship between the name dictionary entry and the associated code space entry can be implicit, rather than requiring an explicit memory pointer to reference from the header space and the code space). This is the organisation used by Gforth, as this example[2] shows:

```
hex
variable fred 123456 fred !
variable jim abcd jim !
: foo + / - ;
' fred 10 - 50 dump
..80: 5C 46 0E 40  84 66 72 65 - 64 20 20 20  20 20 20 20  \F..fred
..90: D0 9B 04 08  00 00 00 00 - 56 34 12 00  80 46 0E 40  ........V4...F.
..A0: 83 6A 69 6D  20 20 20 20 - D0 9B 04 08  00 00 00 00  .jim    ........
..B0: CD AB 00 00  9C 46 0E 40 - 83 66 6F 6F  20 20 20 20  .....F..foo
..C0: 80 9B 04 08  00 00 00 00 - E4 2E 05 08  0C 2F 05 08  ............./..
```

- For a high-performance system running on a modern RISC processor with a modified Harvard architecture (one that has a unified main memory but separate instruction

[2] The addresses in the example have been truncated to fit it onto the page, and the addresses and data shown will not match the output from your system

and data caches), it is desirable to separate processor instructions from processor data. This encourages a high cache density and therefore a high cache hit rate. The Forth code space is not necessarily made up entirely of processor instructions; its nature is dependent upon the Forth implementation.

- A Forth compiler that runs on a segmented 8086 processor could be designed to interleave the name, code and data spaces within a single 64Kbyte segment. A more common implementation choice is to use a separate 64Kbyte segment for each region, which provides more memory overall but provides an address map in which only the data space is accessible.
- Microprocessors exist that run Forth (or many of the primitives required to implement the Forth virtual machine efficiently) directly. On these processors, the relationship between name, code and data spaces may be imposed as a side-effect of the architecture of the processor.
- A Forth compiler that executes from ROM on an embedded system needs its data space separated from the name and code spaces so that the data space can be mapped to a RAM area.
- A Forth compiler that runs on an embedded system may have a requirement for a small memory footprint. On such a system it can be useful to separate the header space from the data and code spaces; once the application has been compiled, the header space is no longer required[3]. The header space can be deleted entirely, or could be stored in memory on a remote *host* system for debug and development purposes. In the latter case, the compiler running on the *target* system could implement a protocol across a communication link that would allow it to interrogate the header space.

4.6.2 Dictionary allocation

Dictionary allocation is a stack-oriented allocation scheme, i.e., if you want to deallocate X, you also deallocate everything allocated after X.

The allocations using the words below are contiguous and grow the region towards increasing addresses. Other words that allocate dictionary memory of any kind (i.e., defining words including `:noname`) end the contiguous region and start a new one.

In ANS Forth only `created` words are guaranteed to produce an address that is the start of the following contiguous region. In particular, the cell allocated by `variable` is not guaranteed to be contiguous with following `allot`ed memory.

You can deallocate memory by using `allot` with a negative argument (with some restrictions, see `allot`). For larger deallocations use `marker`.

`here` – *addr* core "here"

Return the address of the next free location in data space.

`unused` – *u* core-ext "unused"

Return the amount of free space remaining (in address units) in the region addressed by `here`.

[3] more strictly speaking, most applications can be designed so that this is the case

`allot` *n* – core "allot"

Reserve or release *n* address units of data space without initialization; *n* is a signed number. In ANS Forth you can only deallocate memory from the current contiguous region in this way. In Gforth you can deallocate anything in this way but named words. The system does not check this restriction.

`c,` *c* – core "c,"

Reserve data space for one char and store *c* in the space.

`f,` *f* – gforth "f,"

Reserve data space for one floating-point number and store *f* in the space.

`,` *w* – core ","

Reserve data space for one cell and store *w* in the space.

`2,` *w1 w2* – gforth "2,"

Reserve data space for two cells and store the double *w1 w2* in the space.

`udp` unknown "udp"

`uallot` *n* – unknown "uallot"

Memory accesses have to be aligned (see Section 4.6.5 [Address arithmetic], page 41). So of course you should allocate memory in an aligned way, too. I.e., before allocating allocating a cell, `here` must be cell-aligned, etc. The words below align `here` if it is not already. Basically it is only already aligned for a type, if the last allocation was a multiple of the size of this type and if `here` was aligned for this type before.

After freshly `create`ing a word, `here` is `align`ed in ANS Forth (`maxalign`ed in Gforth).

`align` – core "align"

If the data-space pointer is not aligned, reserve enough space to align it.

`falign` – float "falign"

If the data-space pointer is not float-aligned, reserve enough space to align it.

`sfalign` – float-ext "s-f-align"

If the data-space pointer is not single-float-aligned, reserve enough space to align it.

`dfalign` – float-ext "d-f-align"

If the data-space pointer is not double-float-aligned, reserve enough space to align it.

`maxalign` – gforth "maxalign"

`cfalign` – gforth "cfalign"

4.6.3 Heap allocation

Heap allocation supports deallocation of allocated memory in any order. Dictionary allocation is not affected by it (i.e., it does not end a contiguous region). In Gforth, these words are implemented using the standard C library calls malloc(), free() and resize().

`allocate` *u – a-addr wior* memory "allocate"

Allocate *u* address units of contiguous data space. The initial contents of the data space is undefined. If the allocation is successful, *a-addr* is the start address of the allocated region and *wior* is 0. If the allocation fails, *a-addr* is undefined and *wior* is an implementation-defined I/O result code.

`free` *a-addr – wior* memory "free"

Return the region of data space starting at *a-addr* to the system. The regon must originally have been obtained using `allocate` or `resize`. If the operational is successful, *wior* is 0. If the operation fails, *wior* is an implementation-defined I/O result code.

`resize` *a-addr1 u – a-addr2 wior* memory "resize"

Change the size of the allocated area at *a-addr1* to *u* address units, possibly moving the contents to a different area. *a-addr2* is the address of the resulting area. If the operational is successful, *wior* is 0. If the operation fails, *wior* is an implementation-defined I/O result code. If *a-addr1* is 0, Gforth's (but not the Standard) `resize allocates` *u* address units.

4.6.4 Memory Access

`@` *a-addr – w* core "fetch"

Read from the cell at address *a-addr*, and return its contents, *w*.

`!` *w a-addr –* core "store"

Write the value *w* to the cell at address *a-addr*.

`+!` *n a-addr –* core "plus-store"

Add *n* to the value stored in the cell at address *a-addr*.

`c@` *c-addr – c* core "c-fetch"

Read from the char at address *c-addr*, and return its contents, *c*.

`c!` *c c-addr –* core "c-store"

Write the value *c* to the char at address *c-addr*.

`2@` *a-addr – w1 w2* core "two-fetch"

Read from the double at address *a-addr*, and return its contents, *w1, w2*.

`2!` *w1 w2 a-addr –* core "two-store"

Write the value *w1, w2* to the double at address *a-addr*.

`f@` *f-addr – r* float "f-fetch"

Fetch floating-point value *r* from address *f-addr*.

`f!` *r f-addr –* float "f-store"

Store the floating-point value *r* to address *f-addr*.

`sf@` *sf-addr – r* float-ext "s-f-fetch"

Fetch the single-precision IEEE floating-point value *r* from the address *sf-addr*.

`sf!` *r sf-addr –* float-ext "s-f-store"

Store the single-precision IEEE floating-point value *r* to the address *sf-addr*.

`df@` *df-addr – r* float-ext "d-f-fetch"

Fetch the double-precision IEEE floating-point value *r* from the address *df-addr*.

`df!` *r df-addr –* float-ext "d-f-store"

Store the double-precision IEEE floating-point value *r* to the address *df-addr*.

4.6.5 Address arithmetic

Address arithmetic is the foundation on which data structures like arrays, records (see Section 4.20 [Structures], page 105) and objects (see Section 4.21 [Object-oriented Forth], page 109) are built.

ANS Forth does not specify the sizes of the data types. Instead, it offers a number of words for computing sizes and doing address arithmetic. Address arithmetic is performed in terms of address units (aus); on most systems the address unit is one byte. Note that a character may have more than one au, so `chars` is no noop (on systems where it is a noop, it compiles to nothing).

ANS Forth also defines words for aligning addresses for specific types. Many computers require that accesses to specific data types must only occur at specific addresses; e.g., that cells may only be accessed at addresses divisible by 4. Even if a machine allows unaligned accesses, it can usually perform aligned accesses faster.

For the performance-conscious: alignment operations are usually only necessary during the definition of a data structure, not during the (more frequent) accesses to it.

ANS Forth defines no words for character-aligning addresses. This is not an oversight, but reflects the fact that addresses that are not char-aligned have no use in the standard and therefore will not be created.

ANS Forth guarantees that addresses returned by `CREATE`d words are cell-aligned; in addition, Gforth guarantees that these addresses are aligned for all purposes.

Note that the ANS Forth word `char` has nothing to do with address arithmetic.

`chars` *n1 – n2* core “chars”

n2 is the number of address units corresponding to *n1* chars.""

`char+` *c-addr1 – c-addr2* core “char-plus”

Increment *c-addr1* by the number of address units corresponding to the size of one char, to give *c-addr2*.

`cells` *n1 – n2* core “cells”

n2 is the number of address units corresponding to *n1* cells.

`cell+` *a-addr1 – a-addr2* core “cell-plus”

Increment *a-addr1* by the number of address units corresponding to the size of one cell, to give *a-addr2*.

`cell` *– u* gforth “cell”

CONSTANT: the number of address units corresponding to 1 cell.

`aligned` *c-addr – a-addr* core “aligned”

a-addr is the first aligned address greater than or equal to *c-addr*.

`floats` *n1 – n2* float “floats”

n2 is the number of address units corresponding to *n1* floating-point numbers.

`float+` *f-addr1 – f-addr2* float “float-plus”

Increment *f-addr1* by the number of address units corresponding to the size of one floating-point number, to give *f-addr2*.

`float` – *u* gforth "float"

CONSTANT: the number of address units corresponding to a floating-point number.

`faligned` *c-addr* – *f-addr* float "f-aligned"

f-addr is the first float-aligned address greater than or equal to *c-addr*.

`sfloats` *n1* – *n2* float-ext "s-floats"

n2 is the number of address units corresponding to *n1* single-precision IEEE floating-point numbers.

`sfloat+` *sf-addr1* – *sf-addr2* float-ext "s-float-plus"

Increment *sf-addr1* by the number of address units corresponding to the size of a single-precision IEEE floating-point number, to give *sf-addr2*.""

`sfaligned` *c-addr* – *sf-addr* float-ext "s-f-aligned"

sf-addr is the first single-float-aligned address greater than or equal to *c-addr*.

`dfloats` *n1* – *n2* float-ext "d-floats"

n2 is the number of address units corresponding to *n1* double-precision IEEE floating-point numbers.

`dfloat+` *df-addr1* – *df-addr2* float-ext "d-float-plus"

Increment *df-addr1* by the number of address units corresponding to the size of a double-precision IEEE floating-point number, to give *df-addr2*.""

`dfaligned` *c-addr* – *df-addr* float-ext "d-f-aligned"

df-addr is the first double-float-aligned address greater than or equal to *c-addr*.

`maxaligned` *addr* – *f-addr* gforth "maxaligned"

`cfaligned` *addr1* – *addr2* gforth "cfaligned"

`ADDRESS-UNIT-BITS` – *n* environment "ADDRESS-UNIT-BITS"

Size of one address unit, in bits.

4.6.6 Memory Blocks

Memory blocks often represent character strings; See Section 4.15.3 [String Formats], page 87 for ways of storing character strings in memory. See Section 4.15.4 [Displaying characters and strings], page 87 for other string-processing words.

Some of these words work on address units. Others work on character units (increments of `CHAR`), and expect a `CHAR`-aligned address. Choose the correct operation depending upon your data type.

When copying characters between overlapping memory regions, choose carefully between `cmove` and `cmove>`.

You can only use any of these words *portably* to access data space.

`move` *c-from c-to ucount* – core "move"

Copy the contents of *ucount* address units at *c-from* to *c-to*. `move` works correctly even if the two areas overlap.

`erase` *addr len* – core-ext "erase"

If *len*>0, clear all bits in each location of a memory region of *len* address units starting at address *addr*.

`cmove` *c-from c-to u* – string "cmove"

Copy the contents of *ucount* characters from data space at *c-from* to *c-to*. The copy proceeds `char`-by-`char` from low address to high address; i.e., for overlapping areas it is safe if *c-to*=<*c-from*.

`cmove>` *c-from c-to u* – string "c-move-up"

Copy the contents of *ucount* characters from data space at *c-from* to *c-to*. The copy proceeds `char`-by-`char` from high address to low address; i.e., for overlapping areas it is safe if *c-to*>=*c-from*.

`fill` *c-addr u c* – core "fill"

If *u*>0, store character *c* in each of *u* consecutive `char` addresses in memory, starting at address *c-addr*.

`blank` *c-addr u* – string "blank"

If *u*>0, store the character value for a space in each location of a memory region of *u* character units starting at address *c-addr*.

`compare` *c-addr1 u1 c-addr2 u2* – *n* string "compare"

Compare two strings lexicographically. If they are equal, *n* is 0; if the first string is smaller, *n* is -1; if the first string is larger, *n* is 1. Currently this is based on the machine's character comparison. In the future, this may change to consider the current locale and its collation order.

`search` *c-addr1 u1 c-addr2 u2* – *c-addr3 u3 flag* string "search"

Search the string specified by *c-addr1, u1* for the string specified by *c-addr2, u2*. If *flag* is true: match was found at *c-addr3* with *u3* characters remaining. If *flag* is false: no match was found; *c-addr3, u3* are equal to *c-addr1, u1*.

`-trailing` *c-addr u1* – *c-addr u2* string "dash-trailing"

Adjust the string specified by *c-addr, u1* to remove all trailing spaces. *u2* is the length of the modified string.

`/string` *c-addr1 u1 n* – *c-addr2 u2* string "slash-string"

Adjust the string specified by *c-addr1, u1* to remove *n* characters from the start of the string.

4.7 Control Structures

Control structures in Forth cannot be used interpretively, only in a colon definition[4]. We do not like this limitation, but have not seen a satisfying way around it yet, although many schemes have been proposed.

4.7.1 Selection

flag
`IF`
  code

[4] To be precise, they have no interpretation semantics (see Section 4.8.5 [Interpretation and Compilation Semantics], page 61).

```
ENDIF
```

code is executed if *flag* is non-zero (that's truth as far as `IF` etc. are concerned).

```
flag
IF
  code1
ELSE
  code2
ENDIF
```

If *flag* is true, perform *code1*, otherwise *code2*.

You can use `THEN` instead of `ENDIF`. Indeed, `THEN` is standard, and `ENDIF` is not, although it is quite popular. We recommend using `ENDIF`, because it is less confusing for people who also know other languages (and is not prone to reinforcing negative prejudices against Forth in these people). Adding `ENDIF` to a system that only supplies `THEN` is simple:

```
: ENDIF   POSTPONE THEN ; immediate
```

[According to *Webster's New Encyclopedic Dictionary*, *then (adv.)* has the following meanings:

> ... 2b: following next after in order ... 3d: as a necessary consequence (if you were there, then you saw them).

Forth's `THEN` has the meaning 2b, whereas `THEN` in Pascal and many other programming languages has the meaning 3d.]

Gforth also provides the words `?DUP-IF` and `?DUP-0=-IF`, so you can avoid using `?dup`. Using these alternatives is also more efficient than using `?dup`. Definitions in ANS Forth for `ENDIF`, `?DUP-IF` and `?DUP-0=-IF` are provided in '`compat/control.fs`'.

```
n
CASE
  n1 OF code1 ENDOF
  n2 OF code2 ENDOF
  ...
ENDCASE
```

Executes the first *codei*, where the *ni* is equal to *n*. A default case can be added by simply writing the code after the last `ENDOF`. It may use *n*, which is on top of the stack, but must not consume it.

4.7.2 Simple Loops

```
BEGIN
  code1
  flag
WHILE
  code2
REPEAT
```

code1 is executed and *flag* is computed. If it is true, *code2* is executed and the loop is restarted; If *flag* is false, execution continues after the `REPEAT`.

```
BEGIN
  code
  flag
UNTIL
```

code is executed. The loop is restarted if `flag` is false.

```
BEGIN
  code
AGAIN
```

This is an endless loop.

4.7.3 Counted Loops

The basic counted loop is:

```
limit start
?DO
  body
LOOP
```

This performs one iteration for every integer, starting from *start* and up to, but excluding *limit*. The counter, or *index*, can be accessed with `i`. For example, the loop:

```
10 0 ?DO
  i .
LOOP
```

prints `0 1 2 3 4 5 6 7 8 9`

The index of the innermost loop can be accessed with `i`, the index of the next loop with `j`, and the index of the third loop with `k`.

`i` – *n* core "i"

`j` – *n* core "j"

`k` – *n* gforth "k"

The loop control data are kept on the return stack, so there are some restrictions on mixing return stack accesses and counted loop words. In particuler, if you put values on the return stack outside the loop, you cannot read them inside the loop[5]. If you put values on the return stack within a loop, you have to remove them before the end of the loop and before accessing the index of the loop.

There are several variations on the counted loop:

- `LEAVE` leaves the innermost counted loop immediately; execution continues after the associated `LOOP` or `NEXT`. For example:

  ```
  10 0 ?DO  i DUP . 3 = IF LEAVE THEN LOOP
  ```

  prints `0 1 2 3`

- `UNLOOP` prepares for an abnormal loop exit, e.g., via `EXIT`. `UNLOOP` removes the loop control parameters from the return stack so `EXIT` can get to its return address. For example:

[5] well, not in a way that is portable.

```
: demo 10 0 ?DO i DUP . 3 = IF UNLOOP EXIT THEN LOOP ." Done" ;
```

prints `0 1 2 3`

- If *start* is greater than *limit*, a `?DO` loop is entered (and `LOOP` iterates until they become equal by wrap-around arithmetic). This behaviour is usually not what you want. Therefore, Gforth offers `+DO` and `U+DO` (as replacements for `?DO`), which do not enter the loop if *start* is greater than *limit*; `+DO` is for signed loop parameters, `U+DO` for unsigned loop parameters.
- `?DO` can be replaced by `DO`. `DO` always enters the loop, independent of the loop parameters. Do not use `DO`, even if you know that the loop is entered in any case. Such knowledge tends to become invalid during maintenance of a program, and then the `DO` will make trouble.
- `LOOP` can be replaced with *n* `+LOOP`; this updates the index by *n* instead of by 1. The loop is terminated when the border between *limit-1* and *limit* is crossed. E.g.:

  ```
  4 0 +DO  i .  2 +LOOP
  ```

  prints `0 2`

  ```
  4 1 +DO  i .  2 +LOOP
  ```

  prints `1 3`

  The behaviour of *n* `+LOOP` is peculiar when *n* is negative:

  ```
  -1 0 ?DO  i .  -1 +LOOP
  ```

  prints `0 -1`

  ```
  0 0 ?DO  i .  -1 +LOOP
  ```

  prints nothing.

  Therefore we recommend avoiding *n* `+LOOP` with negative *n*. One alternative is *u* `-LOOP`, which reduces the index by *u* each iteration. The loop is terminated when the border between *limit+1* and *limit* is crossed. Gforth also provides `-DO` and `U-DO` for down-counting loops. E.g.:

  ```
  -2 0 -DO  i .  1 -LOOP
  ```

  prints `0 -1`

  ```
  -1 0 -DO  i .  1 -LOOP
  ```

  prints `0`

  ```
  0 0 -DO  i .  1 -LOOP
  ```

  prints nothing.

Unfortunately, `+DO`, `U+DO`, `-DO`, `U-DO` and `-LOOP` are not defined in ANS Forth. However, an implementation for these words that uses only standard words is provided in '`compat/loops.fs`'.

Another counted loop is:

n
`FOR`
  body
`NEXT`

This is the preferred loop of native code compiler writers who are too lazy to optimize `?DO` loops properly. This loop structure is not defined in ANS Forth. In Gforth, this loop

iterates *n+1* times; `i` produces values starting with *n* and ending with 0. Other Forth systems may behave differently, even if they support `FOR` loops. To avoid problems, don't use `FOR` loops.

4.7.4 Arbitrary control structures

ANS Forth permits and supports using control structures in a non-nested way. Information about incomplete control structures is stored on the control-flow stack. This stack may be implemented on the Forth data stack, and this is what we have done in Gforth.

An *orig* entry represents an unresolved forward branch, a *dest* entry represents a backward branch target. A few words are the basis for building any control structure possible (except control structures that need storage, like calls, coroutines, and backtracking).

`IF` *compilation – orig ; run-time f –* core "IF"

`AHEAD` *compilation – orig ; run-time –* tools-ext "AHEAD"

`THEN` *compilation orig – ; run-time –* core "THEN"

`BEGIN` *compilation – dest ; run-time –* core "BEGIN"

`UNTIL` *compilation dest – ; run-time f –* core "UNTIL"

`AGAIN` *compilation dest – ; run-time –* core-ext "AGAIN"

`CS-PICK` *... u – ... destu* tools-ext "CS-PICK"

`CS-ROLL` *destu/origu .. dest0/orig0 u – .. dest0/orig0 destu/origu* tools-ext "CS-ROLL"

The Standard words `CS-PICK` and `CS-ROLL` allow you to manipulate the control-flow stack in a portable way. Without them, you would need to know how many stack items are occupied by a control-flow entry (many systems use one cell. In Gforth they currently take three, but this may change in the future).

Some standard control structure words are built from these words:

`ELSE` *compilation orig1 – orig2 ; run-time f –* core "ELSE"

`WHILE` *compilation dest – orig dest ; run-time f –* core "WHILE"

`REPEAT` *compilation orig dest – ; run-time –* core "REPEAT"

Gforth adds some more control-structure words:

`ENDIF` *compilation orig – ; run-time –* gforth "ENDIF"

`?DUP-IF` *compilation – orig ; run-time n – n|* gforth "question-dupe-if"

This is the preferred alternative to the idiom `"?DUP IF"`, since it can be better handled by tools like stack checkers. Besides, it's faster.

`?DUP-0=-IF` *compilation – orig ; run-time n – n|* gforth "question-dupe-zero-equals-if"

Counted loop words constitute a separate group of words:

`?DO` *compilation – do-sys ; run-time w1 w2 – | loop-sys* core-ext "question-do"

`+DO` *compilation – do-sys ; run-time n1 n2 – | loop-sys* gforth "plus-do"

`U+DO` *compilation – do-sys ; run-time u1 u2 – | loop-sys* gforth "u-plus-do"

`-DO` *compilation – do-sys ; run-time n1 n2 – | loop-sys* gforth "minus-do"

`U-DO` *compilation – do-sys ; run-time u1 u2 – | loop-sys* gforth "u-minus-do"

`DO` *compilation – do-sys ; run-time w1 w2 – loop-sys* core "DO"

`FOR` *compilation – do-sys ; run-time u – loop-sys* gforth "FOR"

`LOOP` *compilation do-sys – ; run-time loop-sys1 – | loop-sys2* core "LOOP"

`+LOOP` *compilation do-sys – ; run-time loop-sys1 n – | loop-sys2* core "plus-loop"

`-LOOP` *compilation do-sys – ; run-time loop-sys1 u – | loop-sys2* gforth "minus-loop"

`NEXT` *compilation do-sys – ; run-time loop-sys1 – | loop-sys2* gforth "NEXT"

`LEAVE` *compilation – ; run-time loop-sys –* core "LEAVE"

`?LEAVE` *compilation – ; run-time f | f loop-sys –* gforth "question-leave"

`unloop` – core "unloop"

`DONE` *compilation orig – ; run-time –* gforth "DONE"

The standard does not allow using `CS-PICK` and `CS-ROLL` on *do-sys*. Gforth allows it, but it's your job to ensure that for every `?DO` etc. there is exactly one `UNLOOP` on any path through the definition (`LOOP` etc. compile an `UNLOOP` on the fall-through path). Also, you have to ensure that all `LEAVE`s are resolved (by using one of the loop-ending words or `DONE`).

Another group of control structure words are:

`case` *compilation – case-sys ; run-time –* core-ext "case"

`endcase` *compilation case-sys – ; run-time x –* core-ext "end-case"

`of` *compilation – of-sys ; run-time x1 x2 – |x1* core-ext "of"

`endof` *compilation case-sys1 of-sys – case-sys2 ; run-time –* core-ext "end-of"

case-sys and *of-sys* cannot be processed using `CS-PICK` and `CS-ROLL`.

4.7.4.1 Programming Style

In order to ensure readability we recommend that you do not create arbitrary control structures directly, but define new control structure words for the control structure you want and use these words in your program. For example, instead of writing:

```
BEGIN
  ...
IF [ 1 CS-ROLL ]
  ...
AGAIN THEN
```

we recommend defining control structure words, e.g.,

```
: WHILE ( DEST -- ORIG DEST )
 POSTPONE IF
 1 CS-ROLL ; immediate

: REPEAT ( orig dest -- )
 POSTPONE AGAIN
 POSTPONE THEN ; immediate
```

and then using these to create the control structure:

```
BEGIN
  ...
WHILE
  ...
REPEAT
```

That's much easier to read, isn't it? Of course, `REPEAT` and `WHILE` are predefined, so in this example it would not be necessary to define them.

4.7.5 Calls and returns

A definition can be called simply be writing the name of the definition to be called. Normally a definition is invisible during its own definition. If you want to write a directly recursive definition, you can use `recursive` to make the current definition visible, or `recurse` to call the current definition directly.

`recursive` *compilation – ; run-time –* gforth "recursive"

Make the current definition visible, enabling it to call itself recursively.

`recurse` *compilation – ; run-time ?? – ??* core "recurse"

Call the current definition.

> Programming style note: I prefer using `recursive` to `recurse`, because calling the definition by name is more descriptive (if the name is well-chosen) than the somewhat cryptic `recurse`. E.g., in a quicksort implementation, it is much better to read (and think) "now sort the partitions" than to read "now do a recursive call".

For mutual recursion, use `Defer`red words, like this:

```
Defer foo

: bar ( ... -- ... )
 ... foo ... ;

:noname ( ... -- ... )
 ... bar ... ;
IS foo
```

Deferred words are discussed in more detail in Section 4.8.1 [Simple Defining Words], page 52.

The current definition returns control to the calling definition when the end of the definition is reached or `EXIT` is encountered.

`EXIT` *compilation – ; run-time nest-sys –* core "EXIT"

Return to the calling definition; usually used as a way of forcing an early return from a definition. Before `EXIT`ing you must clean up the return stack and `UNLOOP` any outstanding `?DO`...`LOOP`s.

`;s` – gforth "semis"

The primitive compiled by `EXIT`.

4.7.6 Exception Handling

If your program detects a fatal error condition, the simplest action that it can take is to `quit`. This resets the return stack and restarts the text interpreter, but does not print any error message.

The next stage in severity is to execute `abort`, which has the same effect as `quit`, with the addition that it resets the data stack.

A slightly more sophisticated approach is use use `abort"`, which compiles a string to be used as an error message and does a conditional `abort` at run-time. For example:

```
: checker abort" That flag was true" ." A false flag" ;⟨RET⟩  ok
0 checker⟨RET⟩ A false flag ok
1 checker⟨RET⟩
:1: That flag was true
1 checker
  ^^^^^^^
$400D1648 throw
$400E4660
```

These simple techniques allow a program to react to a fatal error condition, but they are not exactly user-friendly. The ANS Forth Exception word set provides the pair of words `throw` and `catch`, which can be used to provide sophisticated error-handling.

`catch` has a similar behaviour to `execute`, in that it takes an *xt* as a parameter and starts execution of the xt. However, before passing control to the xt, `catch` pushes an *exception frame* onto the *exception stack*. This exception frame is used to restore the system to a known state if a detected error occurs during the execution of the xt. A typical way to use `catch` would be:

```
... ['] foo catch IF ...
```

Whilst `foo` executes, it can call other words to any level of nesting, as usual. If `foo` (and all the words that it calls) execute successfully, control will ultimately pass to the word following the `catch`, and there will be a 0 at TOS. However, if any word detects an error, it can terminate the execution of `foo` by pushing a non-zero error code onto the stack and then performing a `throw`. The execution of `throw` will pass control to the word following the `catch`, but this time the TOS will hold the error code. Therefore, the `IF` in the example can be used to determine whether `foo` executed successfully.

This simple example shows how you can use `throw` and `catch` to "take over" exception handling from the system:

```
: my-div ['] / catch if ." DIVIDE ERROR" else ." OK.. " . then ;
```

The next example is more sophisticated and shows a multi-level `throw` and `catch`. To understand this example, start at the definition of `top-level` and work backwards:

```
: lowest-level ( -- c )
    key dup 27 = if
1 throw \ ESCAPE key pressed
    else
." lowest-level successfull" CR
    then
;
```

```
: lower-level ( -- c )
    lowest-level
    \ at this level consider a CTRL-U to be a fatal error
    dup 21 = if \ CTRL-U
2 throw
    else
." lower-level successfull" CR
    then
;

: low-level ( -- c )
    ['] lower-level catch
    ?dup if
\ error occurred - do we recognise it?
dup 1 = if
    \ ESCAPE key pressed.. pretend it was an E
    [char] E
else throw \ propogate the error upwards
then
    then
    ." low-level successfull" CR
;

: top-level ( -- )
    CR ['] low-level catch \ CATCH is used like EXECUTE
    ?dup if \ error occurred..
." Error " . ." occurred - contact your supplier"
    else
." The '" emit ." ' key was pressed" CR
    then
;
```

The ANS Forth document assigns `throw` codes thus:

- codes in the range -1 – -255 are reserved to be assigned by the Standard. Assignments for codes in the range -1 – -58 are currently documented in the Standard. In particular, `-1 throw` is equivalent to `abort` and `-2 throw` is equivalent to `abort"`.
- codes in the range -256 – -4095 are reserved to be assigned by the system.
- all other codes may be assigned by programs.

Gforth provides the word `exception` as a mechanism for assigning system throw codes to applications. This allows multiple applications to co-exist in memory without any clash of `throw` codes. A definition of `exception` in ANS Forth is provided in '`compat/exception.fs`'.

`quit` *?? – ??* core "quit"

Empty the return stack, make the user input device the input source, enter interpret state and start the text interpreter.

`abort` *?? – ??* core,exception-ext "abort"

Empty the data stack and perform the functions of `quit`. Since the exception word set is present, this is performed by `-1 throw`.

`abort"` *compilation 'ccc"' – ; run-time f –* core,exception-ext "abort-quote"

If any bit of *f* is non-zero, perform the function of `-2 throw`, displaying the string *ccc* if there is no exception frame on the exception stack.

`catch` *... xt – ... n* exception "catch"

`throw` *y1 .. ym error/0 – y1 .. ym / z1 .. zn error* exception "throw"

`exception` *addr u – n* gforth "exception"

n is a previously unused `throw` value in the range (-4095...-256). Consecutive calls to `exception` return consecutive decreasing numbers. Gforth uses the string *addr u* as an error message.

4.8 Defining Words

4.8.1 Simple Defining Words

Defining words are used to create new entries in the dictionary. The simplest defining word is `CREATE`. `CREATE` is used like this:

```
CREATE new-word1
```

`CREATE` is a parsing word that generates a dictionary entry for `new-word1`. When `new-word1` is executed, all that it does is leave an address on the stack. The address represents the value of the data space pointer (`HERE`) at the time that `new-word1` was defined. Therefore, `CREATE` is a way of associating a name with the address of a region of memory.

`Create` `"`*name*`"` – core "Create"

By extending this example to reserve some memory in data space, we end up with a *variable*. Here are two different ways to do it:

```
CREATE new-word2 1 cells allot  \ reserve 1 cell - initial value undefined
CREATE new-word3 4 ,            \ reserve 1 cell and initialise it (to 4)
```

The variable can be examined and modified using `@` ("fetch") and `!` ("store") like this:

```
new-word2 @ .       \ get address, fetch from it and display
1234 new-word2 !    \ new value, get address, store to it
```

As a final refinement, the whole code sequence can be wrapped up in a defining word (pre-empting the subject of the next section), making it easier to create new variables:

```
: myvariable ( "name" -- a-addr ) CREATE 0 , ;

myvariable foo
myvariable joe

45 3 * foo !    \ set foo to 135
1234 joe !      \ set joe to 1234
3 joe +!        \ increment joe by 3.. to 1237
```

Not surprisingly, there is no need to define `myvariable`, since Forth already has a definition `Variable`. It behaves in exactly the same way as `myvariable`. Forth also provides `2Variable` and `fvariable` for double and floating-point variables, respectively.

`Variable` "*name*" – core "Variable"
`2Variable` "*name*" – double "2Variable"
`fvariable` "*name*" – float "fvariable"

A similar mechanism can be used to create arrays. For example, an 80-character text input buffer:

```
CREATE text-buf 80 chars allot

text-buf 0 chars c@ \ the 1st character (offset 0)
text-buf 3 chars c@ \ the 4th character (offset 3)
```

You can build arbitrarily complex data structures by allocating appropriate areas of memory. See Section 4.20 [Structures], page 105 for further discussions of this, and to learn about some Gforth tools that make it easier.

The defining word `User` behaves in the same way as `Variable`. The difference is that it reserves space in *user (data) space* rather than normal data space. In a Forth system that has a multi-tasker, each task has its own set of user variables.

`User` "*name*" – gforth "User"

After `CREATE` and `Variable`s, the next defining word to consider is `Constant`. `Constant` allows you to declare a fixed value and refer to it by name. For example:

```
12 Constant INCHES-PER-FOOT
3E+08 fconstant SPEED-O-LIGHT
```

A `Variable` can be both read and written, so its run-time behaviour is to supply an address through which its current value can be manipulated. In contrast, the value of a `Constant` cannot be changed once it has been declared[6] so it's not necessary to supply the address – it is more efficient to return the value of the constant directly. That's exactly what happens; the run-time effect of a constant is to put its value on the top of the stack (Section 4.8.3 [User-defined Defining Words], page 56 describes one way of implementing `Constant`).

Gforth also provides `2Constant` and `fconstant` for defining double and floating-point constants, respectively.

`Constant` *w* "*name*" – core "Constant"

Define a constant *name* with value *w*.

name execution: – *w*

`2Constant` *w1 w2* "*name*" – double "2Constant"
`fconstant` *r* "*name*" – float "fconstant"

Constants in Forth behave differently from their equivalents in other programming languages. In other languages, a constant (such as an EQU in assembler or a #define in C) only exists at compile-time; in the executable program the constant has been translated into an absolute number and, unless you are using a symbolic debugger, it's impossible to know what abstract thing that number represents. In Forth a constant has an entry in the header space and remains there after the code that uses it has been defined. In fact, it must remain in the dictionary since it has run-time duties to perform. For example:

[6] Well, often it can be – but not in a Standard, portable way. It's safer to use a `Value` (read on).

```
12 Constant INCHES-PER-FOOT
: FEET-TO-INCHES ( n1 -- n2 ) INCHES-PER-FOOT * ;
```

When `FEET-TO-INCHES` is executed, it will in turn execute the xt associated with the constant `INCHES-PER-FOOT`. If you use `see` to decompile the definition of `FEET-TO-INCHES`, you can see that it makes a call to `INCHES-PER-FOOT`. Some Forth compilers attempt to optimise constants by in-lining them where they are used. You can force Gforth to in-line a constant like this:

```
: FEET-TO-INCHES ( n1 -- n2 ) [ INCHES-PER-FOOT ] LITERAL * ;
```

If you use `see` to decompile *this* version of `FEET-TO-INCHES`, you can see that `INCHES-PER-FOOT` is no longer present. See Section 4.9.3 [Interpret/Compile states], page 69 and Section 4.9.4 [Literals], page 70 on how this works.

In-lining constants in this way might improve execution time fractionally, and can ensure that a constant is now only referenced at compile-time. However, the definition of the constant still remains in the dictionary. Some Forth compilers provide a mechanism for controlling a second dictionary for holding transient words such that this second dictionary can be deleted later in order to recover memory space. However, there is no standard way of doing this.

One aspect of constants and variables that can sometimes be confusing is that they have different stack effects; one returns its value whilst the other returns the address of its value. The defining word `Value` provides an alternative to `Variable`, and has the same stack effect as a constant. A `Value` needs an additional word, `TO` to allow its value to be changed. Here are some examples:

```
12 Value APPLES \ a Value is initialised when it is declared.. like a
                \ constant but unlike a variable
34 TO APPLES    \ Change the value of APPLES. TO is a parsing word
APPLES          \ puts 34 on the top of the stack.
```

`Value` *w* "*name*" – core-ext “Value”

`TO` *w* "*name*" – core-ext “TO”

The defining word `Defer` allows you to define a word by name without defining its behaviour; the definition of its behaviour is deferred. Here are two situation where this can be useful:

- Where you want to allow the behaviour of a word to be altered later, and for all precompiled references to the word to change when its behaviour is changed.
- For mutual recursion; See Section 4.7.5 [Calls and returns], page 49.

In the following example, `foo` always invokes the version of `greet` that prints “`Good morning`” whilst `bar` always invokes the version that prints “`Hello`”. There is no way of getting `foo` to use the later version without re-ordering the source code and recompilng it.

```
: greet ." Good morning" ;
: foo ... greet ... ;
: greet ." Hello" ;
: bar ... greet ... ;
```

This problem can be solved by defining `greet` as a `Defer`red word. The behaviour of a `Defer`red word can be defined and redefined at any time by using `IS` to associate the xt of a previously-defined word with it. The previous example becomes:

```
Defer greet
: foo ... greet ... ;
: bar ... greet ... ;
: greet1 ." Good morning" ;
: greet2 ." Hello" ;
' greet2 <IS> greet  \ make greet behave like greet2
```

One thing to note is that `<IS>` consumes it's name when it is executed. If you want to specify the name at compile time, use `[IS]`:

```
: set-greet ( xt -- )
  [IS] greet ;

' greet1 set-greet
```

A deferred word can only inherit default semantics from the xt (because that is all that an xt can represent – see Section 4.10 [Tokens for Words], page 72 for more discussion of this). However, the semantics of the deferred word itself can be modified at the time that it is defined. For example:

```
: bar .... ; compile-only
Defer fred immediate
Defer jim

' bar <IS> jim  \ jim has default semantics
' bar <IS> fred \ fred is immediate
```

`Defer` "*name*" – gforth "Defer"

`<IS>` "*name*" *xt* – gforth "<IS>"

Changes the `defer`red word *name* to execute *xt*.

`[IS]` *compilation* "*name*" – *; run-time xt* – gforth "bracket-is"

At run-time, changes the `defer`red word *name* to execute *xt*.

`What's` "*name*" – *addr* gforth "What's"

`Defers` "*name*" – gforth "Defers"

Definitions in ANS Forth for `defer`, `<is>` and `[is]` are provided in '`compat/defer.fs`'.

The defining word `Alias` allows you to define a word by name that has the same behaviour as some other word. Here are two situation where this can be useful:

- When you want access to a word's definition from a different word list (for an example of this, see the definition of the `Root` word list in the Gforth source).
- When you want to create a synonym; a definition that can be known by either of two names (for example, `THEN` and `ENDIF` are aliases).

The word whose behaviour the alias is to inherit is represented by an xt. Therefore, the alias only inherits default semantics from its ancestor. The semantics of the alias itself can be modified at the time that it is defined. For example:

```
: foo ... ; immediate

' foo Alias bar \ bar is not an immediate word
' foo Alias fooby immediate \ fooby is an immediate word
```

Words that are aliases have the same xt, different headers in the dictionary, and consequently different name tokens (see Section 4.10 [Tokens for Words], page 72) and possibly different immediate flags. An alias can only have default or immediate compilation semantics; you can define aliases for combined words with `interpret/compile:`.

`Alias` *xt* "*name*" – gforth "Alias"

4.8.2 Colon Definitions

```
: name ( ... -- ... )
    word1 word2 word3 ;
```

Creates a word called `name` that, upon execution, executes `word1 word2 word3`. `name` is a *(colon) definition*.

The explanation above is somewhat superficial. See Section 3.3 [Your first definition], page 21 for simple examples of colon definitions, then See Section 4.8.5 [Interpretation and Compilation Semantics], page 61 for an in-depth discussion of some of the issues involved.

: "*name*" – *colon-sys* core "colon"

; *compilation colon-sys* – ; *run-time nest-sys* core "semicolon"

4.8.3 User-defined Defining Words

You can create a new defining word by wrapping defining-time code around an existing defining word and putting the sequence in a colon definition. For example, suppose that you have a word `stats` that gathers statistics about colon definitions given the *xt* of the definition, and you want every colon definition in your application to make a call to `stats`. You can define and use a new version of : like this:

```
: stats ( xt -- ) DUP ." (Gathering statistics for " . ." )"
  ... ;  \ other code

: my: : lastxt postpone literal ['] stats compile, ;

my: foo + - ;
```

When `foo` is defined using `my:` these steps occur:

- `my:` is executed.
- The : within the definition (the one between `my:` and `lastxt`) is executed, and does just what it always does; it parses the input stream for a name, builds a dictionary header for the name `foo` and switches `state` from interpret to compile.
- The word `lastxt` is executed. It puts the *xt* for the word that is being defined – `foo` – onto the stack.
- The code that was produced by `postpone literal` is executed; this causes the value on the stack to be compiled as a literal in the code area of `foo`.
- The code `['] stats` compiles a literal into the definition of `my:`. When `compile,` is executed, that literal – the execution token for `stats` – is layed down in the code area of `foo` , following the literal[7].

[7] Strictly speaking, the mechanism that `compile,` uses to convert an *xt* into something in the code area is implementation-dependent. A threaded implementation might spit

- At this point, the execution of `my:` is complete, and control returns to the text interpreter. The text interpreter is in compile state, so subsequent text `+ -` is compiled into the definition of `foo` and the `;` terminates the definition as always.

You can use `see` to decompile a word that was defined using `my:` and see how it is different from a normal `:` definition. For example:

```
: bar + - ;  \ like foo but using : rather than my:
see bar
: bar
  + - ;
see foo
: foo
  107645672 stats + - ;

\ use ' stats . to show that 107645672 is the xt for stats
```

Rather than edit your application's source code to change every `:` to a `my:`, use a deferred word:

```
: real: : ;      \ retain access to the original
defer :          \ redefine as a deferred word
' my: IS :       \ use special version of :
\
\ load application here
\
' real: IS :     \ go back to the original
```

You can use techniques like this to make new defining words in terms of *any* existing defining word.

If you want the words defined with your defining words to behave differently from words defined with standard defining words, you can write your defining word like this:

```
: def-word ( "name" -- )
    CREATE code1
DOES> ( ... -- ... )
    code2 ;

def-word name
```

This fragment defines a *defining word* `def-word` and then executes it. When `def-word` executes, it `CREATE`s a new word, `name`, and executes the code *code1*. The code *code2* is not executed at this time. The word `name` is sometimes called a *child* of `def-word`.

When you execute `name`, the address of the body of `name` is put on the data stack and *code2* is executed (the address of the body of `name` is the address `HERE` returns immediately after the `CREATE`).

You can use `def-word` to define a set of child words that behave differently, though atavistically; they all have a common run-time behaviour determined by *code2*. Typically, the *code1* sequence builds a data area in the body of the child word. The structure of the

---

out the execution token directly whilst another implementation might spit out a native code sequence.

data is common to all children of `def-word`, but the data values are specific – and private – to each child word. When a child word is executed, the address of its private data area is passed as a parameter on TOS to be used and manipulated[8] by *code2*.

The two fragments of code that make up the defining words act (are executed) at two completely separate times:

- At *define time*, the defining word executes *code1* to generate a child word
- At *child execution time*, when a child word is invoked, *code2* is executed, using parameters (data) that are private and specific to the child word.

In other words, if you make the following definitions:

```
: def-word1 ( "name" -- )
    CREATE code1 ;

: action1 ( ... -- ... )
    code2 ;

def-word1 name1
```

Using `name1 action1` is equivalent to using `name`.

The classic example is that you can define `CONSTANT` in this way:

```
: CONSTANT ( w "name" -- )
    CREATE ,
DOES> ( -- w )
    @ ;
```

When you create a constant with `5 CONSTANT five`, a set of define-time actions take place; first a new word `five` is created, then the value 5 is laid down in the body of `five` with `,`. When `five` is invoked, the address of the body is put on the stack, and `@` retrieves the value 5. The word `five` has no code of its own; it simply contains a data field and a pointer to the code that follows `DOES>` in its defining word. That makes words created in this way very compact.

The final example in this section is intended to remind you that space reserved in `CREATE`d words is *data* space and therefore can be both read and written by a Standard program[9]:

```
: foo ( "name" -- )
    CREATE -1 ,
DOES> ( -- )
    @ . ;

foo first-word
foo second-word

123 ' first-word >BODY !
```

If `first-word` had been a `CREATE`d word, we could simply have executed it to get the address of its data field. However, since it was defined to have `DOES>` actions, its execution

[8] It is legitimate both to read and write to this data area.

[9] Exercise: use this example as a starting point for your own implementation of `Value` and `TO` – if you get stuck, investigate the behaviour of `'` and `['']`.

semantics are to perform those DOES> actions. To get the address of its data field it's necessary to use ' to get its xt, then >BODY to translate the xt into the address of the data field. When you execute first-word, it will display 123. When you execute second-word it will display -1.

In the examples above the stack comment after the DOES> specifies the stack effect of the defined words, not the stack effect of the following code (the following code expects the address of the body on the top of stack, which is not reflected in the stack comment). This is the convention that I use and recommend (it clashes a bit with using locals declarations for stack effect specification, though).

4.8.3.1 Applications of CREATE..DOES>

You may wonder how to use this feature. Here are some usage patterns:

When you see a sequence of code occurring several times, and you can identify a meaning, you will factor it out as a colon definition. When you see similar colon definitions, you can factor them using CREATE..DOES>. E.g., an assembler usually defines several words that look very similar:

```
: ori, ( reg-target reg-source n -- )
    0 asm-reg-reg-imm ;
: andi, ( reg-target reg-source n -- )
    1 asm-reg-reg-imm ;
```

This could be factored with:

```
: reg-reg-imm ( op-code -- )
    CREATE ,
DOES> ( reg-target reg-source n -- )
    @ asm-reg-reg-imm ;

0 reg-reg-imm ori,
1 reg-reg-imm andi,
```

Another view of CREATE..DOES> is to consider it as a crude way to supply a part of the parameters for a word (known as *currying* in the functional language community). E.g., + needs two parameters. Creating versions of + with one parameter fixed can be done like this:

```
: curry+ ( n1 -- )
    CREATE ,
DOES> ( n2 -- n1+n2 )
    @ + ;

 3 curry+ 3+
-2 curry+ 2-
```

4.8.3.2 The gory details of CREATE..DOES>

DOES> *compilation colon-sys1 – colon-sys2 ; run-time nest-sys –* core "does"

This means that you need not use CREATE and DOES> in the same definition; you can put the DOES>-part in a separate definition. This allows us to, e.g., select among different DOES>-parts:

```
: does1
DOES> ( ... -- ... )
    ... ;

: does2
DOES> ( ... -- ... )
    ... ;

: def-word ( ... -- ... )
    create ...
    IF
       does1
    ELSE
       does2
    ENDIF ;
```

In this example, the selection of whether to use `does1` or `does2` is made at compile-time; at the time that the child word is `CREATE`d.

In a standard program you can apply a `DOES>`-part only if the last word was defined with `CREATE`. In Gforth, the `DOES>`-part will override the behaviour of the last word defined in any case. In a standard program, you can use `DOES>` only in a colon definition. In Gforth, you can also use it in interpretation state, in a kind of one-shot mode; for example:

```
CREATE name ( ... -- ... )
  initialization
DOES>
  code ;
```

is equivalent to the standard:

```
:noname
DOES>
    code ;
CREATE name EXECUTE ( ... -- ... )
    initialization
```

You can get the address of the body of a word with:

`>body` *xt – a-addr* core “to-body”

4.8.4 Supplying the name of a defined word

By default, a defining word takes the name for the defined word from the input stream. Sometimes you want to supply the name from a string. You can do this with:

`nextname` *c-addr u –* gforth “nextname”

The next defined word will have the name *c-addr u*; the defining word will leave the input stream alone.

For example:

```
s" foo" nextname create
```

is equivalent to:

```
create foo
```

Sometimes you want to define an *anonymous word*; a word without a name. You can do this with:

`:noname` – *xt colon-sys* core-ext "colon-no-name"

This leaves the execution token for the word on the stack after the closing `;`. Here's an example in which a deferred word is initialised with an `xt` from an anonymous colon definition:

```
Defer deferred
:noname ( ... -- ... )
  ... ;
IS deferred
```

Gforth provides an alternative way of doing this, using two separate words:

`noname` – gforth "noname"

The next defined word will be anonymous. The defining word will leave the input stream alone. The xt of the defined word will be given by `lastxt`.

`lastxt` – *xt* gforth "lastxt"

xt is the execution token of the last word defined.

The previous example can be rewritten using `noname` and `lastxt`:

```
Defer deferred
noname : ( ... -- ... )
  ... ;
lastxt IS deferred
```

`noname` and `nextname` work with any defining word, not just `:`.

`lastxt` also works when the last word was not defined as `noname`. It also has the useful property that is is valid as soon as the header for a definition has been build. Thus:

```
lastxt . : foo [ lastxt . ] ; ' foo .
```

prints 3 numbers; the last two are the same.

4.8.5 Interpretation and Compilation Semantics

The *interpretation semantics* of a word are what the text interpreter does when it encounters the word in interpret state. It also appears in some other contexts, e.g., the execution token returned by `'` *word* identifies the interpretation semantics of *word* (in other words, `'` *word* `execute` is equivalent to interpret-state text interpretation of *word*).

The *compilation semantics* of a word are what the text interpreter does when it encounters the word in compile state. It also appears in other contexts, e.g, `POSTPONE` *word* compiles[10] the compilation semantics of *word*.

The standard also talks about *execution semantics*. They are used only for defining the interpretation and compilation semantics of many words. By default, the interpretation

[10] In standard terminology, "appends to the current definition".

semantics of a word are to `execute` its execution semantics, and the compilation semantics of a word are to `compile,` its execution semantics.[11]

You can change the semantics of the most-recently defined word:

`immediate` – core "immediate"

Make the compilation semantics of a word be to `execute` the execution semantics.

`compile-only` – gforth "compile-only"

Remove the interpretation semantics of a word.

`restrict` – gforth "restrict"

A synonym for `compile-only`

Note that ticking (') a compile-only word gives an error ("Interpreting a compile-only word").

Gforth also allows you to define words with arbitrary combinations of interpretation and compilation semantics.

`interpret/compile:` *interp-xt comp-xt* `"`*name*`"` – gforth "interpret/compile:"

This feature was introduced for implementing `TO` and `S"`. I recommend that you do not define such words, as cute as they may be: they make it hard to get at both parts of the word in some contexts. E.g., assume you want to get an execution token for the compilation part. Instead, define two words, one that embodies the interpretation part, and one that embodies the compilation part. Once you have done that, you can define a combined word with `interpret/compile:` for the convenience of your users.

You might try to use this feature to provide an optimizing implementation of the default compilation semantics of a word. For example, by defining:

```
:noname
   foo bar ;
:noname
   POSTPONE foo POSTPONE bar ;
interpret/compile: opti-foobar
```

as an optimizing version of:

```
: foobar
    foo bar ;
```

Unfortunately, this does not work correctly with `[compile]`, because `[compile]` assumes that the compilation semantics of all `interpret/compile:` words are non-default. I.e., `[compile] opti-foobar` would compile compilation semantics, whereas `[compile] foobar` would compile interpretation semantics.

Some people try to use *state-smart* words to emulate the feature provided by `interpret/compile:` (words are state-smart if they check `STATE` during execution). E.g., they would try to code `foobar` like this:

[11] In standard terminology: The default interpretation semantics are its execution semantics; the default compilation semantics are to append its execution semantics to the execution semantics of the current definition.

```
: foobar
  STATE @
  IF ( compilation state )
    POSTPONE foo POSTPONE bar
  ELSE
    foo bar
  ENDIF ; immediate
```

Although this works if `foobar` is only processed by the text interpreter, it does not work in other contexts (like `'` or `POSTPONE`). E.g., `' foobar` will produce an execution token for a state-smart word, not for the interpretation semantics of the original `foobar`; when you execute this execution token (directly with `EXECUTE` or indirectly through `COMPILE,`) in compile state, the result will not be what you expected (i.e., it will not perform `foo bar`). State-smart words are a bad idea. Simply don't write them[12]!

It is also possible to write defining words that define words with arbitrary combinations of interpretation and compilation semantics. In general, they look like this:

```
: def-word
    create-interpret/compile
    code1
interpretation>
    code2
<interpretation
compilation>
    code3
<compilation ;
```

For a *word* defined with `def-word`, the interpretation semantics are to push the address of the body of *word* and perform *code2*, and the compilation semantics are to push the address of the body of *word* and perform *code3*. E.g., `constant` can also be defined like this (except that the defined constants don't behave correctly when `[compile]`d):

```
: constant ( n "name" -- )
    create-interpret/compile
    ,
interpretation> ( -- n )
    @
<interpretation
compilation> ( compilation. -- ; run-time. -- n )
    @ postpone literal
<compilation ;
```

`create-interpret/compile` "*name*" – gforth "create-interpret/compile"

`interpretation>` *compilation. – orig colon-sys* gforth "interpretation>"

`<interpretation` *compilation. orig colon-sys –* gforth "<interpretation"

`compilation>` *compilation. – orig colon-sys* gforth "compilation>"

[12] For a more detailed discussion of this topic, see `State`-*smartness – Why it is Evil and How to Exorcise it* by Anton Ertl; presented at EuroForth '98 and available from `http://www.complang.tuwien.ac.at/papers/ertl98.ps.gz`

`<compilation` *compilation. orig colon-sys* – gforth "<compilation"

Words defined with `interpret/compile:` and `create-interpret/compile` have an extended header structure that differs from other words; however, unless you try to access them with plain address arithmetic, you should not notice this. Words for accessing the header structure usually know how to deal with this; e.g., `'` *word* `>body` also gives you the body of a word created with `create-interpret/compile`.

`POSTPONE` `"`*name*`"` – core "POSTPONE"

Compiles the compilation semantics of *name*.

4.9 The Text Interpreter

The text interpreter[13] is an endless loop that processes input from the current input device. It is also called the outer interpreter, in contrast to the inner interpreter (see Chapter 12 [Engine], page 154) which executes the compiled Forth code on interpretive implementations.

The text interpreter operates in one of two states: *interpret state* and *compile state*. The current state is defined by the aptly-named variable, `state`.

This section starts by describing how the text interpreter behaves when it is in interpret state, processing input from the user input device – the keyboard. This is the mode that a Forth system is in after it starts up.

The text interpreter works from an area of memory called the *input buffer*[14], which stores your keyboard input when you press the ⟨RET⟩ key. Starting at the beginning of the input buffer, it skips leading spaces (called *delimiters*) then parses a string (a sequence of non-space characters) until it reaches either a space character or the end of the buffer. Having parsed a string, it makes two attempts to process it:

- It looks for the string in a *dictionary* of definitions. If the string is found, the string names a *definition* (also known as a *word*) and the dictionary search returns information that allows the text interpreter to perform the word's *interpretation semantics*. In most cases, this simply means that the word will be executed.
- If the string is not found in the dictionary, the text interpreter attempts to treat it as a number, using the rules described in Section 4.9.2 [Number Conversion], page 67. If the string represents a legal number in the current radix, the number is pushed onto a parameter stack (the data stack for integers, the floating-point stack for floating-point numbers).

If both attempts fail, or if the word is found in the dictionary but has no interpretation semantics[15] the text interpreter discards the remainder of the input buffer, issues an error message and waits for more input. If one of the attempts succeeds, the text interpreter

[13] This is an expanded version of the material in Section 3.1 [Introducing the Text Interpreter], page 16.

[14] When the text interpreter is processing input from the keyboard, this area of memory is called the *terminal input buffer* (TIB) and is addressed by the (obsolescent) words `TIB` and `#TIB`.

[15] This happens if the word was defined as `COMPILE-ONLY`.

repeats the parsing process until the whole of the input buffer has been processed, at which point it prints the status message " `ok`" and waits for more input.

The text interpreter keeps track of its position in the input buffer by updating a variable called `>IN` (pronounced "to-in"). The value of `>IN` starts out as 0, indicating an offset of 0 from the start of the input buffer. The region from offset `>IN @` to the end of the input buffer is called the *parse area*[16]. This example shows how `>IN` changes as the text interpreter parses the input buffer:

```
: remaining >IN @ SOURCE 2 PICK - -ROT + SWAP
  CR ." ->" TYPE ." <-" ; IMMEDIATE

1 2 3 remaining + remaining .

: foo 1 2 3 remaining SWAP remaining ;
```

The result is:

```
->+ remaining .<-
->.<-5  ok

->SWAP remaining ;-<
->;<-  ok
```

The value of `>IN` can also be modified by a word in the input buffer that is executed by the text interpreter. This means that a word can "trick" the text interpreter into either skipping a section of the input buffer[17] or into parsing a section twice. For example:

```
: lat ." <<lat>>" ;
: flat ." <<flat>>" >IN DUP @ 3 - SWAP ! ;
```

When `flat` is executed, this output is produced[18]:

```
<<flat>><<lat>>
```

Two important notes about the behaviour of the text interpreter:

- It processes each input string to completion before parsing additional characters from the input buffer.
- It treats the input buffer as a read-only region (and so must your code).

When the text interpreter is in compile state, its behaviour changes in these ways:

- If a parsed string is found in the dictionary, the text interpreter will perform the word's *compilation semantics*. In most cases, this simply means that the execution semantics of the word will be appended to the current definition.
- When a number is encountered, it is compiled into the current definition (as a literal) rather than being pushed onto a parameter stack.
- If an error occurs, `state` is modified to put the text interpreter back into interpret state.

---

[16] In other words, the text interpreter processes the contents of the input buffer by parsing strings from the parse area until the parse area is empty.

[17] This is how parsing words work.

[18] Exercise for the reader: what would happen if the `3` were replaced with `4`?

- Each time a line is entered from the keyboard, Gforth prints " `compiled`" rather than " `ok`".

When the text interpreter is using an input device other than the keyboard, its behaviour changes in these ways:

- When the parse area is empty, the text interpreter attempts to refill the input buffer from the input source. When the input source is exhausted, the input source is set back to the user input device.
- It doesn't print out " `ok`" or " `compiled`" messages each time the parse area is emptied.
- If an error occurs, the input source is set back to the user input device.

Section 4.9.1 [Input Sources], page 66 describes this in more detail.

`>in` – *a-addr* core ">in"

USER VARIABLE: *a-addr* is the address of a cell containing the char offset from the start of the input buffer to the start of the parse area.

`source` – *c-addr u* core "source"

c-addr is the address of the input buffer and *u* is the number of characters in it.

`tib` – *c-addr* core-ext "tib"

c-addr is the address of the Terminal Input Buffer. OBSOLESCENT: `source` superceeds the function of this word.

`#tib` – *a-addr* core-ext "#tib"

USER VARIABLE: *a-addr* is the address of a cell containing the number of characters in the terminal input buffer. OBSOLESCENT: `source` superceeds the function of this word.

4.9.1 Input Sources

By default, the text interpreter accepts input from the user input device (the keyboard) when Forth starts up. The text interpreter can process input from any of these sources:

- The user input device – the keyboard.
- A file, using the words described in Section 4.13.1 [Forth source files], page 78.
- A block, using the words described in Section 4.14 [Blocks], page 81.
- A text string, using `evaluate`.

A program can identify the current input device from the values of `source-id` and `blk`.

`source-id` – *0 | -1 | fileid* core-ext,file "source-i-d"

Return 0 (the input source is the user input device), -1 (the input source is a string being processed by `evaluate`) or a *fileid* (the input source is the file specified by *fileid*).

`blk` – *a-addr* block "blk"

USER VARIABLE: *a-addr* is the address of a cell containing zero (in which case the input source is not a block and can be identified by `source-id`) or the number of the block currently being interpreted. A Standard program should not alter `blk` directly.

`save-input` – *xn .. x1 n* core-ext "save-input"

The *n* entries *xn - x1* describe the current state of the input source specification, in some platform-dependent way that can be used by `restore-input`.

`restore-input` *xn .. x1 n – flag* core-ext "restore-input"

Attempt to restore the input source specification to the state described by the *n* entries *xn - x1*. *flag* is true if the restore fails. In Gforth it fails pretty often (and sometimes with a `throw`).

`evaluate` *c-addr u –* core,block "evaluate"

Save the current input source specification. Store -1 in `source-id` and 0 in `blk`. Set `>IN` to 0 and make the string *c-addr u* the input source and input buffer. Interpret. When the parse area is empty, restore the input source specification.

4.9.2 Number Conversion

This section describes the rules that the text interpreter uses when it tries to convert a string into a number.

Let <digit> represent any character that is a legal digit in the current number base[19].

Let <decimal digit> represent any character in the range 0-9.

Let {*a b*} represent the *optional* presence of any of the characters in the braces (*a* or *b* or neither).

Let * represent any number of instances of the previous character (including none).

Let any other character represent itself.

Now, the conversion rules are:

- A string of the form <digit><digit>* is treated as a single-precision (cell-sized) positive integer. Examples are 0 123 6784532 32343212343456 42
- A string of the form -<digit><digit>* is treated as a single-precision (cell-sized) negative integer, and is represented using 2's-complement arithmetic. Examples are -45 -5681 -0
- A string of the form <digit><digit>*.<digit>* is treated as a double-precision (double-cell-sized) positive integer. Examples are 3465. 3.465 34.65 (all three of these represent the same number).
- A string of the form -<digit><digit>*.<digit>* is treated as a double-precision (double-cell-sized) negative integer, and is represented using 2's-complement arithmetic. Examples are -3465. -3.465 -34.65 (all three of these represent the same number).
- A string of the form {+ -}<decimal digit>{.}<decimal digit>*{e E}{+ -}<decimal digit><decimal digit>* is treated as a floating-point number. Examples are 1e 1e0 1.e 1.e0 +1e+0 (which all represent the same number) +12.E-4

By default, the number base used for integer number conversion is given by the contents of the variable `base`. Note that a lot of confusion can result from unexpected values of `base`. If you change `base` anywhere, make sure to save the old value and restore it afterwards. In general I recommend keeping `base` decimal, and using the prefixes described below for the popular non-decimal bases.

[19] For example, 0-9 when the number base is decimal or 0-9, A-F when the number base is hexadecimal.

`dpl` – *a-addr* gforth "dpl"

USER VARIABLE: *a-addr* is the address of a cell that stores the position of the decimal point in the most recent numeric conversion. Initialised to -1. After the conversion of a number containing no decimal point, `dpl` is -1. After the conversion of `2.` it holds 0. After the conversion of 234123.9 it contains 1, and so forth.

`base` – *a-addr* core "base"

USER VARIABLE: *a-addr* is the address of a cell that stores the number base used by default for number conversion during input and output.

`hex` – core-ext "hex"

Set the numeric conversion radix (the value of `BASE`) to 16 (hexadecimal).

`decimal` – core "decimal"

Set the numeric conversion radix (the value of `BASE`) to 10 (decimal).

Gforth allows you to override the value of `base` by using a prefix[20] before the first digit of an (integer) number. Four prefixes are supported:

- `&` – decimal
- `%` – binary
- `$` – hexadecimal
- `'` – base `max-char+1`

Here are some examples, with the equivalent decimal number shown after in braces:

-$41 (-65), %1001101 (205), %1001.0001 (145 - a double-precision number), 'AB (16706; ascii A is 65, ascii B is 66, number is 65*256 + 66), 'ab (24930; ascii a is 97, ascii B is 98, number is 97*256 + 98), &905 (905), $abc (2478), $ABC (2478).

Number conversion has a number of traps for the unwary:

- You cannot determine the current number base using the code sequence `base @ .` – the number base is always 10 in the current number base. Instead, use something like `base @ dec.`
- If the number base is set to a value greater than 14 (for example, hexadecimal), the number 123E4 is ambiguous; the conversion rules allow it to be intepreted as either a single-precision integer or a floating-point number (Gforth treats it as an integer). The ambiguity can be resolved by explicitly stating the sign of the mantissa and/or exponent: 123E+4 or +123E4 – if the number base is decimal, no ambiguity arises; either representation will be treated as a floating-point number.
- There is a word `bin` but it does *not* set the number base! It is used to specify file types.
- ANS Forth requires the `.` of a double-precision number to be the final character in the string. Allowing the `.` to be anywhere after the first digit is a Gforth extension.
- The number conversion process does not check for overflow.

[20] Some Forth implementations provide a similar scheme by implementing `$` etc. as parsing words that process the subsequent number in the input stream and push it onto the stack. For example, see *Number Conversion and Literals*, by Wil Baden; Forth Dimensions 20(3) pages 26–27. In such implementations, unlike in Gforth, a space is required between the prefix and the number.

- In Gforth, number conversion to floating-point numbers always use base 10, irrespective of the value of `base`. In ANS Forth, conversion to floating-point numbers whilst the value of `base` is not 10 is an ambiguous condition.

Section 4.15.5 [Input], page 89 describes words that you can use to read numbers into your programs.

4.9.3 Interpret/Compile states

A standard program is not permitted to change `state` explicitly. However, it can change `state` implicitly, using the words `[` and `]`. When `[` is executed it switches `state` to interpret state, and therefore the text interpreter starts interpreting. When `]` is executed it switches `state` to compile state and therefore the text interpreter starts compiling. The most common usage for these words is to compile literals, as shown in Section 4.9.4 [Literals], page 70. However, they give you the freedom to switch modes at will.

Here is an example of building a jump-table of execution tokens:

```
: AA ." this is A" ;
: BB ." this is B" ;
: CC ." this is C" ;

create table ' aa COMPILE, ' bb COMPILE, ' cc COMPILE,
: go ( n -- ) \ n is offset into table.. 0 for 1st entry
  cells table +  execute ;
```

Now `0 go` will display "`this is A`". The table can be built far more neatly[21] like this:

```
create table ] aa bb cc [
```

The problem with this code is that it is not portable; it will only work on systems where code space and data space co-incide. The reason is that both tables *compile* execution tokens – into code space. The Standard only allows data space to be assigned for a `CREATE`d word. In addition, the Standard only allows `@` to access data space, whilst this example is using it to access code space. The only portable, Standard way to build this table is to build it in data space, like this:

```
create table ' aa , ' bb , ' cc ,
```

A similar technique can be used to build a table of constants:

```
create primes 1 , 3 , 5 , 7 , 11 ,
```

`state` – *a-addr* core,tools-ext "state"

USER VARIABLE: *a-addr* is the address of a cell containing the compilation state flag. 0 => interpreting, -1 => compiling. A program shall not directly alter the value of `state`. The following Standard words alter the value in `state`: `:` (colon) `;` (semicolon) `abort quit :noname [` (left-bracket) `]` (right-bracket) `;code`. Don't use `state`! See Section 4.8.5 [Interpretation and Compilation Semantics], page 61 for an alternative.

`[` – core "left-bracket"

Enter interpretation state. Immediate word.

`]` – core "right-bracket"

Enter compilation state.

[21] The source code is neater.. what is compiled in memory in each case is identical.

4.9.4 Literals

Often, you want to use a number within a colon definition. When you do this, the text interpreter automatically compiles the number as a *literal*. A literal is a number whose run-time effect is to be pushed onto the stack. If you had to do some maths to generate the number, you might write it like this:

```
: HOUR-TO-SEC ( n1 -- n2 )
  60 *      \ to minutes
  60 * ;    \ to seconds
```

It is very clear what this definition is doing, but it's inefficient since it is performing 2 multiples at run-time. An alternative would be to write:

```
: HOUR-TO-SEC ( n1 -- n2 )
  3600 * ;  \ to seconds
```

Which does the same thing, and has the advantage of using a single multiply. Ideally, we'd like the efficiency of the second with the readability of the first.

`Literal` allows us to achieve that. It takes a number from the stack and lays it down in the current definition just as though the number had been typed directly into the definition. Our first attempt might look like this:

```
60          \ mins per hour
60 *        \ seconds per minute
: HOUR-TO-SEC ( n1 -- n2 )
  Literal * ;  \ to seconds
```

But this produces the error message `unstructured`. What happened? The stack notation for : is (– *colon-sys*) and the size of *colon-sys* is implementation-defined. In other words, once we start a colon definition we can't portably access anything that was on the stack before the definition began[22]. The correct way of solving this problem in this instance is to use `[ ]` like this:

```
: HOUR-TO-SEC ( n1 -- n2 )
  [ 60          \ minutes per hour
    60 * ]      \ seconds per minute
  LITERAL * ;   \ to seconds
```

`Literal` *compilation n – ; run-time – n* core "Literal"

Compile appropriate code such that, at run-time, *n* is placed on the stack. Interpretation semantics are undefined.

`]L` *compilation: n – ; run-time: – n* gforth "]L"

equivalent to `] literal`

`2Literal` *compilation w1 w2 – ; run-time – w1 w2* double "two-literal"

Compile appropriate code such that, at run-time, cell pair *w1, w2* are placed on the stack. Interpretation semantics are undefined.

[22] *Two Problems in ANS Forth*, by Thomas Worthington; Forth Dimensions 20(2) pages 32–34 describes some situations where you might want to access stack items above colon-sys, and provides a solution to the problem.

`FLiteral` *compilation r – ; run-time – r* float "FLiteral"

Compile appropriate code such that, at run-time, *r* is placed on the (floating-point) stack. Interpretation semantics are undefined.

4.9.5 Interpreter Directives

These words are usually used in interpret state; typically to control which parts of a source file are processed by the text interpreter. There are only a few ANS Forth Standard words, but Gforth supplements these with a rich set of immediate control structure words to compensate for the fact that the non-immediate versions can only be used in compile state (see Section 4.7 [Control Structures], page 43). Typical usages:

```
FALSE Constant ASSEMBLER
.
.
ASSEMBLER [IF]
: ASSEMBLER-FEATURE
  ...
;
[ENDIF]
.
.
: SEE
  ... \ general-purpose SEE code
  [ ASSEMBLER [IF] ]
  ... \ assembler-specific SEE code
  [ [ENDIF] ]
;
```

`[IF]` *flag* | *flag* "<*spaces*>*name ...*" – tools-ext "bracket-if"

If flag is `TRUE` do nothing (and therefore execute subsequent words as normal). If flag is `FALSE`, parse and discard words from the parse area (refilling it if necessary using `REFILL`) including nested instances of `[IF]`.. `[ELSE]`.. `[THEN]` and `[IF]`.. `[THEN]` until the balancing `[ELSE]` or `[THEN]` has been parsed and discarded. Immediate word.

`[ELSE]` "<*spaces*>*name ...*" – tools-ext "bracket-else"

Parse and discard words from the parse area (refilling it if necessary using `REFILL`) including nested instances of `[IF]`.. `[ELSE]`.. `[THEN]` and `[IF]`.. `[THEN]` until the balancing `[THEN]` has been parsed and discarded. `[ELSE]` only gets executed if the balancing `[IF]` was `TRUE`; if it was `FALSE`, `[IF]` would have parsed and discarded the `[ELSE]`, leaving the subsequent words to be executed as normal. Immediate word.

`[THEN]` – tools-ext "bracket-then"

Do nothing; used as a marker for other words to parse and discard up to. Immediate word.

`[ENDIF]` – gforth "bracket-end-if"

Do nothing; synonym for `[THEN]`

`[IFDEF]` "<*spaces*>*name*" – gforth "bracket-if-def"

If name is found in the current search-order, behave like `[IF]` with a `TRUE` flag, otherwise behave like `[IF]` with a `FALSE` flag. Immediate word.

`[IFUNDEF]` `"<spaces>name"` – gforth "bracket-if-un-def"

If name is not found in the current search-order, behave like `[IF]` with a `TRUE` flag, otherwise behave like `[IF]` with a `FALSE` flag. Immediate word.

`[?DO]` *n-limit n-index* – gforth "bracket-question-do"

`[DO]` *n-limit n-index* – gforth "bracket-do"

`[FOR]` *n* – gforth "bracket-for"

`[LOOP]` – gforth "bracket-loop"

`[+LOOP]` *n* – gforth "bracket-question-plus-loop"

`[NEXT]` *n* – gforth "bracket-next"

`[BEGIN]` – gforth "bracket-begin"

`[UNTIL]` *flag* – gforth "bracket-until"

`[AGAIN]` – gforth "bracket-again"

`[WHILE]` *flag* – gforth "bracket-while"

`[REPEAT]` – gforth "bracket-repeat"

4.10 Tokens for Words

This section describes the creation and use of tokens that represent words.

Named words have information stored in their header space entries to indicate any non-default semantics (see Section 4.8.5 [Interpretation and Compilation Semantics], page 61). The semantics can be modified, using `immediate` and/or `compile-only`, at the time that the words are defined. Unnamed words have (by definition) no header space entry, and therefore must have default semantics.

Named words have interpretation and compilation semantics. Unnamed words just have execution semantics.

The execution semantics of an unnamed word are represented by an *execution token* (*xt*). As explained in Section 4.8.4 [Supplying names], page 60, the execution token of the last word defined can be produced with `lastxt`.

The interpretation semantics of a named word are also represented by an execution token. You can produce the execution token using `'` or `[']`. A simple example shows the difference between the two:

```
: greet ( -- )   ." Hello" ;
: foo ( -- xt )  ['] greet execute ; \ ['] parses greet at compile-time
: bar ( -- )     ' execute ; \  '  parses at run-time

\ the next four lines all do the same thing
foo
bar greet
greet
' greet EXECUTE
```

An execution token occupies one cell. In Gforth, the abstract data type *execution token* is implemented as a code field address (CFA).

For literals, use ' in interpreted code and ['] in compiled code. Gforth's ' and ['] behave somewhat unusually by complaining about compile-only words. To get the execution token for a compile-only word *name*, use COMP' *name* DROP or [COMP'] *name* DROP.

The compilation semantics of a named word are represented by a *compilation token* consisting of two cells: *w xt*. The top cell *xt* is an execution token. The compilation semantics represented by the compilation token can be performed with execute, which consumes the whole compilation token, with an additional stack effect determined by the represented compilation semantics.

At present, the *w* part of a compilation token is an execution token, and the *xt* part represents either execute or compile,[23]. However, don't rely on that knowledge, unless necessary; future versions of Gforth may introduce unusual compilation tokens (e.g., a compilation token that represents the compilation semantics of a literal).

You can compile the compilation semantics with postpone,. I.e., COMP' *word* postpone, is equivalent to postpone *word*.

Named words are also represented by the *name token*, (*nt*). In Gforth, the abstract data type *name token* is implemented as a name field address (NFA).

execute *xt* – core "execute"

Perform the semantics represented by the execution token, *xt*.

compile, *xt* – core-ext "compile-comma"

Compile the word represented by the execution token, *xt*, into the current definition.

['] *compilation.* "*name*" *– ; run-time. – xt* core "bracket-tick"

xt represents *name*'s interpretation semantics. Perform -14 throw if the word has no interpretation semantics.

' "*name*" *– xt* core "tick"

xt represents *name*'s interpretation semantics. Perform -14 throw if the word has no interpretation semantics.

[COMP'] *compilation* "*name*" *– ; run-time – w xt* gforth "bracket-comp-tick"

Compilation token *w xt* represents *name*'s compilation semantics.

COMP' "*name*" *– w xt* gforth "comp-tick"

Compilation token *w xt* represents *name*'s compilation semantics.

postpone, *w xt* – gforth "postpone-comma"

Compile the compilation semantics represented by *w xt*.

find-name *c-addr u – nt | 0* gforth "find-name"

Find the name *c-addr u* in the current search order. Return its *nt*, if found, otherwise 0.

name>int *nt – xt* gforth "name>int"

xt represents the interpretation semantics of the word *nt*. If *nt* has no interpretation semantics (i.e. is compile-only), *xt* is the execution token for compile-only-error, which performs -14 throw.

[23] Depending upon the compilation semantics of the word. If the word has default compilation semantics, the *xt* will represent compile,. Otherwise (e.g., for immediate words), the *xt* will represent execute.

`name?int` *nt – xt* gforth "name?int"

Like `name>int`, but perform `-14 throw` if *nt* has no interpretation semantics.

`name>comp` *nt – w xt* gforth "name>comp"

w xt is the compilation token for the word *nt*.

`name>string` *nt – addr count* gforth "head-to-string"

addr count is the name of the word represented by *nt*.

4.11 Word Lists

A wordlist is a list of named words; you can add new words and look up words by name (and you can remove words in a restricted way with markers). Every named (and `revealed`) word is in one wordlist.

The text interpreter searches the wordlists present in the search order (a stack of wordlists), from the top to the bottom. Within each wordlist, the search starts conceptually at the newest word; i.e., if two words in a wordlist have the same name, the newer word is found.

New words are added to the *compilation wordlist* (aka current wordlist).

A word list is identified by a cell-sized word list identifier (*wid*) in much the same way as a file is identified by a file handle. The numerical value of the wid has no (portable) meaning, and might change from session to session.

The ANS Forth "Search order" word set is intended to provide a set of low-level tools that allow various different schemes to be implemented. Gforth provides `vocabulary`, a traditional Forth word. '`compat/vocabulary.fs`' provides an implementation in ANS Standard Forth.

`forth-wordlist` *– wid* search "forth-wordlist"

CONSTANT: *wid* identifies the word list that includes all of the standard words provided by Gforth. When Gforth is invoked, this word list is the compilation word list and is at the top of the word list stack.

`definitions` – search "definitions"

Make the compilation word list the same as the word list that is currently at the top of the search order stack.

`get-current` *– wid* search "get-current"

wid is the identifier of the current compilation word list.

`set-current` *wid –* search "set-current"

Set the compilation word list to the word list identified by *wid*.

`get-order` *– widn .. wid1 n* search "get-order"

Copy the search order stack to the data stack. The current search order has *n* entries, of which *wid1* represents the word list that is searched first (the word list at the top of the stack) and *widn* represents the word order that is searched last.

`set-order` *widn .. wid1 n –* search "set-order"

If *n*=0, empty the search order. If *n*=-1, set the search order to the implementation-defined minimum search order (for Gforth, this is the word list `Root`). Otherwise, replace

the existing search order with the *n* wid entries such that *wid1* represents the word list that will be searched first and *widn* represents the word list that will be searched last.

`wordlist` – *wid* search "wordlist"

Create a new, empty word list represented by *wid*.

`table` – *wid* unknown "table"

create a case-sensitive wordlist

`push-order` *wid* – gforth "push-order"

Push *wid* on the search order.

`previous` – search "ext"

Perform a `DROP` on the search order stack, thereby removing the wid at the top of the (search order) stack from the search order.

`also` – search "ext"

Perform a `DUP` on the search order stack. Usually used prior to `Forth`, `definitions` etc.

`Forth` – search-ext "Forth"

Push the *wid* associated with `forth-wordlist` onto the search order stack.

`Only` – search-ext "Only"

Set the search order to the implementation-defined minimum search order (for Gforth, this is the word list `Root`).

`order` – search-ext "order"

Print the search order and the compilation word list. The word lists are printed in the order in which they are searched (which is reversed with respect to the conventional way of displaying stacks). The compilation word list is displayed last.

`find` *c-addr* – *xt* `+-1` | *c-addr 0* core,search "find"

Search all word lists in the current search order for the definition named by the counted string at *c-addr*. If the definition is not found, return 0. If the definition is found return 1 (if the definition is immediate) or -1 (if the definition is not immediate) together with the *xt*.

`search-wordlist` *c-addr count wid* – *0* | *xt* `+-1` search "search-wordlist"

Search the word list identified by *wid* for the definition named by the string at *c-addr count*. If the definition is not found, return 0. If the definition is found return 1 (if the definition is immediate) or -1 (if the definition is not immediate) together with the *xt*. The *xt* returned represents the interpretation semantics.

`words` – tools "words"

Display a list of all of the definitions in the word list at the top of the search order.

`vlist` – gforth "vlist"

Old (pre-Forth-83) name for `WORDS`.

`mappedwordlist` *map-struct* – *wid* gforth "mappedwordlist"

Create a wordlist with a special map-structure.

`Root` – gforth "Root"

Add the vocabulary `Root` to the search order stack. This vocabulary makes up the minimum search order and contains these words: `order` `set-order` `forth-wordlist` `Forth` `words`

`Vocabulary` "*name*" – gforth "Vocabulary"

Create a definition "name" and associate a new word list with it. The run-time effect of "name" is to push the new word list's wid onto the top of the search order stack.

`seal` – gforth "seal"

Remove all word lists from the search order stack other than the word list that is currently on the top of the search order stack.

`vocs` – gforth "vocs"

List vocabularies and wordlists defined in the system.

`current` – *addr* gforth "current"

VARIABLE: holds the wid of the current compilation word list.

`context` – *addr* gforth "context"

VALUE: `context @` is the wid of the word list at the top of the search order stack.

4.11.1 Why use word lists?

Here are some reasons for using multiple word lists:

- To improve compilation speed by reducing the number of header space entries that must be searched. This is achieved by creating a new word list that contains all of the definitions that are used in the definition of a Forth system but which would not usually be used by programs running on that system. That word list would be on the search list when the Forth system was compiled but would be removed from the search list for normal operation. This can be a useful technique for low-performance systems (for example, 8-bit processors in embedded systems) but is unlikely to be necessary in high-performance desktop systems.
- To prevent a set of words from being used outside the context in which they are valid. Two classic examples of this are an integrated editor (all of the edit commands are defined in a separate word list; the search order is set to the editor word list when the editor is invoked; the old search order is restored when the editor is terminated) and an integrated assembler (the op-codes for the machine are defined in a separate word list which is used when a `CODE` word is defined).
- To prevent a name-space clash between multiple definitions with the same name. For example, when building a cross-compiler you might have a word `IF` that generates conditional code for your target system. By placing this definition in a different word list you can control whether the host system's `IF` or the target system's `IF` get used in any particular context by controlling the order of the word lists on the search order stack.

4.11.2 Word list examples

Here is an example of creating and using a new wordlist using ANS Forth Standard words:

```
wordlist constant my-new-words-wordlist
: my-new-words get-order nip my-new-words-wordlist swap set-order ;
```

```
\ add it to the search order
also my-new-words

\ alternatively, add it to the search order and make it
\ the compilation word list
also my-new-words definitions
\ type "order" to see the problem
```

The problem with this example is that `order` has no way to associate the name `my-new-words` with the wid of the word list (in Gforth, `order` and `vocs` will display `???` for a wid that has no associated name). There is no Standard way of associating a name with a wid.

In Gforth, this example can be re-coded using `vocabulary`, which associates a name with a wid:

```
vocabulary my-new-words

\ add it to the search order
my-new-words

\ alternatively, add it to the search order and make it
\ the compilation word list
my-new-words definitions
\ type "order" to see that the problem is solved
```

4.12 Environmental Queries

ANS Forth introduced the idea of "environmental queries" as a way for a program running on a system to determine certain characteristics of the system. The Standard specifies a number of strings that might be recognised by a system.

The Standard requires that the header space used for environmental queries be distinct from the header space used for definitions.

Typically, environmental queries are supported by creating a set of definitions in a word list that is *only* used during environmental queries; that is what Gforth does. There is no Standard way of adding definitions to the set of recognised environmental queries, but any implementation that supports the loading of optional word sets must have some mechanism for doing this (after loading the word set, the associated environmental query string must return `true`). In Gforth, the word list used to honour environmental queries can be manipulated just like any other word list.

`environment?` *c-addr u – false / ... true* core "environment-query"

c-addr, u specify the address and length of a string. If the string is not recognised, return a `false` flag. Otherwise return a true flag and some (string-specific) information about the queried string.

`environment-wordlist` *– wid* gforth "environment-wordlist"

wid identifies the word list that is searched by environmental queries.

`gforth` *– c-addr u* gforth-environment "gforth"

Counted string representing a version string for this version of Gforth (for versions>0.3.0).

`os-class` – *c-addr u* gforth-environment "os-class"

Counted string representing a description of the host operating system.

Note that, whilst the documentation for (e.g.) `gforth` shows it returning two items on the stack, querying it using `environment?` will return an additional item; the `true` flag that shows that the string was recognised.

Here are some examples of using environmental queries:

```
s" address-unit-bits" environment? 0=
[IF]
     cr .( environmental attribute address-units-bits unknown... ) cr
[THEN]

s" block" environment? [IF] DROP include block.fs [THEN]

s" gforth" environment? [IF] 2DROP include compat/vocabulary.fs [THEN]

s" gforth" environment? [IF] .( Gforth version ) TYPE
                        [ELSE] .( Not Gforth..) [THEN]
```

Here is an example of adding a definition to the environment word list:

```
get-current environment-wordlist set-current
true constant block
true constant block-ext
set-current
```

You can see what definitions are in the environment word list like this:

```
get-order 1+ environment-wordlist swap set-order words previous
```

4.13 Files

Gforth provides facilities for accessing files that are stored in the host operating system's file-system. Files that are processed by Gforth can be divided into two categories:

- Files that are processed by the Text Interpreter (*Forth source files*).
- Files that are processed by some other program (*general files*).

4.13.1 Forth source files

The simplest way to interpret the contents of a file is to use one of these two formats:

```
include mysource.fs
s" mysource.fs" included
```

Sometimes you want to include a file only if it is not included already (by, say, another source file). In that case, you can use one of these fomats:

```
require mysource.fs
needs mysource.fs
s" mysource.fs" required
```

I recommend that you write your source files such that interpreting them does not change the stack. This allows using these files with `required` and friends without complications. For example:

```
1 require foo.fs drop
```

`include-file` *i*x wfileid – j*x* file "include-file"

Interpret (process using the text interpreter) the contents of the file *wfileid*.

`included` *i*x c-addr u – j*x* file "included"

`include-file` the file whose name is given by the string *c-addr u*.

`included?` *c-addr u – f* gforth "included?"

True only if the file *c-addr u* is in the list of earlier included files. If the file has been loaded, it may have been specified as, say, foo.fs and found somewhere on the Forth search path. To return true from `included?`, you must specify the exact path to the file, even if that is `./foo.fs`

`include` ... "*file*" – ... gforth "include"

`include-file` the file *file*.

`required` *i*x addr u – j*x* gforth "required"

`include-file` the file with the name given by *addr u*, if it is not `included` (or `required`) already. Currently this works by comparing the name of the file (with path) against the names of earlier included files.

`require` ... "*file*" – ... gforth "require"

`include-file` *file* only if it is not included already.

`needs` ... "*name*" – ... gforth "needs"

An alias for `require`; exists on other systems (e.g., Win32Forth).

`init-included-files` – gforth "init-included-files"

Clear the list of earlier included files.

A definition in ANS Forth for `required` is provided in '`compat/required.fs`'.

4.13.2 General files

Files are opened/created by name and type. The following types are recognised:

`r/o` – *ntype* file "r-o"

`r/w` – *ntype* file "r-w"

`w/o` – *ntype* file "w-o"

`bin` *ntype1 – ntype2* file "bin"

When a file is opened/created, it returns a file identifier, *wfileid* that is used for all other file commands. All file commands also return a status value, *wior*, that is 0 for a successful operation and an implementation-defined non-zero value in the case of an error.

`open-file` *c-addr u ntype – wfileid wior* file "open-file"

`create-file` *c-addr u ntype – wfileid wior* file "create-file"

`close-file` *wfileid – wior* file "close-file"

`delete-file` *c-addr u – wior* file "delete-file"

`rename-file` *c-addr1 u1 c-addr2 u2 – wior* file-ext "rename-file"

Rename file *c_addr1 u1* to new name *c_addr2 u2*

`read-file` *c-addr u1 wfileid – u2 wior* file "read-file"

`read-line` *c-addr u1 wfileid – u2 flag wior* file “read-line”
`write-file` *c-addr u1 wfileid – wior* file “write-file”
`write-line` *c-addr u fileid – ior* file “write-line”
`emit-file` *c wfileid – wior* gforth “emit-file”
`flush-file` *wfileid – wior* file-ext “flush-file”
`file-status` *c-addr u – ntype wior* file-ext “file-status”
`file-position` *wfileid – ud wior* file “file-position”
`reposition-file` *ud wfileid – wior* file “reposition-file”
`file-size` *wfileid – ud wior* file “file-size”
`resize-file` *ud wfileid – wior* file “resize-file”

4.13.3 Search Paths

If you specify an absolute filename (i.e., a filename starting with ‘`/`’ or ‘`~`’, or with ‘`:`’ in the second position (as in ‘`C:...`’)) for `included` and friends, that file is included just as you would expect.

For relative filenames, Gforth uses a search path similar to Forth’s search order (see Section 4.11 [Word Lists], page 74). It tries to find the given filename in the directories present in the path, and includes the first one it finds. There are separate search paths for Forth source files and general files.

If the search path contains the directory ‘`.`’ (as it should), this refers to the directory that the present file was `included` from. This allows files to include other files relative to their own position (irrespective of the current working directory or the absolute position). This feature is essential for libraries consisting of several files, where a file may include other files from the library. It corresponds to `#include "..."` in C. If the current input source is not a file, ‘`.`’ refers to the directory of the innermost file being included, or, if there is no file being included, to the current working directory.

Use ‘`~+`’ to refer to the current working directory (as in the `bash`).

If the filename starts with ‘`./`’, the search path is not searched (just as with absolute filenames), and the ‘`.`’ has the same meaning as described above.

4.13.3.1 Forth Search Paths

The search path is initialized when you start Gforth (see Section 2.1 [Invoking Gforth], page 11). You can display it and change it using these words:

`.fpath` – gforth “.fpath”

Display the contents of the Forth search path.

`fpath+` `"`*dir*`"` gforth “fpath+”

Add directory *dir* to the Forth search path.

`fpath=` `"`*dir1*`|`*dir2*`|`*dir3*`"` gforth “fpath=”

Make a complete new Forth search path; the path separator is `|`.

`open-fpath-file` *addr1 u1 – wfileid addr2 u2 0 | ior* gforth "open-fpath-file"

Look in the Forth search path for the file specified by *addr1 u1*. If found, the resulting path and an open file descriptor are returned. If the file is not found, *ior* is non-zero.

Here is an example of using `fpath` and `require`:

```
fpath= /usr/lib/forth/|./
require timer.fs
```

4.13.3.2 General Search Paths

Your application may need to search files in several directories, like `included` does. To facilitate this, Gforth allows you to define and use your own search paths, by providing generic equivalents of the Forth search path words:

`.path` *path-addr –* gforth ".path"

Display the contents of the search path *path-addr*.

`path+` *path-addr "dir" –* gforth "path+"

Add the directory *dir* to the search path *path-addr*.

`path=` *path-addr "dir1|dir2|dir3"* gforth "path="

Make a complete new search path; the path separator is `|`.

`open-path-file` *addr1 u1 path-addr – wfileid addr2 u2 0 | ior* gforth "open-path-file"

Look in path *path-addr* for the file specified by *addr1 u1*. If found, the resulting path and an open file descriptor are returned. If the file is not found, *ior* is non-zero.

Here's an example of creating a search path:

```
\ Make a buffer for the path:
create mypath   100 chars ,     \ maximum length (is checked)
                0 ,             \ real len
                100 chars allot \ space for path
```

4.14 Blocks

When you run Gforth on a modern desk-top computer, it runs under the control of an operating system which provides certain services. One of these services is *file services*, which allows Forth source code and data to be stored in files and read into Gforth (see Section 4.13 [Files], page 78).

Traditionally, Forth has been an important programming language on systems where it has interfaced directly to the underlying hardware with no intervening operating system. Forth provides a mechanism, called *blocks*, for accessing mass storage on such systems.

A block is a 1024-byte data area, which can be used to hold data or Forth source code. No structure is imposed on the contents of the block. A block is identified by its number; blocks are numbered contiguously from 1 to an implementation-defined maximum.

A typical system that used blocks but no operating system might use a single floppy-disk drive for mass storage, with the disks formatted to provide 256-byte sectors. Blocks would be implemented by assigning the first four sectors of the disk to block 1, the second four

sectors to block 2 and so on, up to the limit of the capacity of the disk. The disk would not contain any file system information, just the set of blocks.

On systems that do provide file services, blocks are typically implemented by storing a sequence of blocks within a single *blocks file*. The size of the blocks file will be an exact multiple of 1024 bytes, corresponding to the number of blocks it contains. This is the mechanism that Gforth uses.

Only 1 blocks file can be open at a time. If you use block words without having specified a blocks file, Gforth defaults to the blocks file '`blocks.fb`'. Gforth uses the Forth search path when attempting to locate a blocks file (see Section 4.13.3.1 [Forth Search Paths], page 80).

When you read and write blocks under program control, Gforth uses a number of *block buffers* as intermediate storage. These buffers are not used when you use `load` to interpret the contents of a block.

The behaviour of the block buffers is directly analagous to that of a cache. Each block buffer has three states:

- Unassigned
- Assigned-clean
- Assigned-dirty

Initially, all block buffers are *unassigned*. In order to access a block, the block (specified by its block number) must be assigned to a block buffer.

The assignment of a block to a block buffer is performed by `block` or `buffer`. Use `block` when you wish to modify the existing contents of a block. Use `buffer` when you don't care about the existing contents of the block[24].

Once a block has been assigned to a block buffer, the block buffer state becomes *assigned-clean*. Data can now be manipulated within the block buffer.

When the contents of a block buffer is changed it is necessary, *before calling* `block` *or* `buffer` *again*, to either abandon the changes (by doing nothing) or commit the changes, using `update`. Using `update` does not change the blocks file; it simply changes a block buffer's state to *assigned-dirty*.

The word `flush` causes all *assigned-dirty* blocks to be written back to the blocks file on disk. Leaving Gforth using `bye` also causes a `flush` to be performed.

In Gforth, `block` and `buffer` use a *direct-mapped* algorithm to assign a block buffer to a block. That means that any particular block can only be assigned to one specific block buffer, called (for the particular operation) the *victim buffer*. If the victim buffer is *unassigned* or *assigned-clean* it can be allocated to the new block immediately. If it is *assigned-dirty* its current contents must be written out to disk before it can be allocated to the new block.

[24] The ANS Forth definition of `buffer` is intended not to cause disk I/O; if the data associated with the particular block is already stored in a block buffer due to an earlier `block` command, `buffer` will return that block buffer and the existing contents of the block will be available. Otherwise, `buffer` will simply assign a new, empty block buffer for the block.

Although no structure is imposed on the contents of a block, it is traditional to display the contents as 16 lines each of 64 characters. A block provides a single, continuous stream of input (for example, it acts as a single parse area) – there are no end-of-line characters within a block, and no end-of-file character at the end of a block. There are two consequences of this:

- The last character of one line wraps straight into the first character of the following line
- The word \ – comment to end of line – requires special treatment; in the context of a block it causes all characters until the end of the current 64-character "line" to be ignored.

In Gforth, when you use `block` with a non-existent block number, the current block file will be extended to the appropriate size and the block buffer will be initialised with spaces.

Gforth doesn't encourage the use of blocks; the mechanism is only provided for backward compatibility – ANS Forth requires blocks to be available when files are.

Common techniques that are used when working with blocks include:

- A screen editor that allows you to edit blocks without leaving the Forth environment.
- Shadow screens; where every code block has an associated block containing comments (for example: code in odd block numbers, comments in even block numbers). Typically, the block editor provides a convenient mechanism to toggle between code and comments.
- Load blocks; a single block (typically block 1) contains a number of `thru` commands which `load` the whole of the application.

See Frank Sergeant's Pygmy Forth to see just how well blocks can be integrated into a Forth programming environment.

doc-open-blocks doc-use

`get-block-fid` – *fid* unknown "get-block-fid"

`block-position` *u* – unknown "block-position"

`scr` unknown "scr"

`list` *u* – unknown "list"

doc—block-block

`buffer` *u* – *a-addr* unknown "buffer"

`update` – unknown "update"

doc-updated?

`save-buffers` – unknown "save-buffers"

`empty-buffers` – unknown "empty-buffers"

doc-empty-buffer

`flush` – unknown "flush"

`load` *i*x n* – *j*x* unknown "load"

`thru` *i*x n1 n2* – *j*x* unknown "thru"

`+load` *i*x n* – *j*x* unknown "+load"

`+thru` *i*x n1 n2* – *j*x* unknown "+thru"

xdoc–gforth—> doc-block-included

4.15 Other I/O

4.15.1 Simple numeric output

The simplest output functions are those that display numbers from the data or floating-point stacks. Floating-point output is always displayed using base 10. Numbers displayed from the data stack use the value stored in `base`.

`.` *n* – core "dot"

Display (the signed single number) *n* in free-format, followed by a space.

`dec.` *n* – gforth "dec."

Display *n* as a signed decimal number, followed by a space. !! not used...

`hex.` *u* – gforth "hex."

Display *u* as an unsigned hex number, prefixed with a `"$"` and followed by a space. !! not used...

`u.` *u* – core "u-dot"

Display (the unsigned single number) *u* in free-format, followed by a space.

`.r` *n1 n2* – core-ext "dot-r"

Display *n1* right-aligned in a field *n2* characters wide. If more than *n2* characters are needed to display the number, all digits are displayed. If appropriate, *n2* must include a character for a leading `"-"`.

`u.r` *u n* – core-ext "u-dot-r"

Display *u* right-aligned in a field *n* characters wide. If more than *n* characters are needed to display the number, all digits are displayed.

`d.` *d* – double "d-dot"

Display (the signed double number) *d* in free-format. followed by a space.

`ud.` *ud* – gforth "u-d-dot"

Display (the signed double number) *ud* in free-format, followed by a space.

`d.r` *d n* – double "d-dot-r"

Display *d* right-aligned in a field *n* characters wide. If more than *n* characters are needed to display the number, all digits are displayed. If appropriate, *n* must include a character for a leading `"-"`.

`ud.r` *ud n* – gforth "u-d-dot-r"

Display *ud* right-aligned in a field *n* characters wide. If more than *n* characters are needed to display the number, all digits are displayed.

`f.` *r* – floating-ext "f-dot"

Display (the floating-point number) *r* using fixed-point notation, followed by a space.

`fe.` *r* – floating-ext "f-e-dot"

Display *r* using engineering notation, followed by a space.

`fs.` *r* – floating-ext "f-s-dot"

Display *r* using scientific notation, followed by a space.

Examples of printing the number 1234.5678E23 in the different floating-point output formats are shown below:

```
f. 123456779999999000000000000.
fe. 123.456779999999E24
fs. 1.23456779999999E26
```

4.15.2 Formatted numeric output

Forth traditionally uses a technique called *pictured numeric output* for formatted printing of integers. In this technique, digits are extracted from the number (using the current output radix defined by `base`), converted to ASCII codes and appended to a string that is built in a scratch-pad area of memory (see Section 7.1.1 [Implementation-defined options], page 132). Arbitrary characters can be appended to the string during the extraction process. The completed string is specified by an address and length and can be manipulated (`TYPE`ed, copied, modified) under program control.

All of the words described in the previous section for simple numeric output are implemented in Gforth using pictured numeric output.

Three important things to remember about Pictured Numeric Output:

- It always operates on double-precision numbers; to display a single-precision number, convert it first (see Section 4.4.3 [Double precision], page 30 for ways of doing this).
- It always treats the double-precision number as though it were unsigned. The examples below show ways of printing signed numbers.
- The string is built up from right to left; least significant digit first.

`<#` – core "less-number-sign"

Initialise/clear the pictured numeric output string.

`#` *ud1 – ud2* core "number-sign"

Used within `<#` and `#>`. Add the next least-significant digit to the pictured numeric output string. This is achieved by dividing ud1 by the number in `base` to leave quotient ud2 and remainder n; n is converted to the appropriate display code (eg ASCII code) and appended to the string. If the number has been fully converted, ud1 will be 0 and `#` will append a "0" to the string.

`#s` *ud – 0 0* core "number-sign-s"

Used within `<#` and `#>`. Convert all remaining digits using the same algorithm as for `#`. `#s` will convert at least one digit. Therefore, if ud is 0, `#s` will append a "0" to the pictured numeric output string.

`hold` *char –* core "hold"

Used within `<#` and `#>`. Append the character *char* to the pictured numeric output string.

`sign` *n –* core "sign"

Used within `<#` and `#>`. If n (a *single* number) is negative, append the display code for a minus sign to the pictured numeric output string. Since the string is built up "backwards" this is usually used immediately prior to `#>`, as shown in the examples below.

`#>` *xd – addr u* core "number-sign-greater"

Complete the pictured numeric output string by discarding xd and returning addr u; the address and length of the formatted string. A Standard program may modify characters within the string.

`represent` *r c-addr u – n f1 f2* float "represent"

Here are some examples of using pictured numeric output:

```
: my-u. ( u -- )
  \ Simplest use of pns.. behaves like Standard u.
  0              \ convert to unsigned double
  <#             \ start conversion
  #s             \ convert all digits
  #>             \ complete conversion
  TYPE SPACE ;   \ display, with trailing space

: cents-only ( u -- )
  0              \ convert to unsigned double
  <#             \ start conversion
  # #            \ convert two least-significant digits
  #>             \ complete conversion, discard other digits
  TYPE SPACE ;   \ display, with trailing space

: dollars-and-cents ( u -- )
  0              \ convert to unsigned double
  <#             \ start conversion
  # #            \ convert two least-significant digits
  [char] . hold  \ insert decimal point
  #s             \ convert remaining digits
  [char] $ hold  \ append currency symbol
  #>             \ complete conversion
  TYPE SPACE ;   \ display, with trailing space

: my-. ( n -- )
  \ handling negatives.. behaves like Standard .
  s>d            \ convert to signed double
  swap over dabs \ leave sign byte followed by unsigned double
  <#             \ start conversion
  #s             \ convert all digits
  rot sign       \ get at sign byte, append "-" if needed
  #>             \ complete conversion
  TYPE SPACE ;   \ display, with trailing space

: account. ( n -- )
  \ accountants don't like minus signs, they use braces
  \ for negative numbers
  s>d            \ convert to signed double
  swap over dabs \ leave sign byte followed by unsigned double
  <#             \ start conversion
  2 pick         \ get copy of sign byte
  0< IF [char] ) hold THEN \ right-most character of output
  #s             \ convert all digits
  rot            \ get at sign byte
  0< IF [char] ( hold THEN
```

```
    #>              \ complete conversion
    TYPE SPACE ;    \ display, with trailing space
```

Here are some examples of using these words:

```
1 my-u. 1
hex -1 my-u. decimal FFFFFFFF
1 cents-only 01
1234 cents-only 34
2 dollars-and-cents $0.02
1234 dollars-and-cents $12.34
123 my-. 123
-123 my. -123
123 account. 123
-456 account. (456)
```

4.15.3 String Formats

Forth commonly uses two different methods for representing character strings:

- As a *counted string*, represented by a *c-addr*. The char addressed by *c-addr* contains a character-count, *n*, of the string and the string occupies the subsequent *n* char addresses in memory.
- As cell pair on the stack; *c-addr u*, where *u* is the length of the string in characters, and *c-addr* is the address of the first byte of the string.

ANS Forth encourages the use of the second format when representing strings on the stack, whilst conceeding that the counted string format remains useful as a way of storing strings in memory.

`count` *c-addr1 – c-addr2 u* core "count"

If *c-add1* is the address of a counted string return the length of the string, *u*, and the address of its first character, *c-addr2*.

See Section 4.6.6 [Memory Blocks], page 42 for words that move, copy and search for strings. See Section 4.15.4 [Displaying characters and strings], page 87 for words that display characters and strings.

4.15.4 Displaying characters and strings

This section starts with a glossary of Forth words and ends with a set of examples.

`bl` *– c-char* core "bl"

c-char is the character value for a space.

`space` – core "space"

Display one space.

`spaces` *u* – core "spaces"

If *n* > 0, display *n* spaces.

`emit` *c* – core "emit"

Display the character associated with character value c.

`toupper` *c1 – c2* gforth “toupper”

If *c1* is a lower-case character (in the current locale), *c2* is the equivalent upper-case character. All other characters are unchanged.

`."` *compilation 'ccc"' – ; run-time –* core “dot-quote”

Compilation: Parse a string *ccc* delimited by a `"` (double quote). At run-time, display the string. Interpretation semantics for this word are undefined in ANS Forth. Gforth's interpretation semantics are to display the string. This is the simplest way to display a string from within a definition; see examples below.

`.(` *"ccc<paren>"* – core-ext “dot-paren”

Parse a string *ccc* delimited by a `)` (right parenthesis). Display the string. This is often used to display progress information during compilation; see examples below.

`type` *c-addr u –* core “type”

If *u*>0, display *u* characters from a string starting with the character stored at *c-addr*.

`cr` – core “cr”

Output a carriage-return and (if appropriate for the host operating system) a line feed.

`at-xy` *u1 u2 –* facility “at-x-y”

Position the cursor so that subsequent text output will take place at column *u1*, row *u2* of the display. (column 0, row 0 is the top left-hand corner of the display).

`page` – gforth “page”

Clear the display and set the cursor to the top left-hand corner.

`S"` *compilation 'ccc"' – ; run-time – c-addr u* core,file “s-quote”

Compilation: Parse a string *ccc* delimited by a `"` (double quote). At run-time, return the length, *u*, and the start address, *c-addr* of the string. Interpretation: parse the string as before, and return *c-addr*, *u*. The string is stored in a temporary buffer which may be overwritten by subsequent uses of `S"`.

`C"` *compilation "ccc<quote>" – ; run-time – c-addr* core-ext “c-quote”

Compilation: parse a string *ccc* delimited by a `"` (double quote). At run-time, return *c-addr* which specifies the counted string *ccc*. Interpretation semantics are undefined.

`char` *'<spaces>ccc' – c* core “char”

Skip leading spaces. Parse the string *ccc* and return *c*, the display code representing the first character of *ccc*.

`[char]` *compilation '<spaces>ccc' – ; run-time – c* core “bracket-char”

Compilation: skip leading spaces. Parse the string *ccc*. Run-time: return *c*, the display code representing the first character of *ccc*. Interpretation semantics for this word are undefined.

`SLiteral` *Compilation c-addr1 u ; run-time – c-addr2 u* string “SLiteral”

Compilation: compile the string specified by *c-addr1*, *u* into the current definition. Run-time: return *c-addr2 u* describing the address and length of the string.

As an example, consider the following text, stored in a file ‘`test.fs`’:

```
.( text-1)
: my-word
  ." text-2" cr
  .( text-3)
;

." text-4"

: my-char
  [char] ALPHABET emit
  char emit
;
```

When you load this code into Gforth, the following output is generated:

```
include test.fs ⟨RET⟩ text-1text-3text-4 ok
```

- Messages `text-1` and `text-3` are displayed because `.(` is an immediate word; it behaves in the same way whether it is used inside or outside a colon definition.
- Message `text-4` is displayed because of Gforth's added interpretation semantics for `."`.
- Message `text-2` is *not* displayed, because the text interpreter performs the compilation semantics for `."` within the definition of `my-word`.

Here are some examples of executing `my-word` and `my-char`:

```
my-word ⟨RET⟩ text-2
 ok
my-char fred ⟨RET⟩ Af ok
my-char jim ⟨RET⟩ Aj ok
```

- Message `text-2` is displayed because of the run-time behaviour of `."`.
- `[char]` compiles the "A" from "ALPHABET" and puts its display code on the stack at run-time. `emit` always displays the character when `my-char` is executed.
- `char` parses a string at run-time and the second `emit` displays the first character of the string.
- If you type `see my-char` you can see that `[char]` discarded the text "LPHABET" and only compiled the display code for "A" into the definition of `my-char`.

4.15.5 Input

See Section 4.15.3 [String Formats], page 87 for ways of storing character strings in memory.

`key` – *char* core "key"

Receive (but do not display) one character, *char*.

`key?` – *flag* facility "key?"

Determine whether a character is available. If a character is available, *flag* is true; the next call to `key` will yield the character. Once `key?` returns true, subsequent calls to `key?` without calling `key` or `ekey` will also return true.

`>number` *ud1 c-addr1 u1 – ud2 c-addr2 u2* core ">number"

Attempt to convert the character string *c-addr1, u1* to an unsigned number in the current number base. The double *ud1* accumulates the result of the conversion to form *ud2*. Conversion continues, left-to-right, until the whole string is converted or a character that is not convertable in the current number base is encountered (including + or -). For each convertable character, *ud1* is first multiplied by the value in `BASE` and then incremented by the value represented by the character. *c-addr2* is the location of the first unconverted character (past the end of the string if the whole string was converted). *u2* is the number of unconverted characters in the string. Overflow is not detected.

`>float` *c-addr u – flag* float "to-float"

Attempt to convert the character string *c-addr u* to internal floating-point representation. If the string represents a valid floating-point number *r* is placed on the floating-point stack and *flag* is true. Otherwise, *flag* is false. A string of blanks is a special case and represents the flotaing-point number 0.

`accept` *c-addr +n1 – +n2* core "accept"

Receive a string of at most *+n2* characters, and store it in memory starting at *c-addr*. The string is displayed. Input terminates when the <return> key is pressed or *n1* characters have been received. The normal Gforth line editing capabilites are available. *+n2* is the length of the string; it does not include the <return> character.

`pad` – *c-addr* core-ext "pad"

c-addr is the address of a transient region that can be used as temporary data storage. At least 84 characters of space is available.

`parse` *char "ccc<char>"* – *c-addr u* core-ext "parse"

Parse *ccc*, delimited by *char*, in the parse area. *c-addr u* specifies the parsed string within the parse area. If the parse area was empty, *u* is 0.

`word` *char "<chars>ccc<char>*– *c-addr* core "word"

Skip leading delimiters. Parse *ccc*, delimited by *char*, in the parse area. *c-addr* is the addres of a transient region containing the parsed string in counted-strinng format. If the parse area was empty or contained no characters other than delimiters, the resulting string has zero length. A program may replace characters within the counted string. OBSOLESCENT: the counted string has a trailing space that is not included in its length.

`sword` *char – addr len* gforth "s-word"

Parses like `word`, but the output is like `parse` output

`refill` – *flag* core-ext,block-ext,file-ext "refill"

Attempt to fill the input buffer from the input source. When the input source is the user input device, attempt to receive input into the terminal input device. If successful, make the result the input buffer, set `>IN` to 0 and return true; otherwise return false. When the input source is a block, add 1 to the value of `BLK` to make the next block the input source and current input buffer, and set `>IN` to 0; return true if the new value of `BLK` is a valid block number, false otherwise. When the input source is a text file, attempt to read the next line from the file. If successful, make the result the current input buffer, set `>IN` to 0 and return true; otherwise, return false. A successful result includes receipt of a line containing 0 characters.

`convert` *ud1 c-addr1 – ud2 c-addr2* core-ext "convert"

OBSOLESCENT: superseded by `>number`.

`query` – core-ext "query"

Make the user input device the input source. Receive input into the Terminal Input Buffer. Set `>IN` to zero. OBSOLESCENT: superceeded by `accept`.

`expect` *c-addr +n* – core-ext "expect"

Receive a string of at most *+n* characters, and store it in memory starting at *c-addr*. The string is displayed. Input terminates when the <return> key is pressed or *+n* characters have been received. The normal Gforth line editing capabilites are available. The length of the string is stored in `span`; it does not include the <return> character. OBSOLESCENT: superceeded by `accept`.

`span` – *c-addr* core-ext "span"

4.16 Programming Tools

4.16.1 Debugging

Languages with a slow edit/compile/link/test development loop tend to require sophisticated tracing/stepping debuggers to facilate productive debugging.

A much better (faster) way in fast-compiling languages is to add printing code at well-selected places, let the program run, look at the output, see where things went wrong, add more printing code, etc., until the bug is found.

The simple debugging aids provided in '`debugs.fs`' are meant to support this style of debugging. In addition, there are words for non-destructively inspecting the stack and memory:

`.s` – tools "dot-s"

Display the number of items on the data stack, followed by a list of the items; TOS is the right-most item.

`f.s` – gforth "f-dot-s"

Display the number of items on the floating-point stack, followed by a list of the items; TOS is the right-most item.

There is a word `.r` but it does *not* display the return stack! It is used for formatted numeric output.

`depth` – *+n* core "depth"

+n is the number of values that were on the data stack before *+n* itself was placed on the stack.

`fdepth` – *+n* floating "f-depth"

+n is the current number of (floating-point) values on the floating-point stack.

`clearstack` ... – gforth "clear-stack"

remove and discard all/any items from the data stack.

`?` *a-addr* – tools "question"

Display the contents of address *a-addr* in the current number base.

`dump` *addr u* – tools "dump"

Display *u* lines of memory starting at address *addr*. Each line displays the contents of 16 bytes. When Gforth is running under an operating system you may get '`Invalid memory address`' errors if you attempt to access arbitrary locations.

The word `~~` prints debugging information (by default the source location and the stack contents). It is easy to insert. If you use Emacs it is also easy to remove (`C-x ~` in the Emacs Forth mode to query-replace them with nothing). The deferred words `printdebugdata` and `printdebugline` control the output of `~~`. The default source location output format works well with Emacs' compilation mode, so you can step through the program at the source level using `C-x '` (the advantage over a stepping debugger is that you can step in any direction and you know where the crash has happened or where the strange data has occurred).

The default actions of `~~` clobber the contents of the pictured numeric output string, so you should not use `~~`, e.g., between `<#` and `#>`.

`~~` *compilation* – ; *run-time* – gforth "tilde-tilde"

`printdebugdata` – gforth "print-debug-data"

`printdebugline` *addr* – gforth "print-debug-line"

`see` "<*spaces*>*name*" – tools "see"

Locate *name* using the current search order. Display the definition of *name*. Since this is achieved by decompiling the definition, the formatting is mechanised and some source information (comments, interpreted sequences within definitions etc.) is lost.

`marker` "<*spaces*> *name*" – core-ext "marker"

Create a definition, *name* (called a *mark*) whose execution semantics are to remove itself and everything defined after it.

Here's an example of using `marker` at the start of a source file that you are debugging; it ensures that you only ever have one copy of the file's definitions compiled at any time:

```
[IFDEF] my-code
    my-code
[ENDIF]

marker my-code
init-included-files

\ .. definitions start here
\ .
\ .
\ end
```

4.16.2 Assertions

It is a good idea to make your programs self-checking, especially if you make an assumption that may become invalid during maintenance (for example, that a certain field of a data structure is never zero). Gforth supports *assertions* for this purpose. They are used like this:

`assert(` *flag* `)`

The code between `assert(` and `)` should compute a flag, that should be true if everything is alright and false otherwise. It should not change anything else on the stack. The overall stack effect of the assertion is `( -- )`. E.g.

```
assert( 1 1 + 2 = ) \ what we learn in school
assert( dup 0<> ) \ assert that the top of stack is not zero
assert( false ) \ this code should not be reached
```

The need for assertions is different at different times. During debugging, we want more checking, in production we sometimes care more for speed. Therefore, assertions can be turned off, i.e., the assertion becomes a comment. Depending on the importance of an assertion and the time it takes to check it, you may want to turn off some assertions and keep others turned on. Gforth provides several levels of assertions for this purpose:

`assert0(` – gforth "assert-zero"

Important assertions that should always be turned on.

`assert1(` – gforth "assert-one"

Normal assertions; turned on by default.

`assert2(` – gforth "assert-two"

Debugging assertions.

`assert3(` – gforth "assert-three"

Slow assertions that you may not want to turn on in normal debugging; you would turn them on mainly for thorough checking.

`assert(` – gforth "assert("

Equivalent to `assert1(`

`)` – gforth "close-paren"

End an assertion.

The variable `assert-level` specifies the highest assertions that are turned on. I.e., at the default `assert-level` of one, `assert0(` and `assert1(` assertions perform checking, while `assert2(` and `assert3(` assertions are treated as comments.

The value of `assert-level` is evaluated at compile-time, not at run-time. Therefore you cannot turn assertions on or off at run-time; you have to set the `assert-level` appropriately before compiling a piece of code. You can compile different pieces of code at different `assert-level`s (e.g., a trusted library at level 1 and newly-written code at level 3).

`assert-level` – *a-addr* gforth "assert-level"

All assertions above this level are turned off.

If an assertion fails, a message compatible with Emacs' compilation mode is produced and the execution is aborted (currently with `ABORT"`. If there is interest, we will introduce a special throw code. But if you intend to `catch` a specific condition, using `throw` is probably more appropriate than an assertion).

Definitions in ANS Forth for these assertion words are provided in '`compat/assert.fs`'.

4.16.3 Singlestep Debugger

When you create a new word there's often the need to check whether it behaves correctly or not. You can do this by typing `dbg badword`. A debug session might look like this:

```
: badword 0 DO i . LOOP ;  ok
2 dbg badword
: badword
Scanning code...

Nesting debugger ready!

400D4738  8049BC4 0            -> [ 2 ] 00002 00000
400D4740  8049F68 DO           -> [ 0 ]
400D4744  804A0C8 i            -> [ 1 ] 00000
400D4748 400C5E60 .            -> 0 [ 0 ]
400D474C  8049D0C LOOP         -> [ 0 ]
400D4744  804A0C8 i            -> [ 1 ] 00001
400D4748 400C5E60 .            -> 1 [ 0 ]
400D474C  8049D0C LOOP         -> [ 0 ]
400D4758  804B384 ;            ->  ok
```

Each line displayed is one step. You always have to hit return to execute the next word that is displayed. If you don't want to execute the next word in a whole, you have to type *n* for `nest`. Here is an overview what keys are available:

⟨RET⟩ Next; Execute the next word.

n Nest; Single step through next word.

u Unnest; Stop debugging and execute rest of word. If we got to this word with nest, continue debugging with the calling word.

d Done; Stop debugging and execute rest.

s Stop; Abort immediately.

Debugging large application with this mechanism is very difficult, because you have to nest very deeply into the program before the interesting part begins. This takes a lot of time.

To do it more directly put a `BREAK:` command into your source code. When program execution reaches `BREAK:` the single step debugger is invoked and you have all the features described above.

If you have more than one part to debug it is useful to know where the program has stopped at the moment. You can do this by the `BREAK" string"` command. This behaves like `BREAK:` except that string is typed out when the "breakpoint" is reached.

`dbg` unknown "dbg"

doc-BREAK: doc-BREAK"

4.17 Assembler and Code Words

Gforth provides some words for defining primitives (words written in machine code), and for defining the machine-code equivalent of `DOES>`-based defining words. However, the machine-independent nature of Gforth poses a few problems: First of all, Gforth runs on several architectures, so it can provide no standard assembler. What's worse is that the register allocation not only depends on the processor, but also on the `gcc` version and options used.

The words that Gforth offers encapsulate some system dependences (e.g., the header structure), so a system-independent assembler may be used in Gforth. If you do not have an assembler, you can compile machine code directly with `,` and `c,`[25].

`assembler` – tools-ext "assembler"

`code` "*name*" – *colon-sys* tools-ext "code"

`end-code` *colon-sys* – gforth "end-code"

`;code` *compilation. colon-sys1* – *colon-sys2* tools-ext "semicolon-code"

`flush-icache` *c-addr u* – gforth "flush-icache"

Make sure that the instruction cache of the processor (if there is one) does not contain stale data at *c-addr* and *u* bytes afterwards. `END-CODE` performs a `flush-icache` automatically. Caveat: `flush-icache` might not work on your installation; this is usually the case if direct threading is not supported on your machine (take a look at your '`machine.h`') and your machine has a separate instruction cache. In such cases, `flush-icache` does nothing instead of flushing the instruction cache.

If `flush-icache` does not work correctly, `code` words etc. will not work (reliably), either.

The typical usage of these `code` words can be shown most easily by analogy to the equivalent high-level defining words:

```
: foo                                   code foo
   <high-level Forth words>                   <assembler>
;                                       end-code

: bar                                   : bar
   <high-level Forth words>                   <high-level Forth words>
   CREATE                                     CREATE
      <high-level Forth words>                   <high-level Forth words>
   DOES>                                      ;code
      <high-level Forth words>                   <assembler>
;                                       end-code
```

`flush-icache` is always present. The other words are rarely used and reside in `code.fs`, which is usually not loaded. You can load it with `require code.fs`.

In the assembly code you will want to refer to the inner interpreter's registers (e.g., the data stack pointer) and you may want to use other registers for temporary storage. Unfortunately, the register allocation is installation-dependent.

[25] This isn't portable, because these words emit stuff in *data* space; it works because Gforth has unified code/data spaces. Assembler isn't likely to be portable anyway.

The easiest solution is to use explicit register declarations (see section "Variables in Specified Registers" in *GNU C Manual*) for all of the inner interpreter's registers: You have to compile Gforth with `-DFORCE_REG` (configure option `--enable-force-reg`) and the appropriate declarations must be present in the `machine.h` file (see `mips.h` for an example; you can find a full list of all declarable register symbols with `grep register engine.c`). If you give explicit registers to all variables that are declared at the beginning of `engine()`, you should be able to use the other caller-saved registers for temporary storage. Alternatively, you can use the `gcc` option `-ffixed-REG` (see section "Options for Code Generation Conventions" in *GNU C Manual*) to reserve a register (however, this restriction on register allocation may slow Gforth significantly).

If this solution is not viable (e.g., because `gcc` does not allow you to explicitly declare all the registers you need), you have to find out by looking at the code where the inner interpreter's registers reside and which registers can be used for temporary storage. You can get an assembly listing of the engine's code with `make engine.s`.

In any case, it is good practice to abstract your assembly code from the actual register allocation. E.g., if the data stack pointer resides in register `$17`, create an alias for this register called `sp`, and use that in your assembly code.

Another option for implementing normal and defining words efficiently is to add the desired functionality to the source of Gforth. For normal words you just have to edit '`primitives`' (see Section 12.3.1 [Automatic Generation], page 157). Defining words (equivalent to `;CODE` words, for fast defined words) may require changes in '`engine.c`', '`kernel.fs`', '`prims2x.fs`', and possibly '`cross.fs`'.

4.18 Threading Words

These words provide access to code addresses and other threading stuff in Gforth (and, possibly, other interpretive Forths). It more or less abstracts away the differences between direct and indirect threading (and, for direct threading, the machine dependences). However, at present this wordset is still incomplete. It is also pretty low-level; some day it will hopefully be made unnecessary by an internals wordset that abstracts implementation details away completely.

`threading-method` – *n* gforth "threading-method"

0 if the engine is direct threaded. Note that this may change during the lifetime of an image.

`>code-address` *xt* – *c-addr* gforth "to-code-address"

c-addr is the code address of the word *xt*.

`>does-code` *xt* – *a-addr* gforth "to-does-code"

If *xt* is the execution token of a defining-word-defined word, *a-addr* is the start of the Forth code after the `DOES>`; Otherwise *a-addr* is 0.

`code-address!` *c-addr xt* – gforth "code-address-store"

Create a code field with code address *c-addr* at *xt*.

`does-code!` *a-addr xt* – gforth "does-code-store"

Create a code field at *xt* for a defining-word-defined word; *a-addr* is the start of the Forth code after `DOES>`.

`does-handler!` *a-addr* – gforth "does-handler-store"

Create a `DOES>`-handler at address *a-addr*. Usually, *a-addr* points just behind a `DOES>`.

`/does-handler` – *n* gforth "slash-does-handler"

The size of a `DOES>`-handler (includes possible padding).

The code addresses produced by various defining words are produced by the following words:

`docol:` – *addr* gforth "docol:"

The code address of a colon definition.

`docon:` – *addr* gforth "docon:"

The code address of a `CONSTANT`.

`dovar:` – *addr* gforth "dovar:"

The code address of a `CREATE`d word.

`douser:` – *addr* gforth "douser:"

The code address of a `USER` variable.

`dodefer:` – *addr* gforth "dodefer:"

The code address of a `defer`ed word.

`dofield:` – *addr* gforth "dofield:"

The code address of a `field`.

You can recognize words defined by a `CREATE`...`DOES>` word with `>does-code`. If the word was defined in that way, the value returned is non-zero and identifies the `DOES>` used by the defining word.

4.19 Locals

Local variables can make Forth programming more enjoyable and Forth programs easier to read. Unfortunately, the locals of ANS Forth are laden with restrictions. Therefore, we provide not only the ANS Forth locals wordset, but also our own, more powerful locals wordset (we implemented the ANS Forth locals wordset through our locals wordset).

The ideas in this section have also been published in the paper *Automatic Scoping of Local Variables* by M. Anton Ertl, presented at EuroForth '94; it is available at `http://www.complang.tuwien.ac.at/papers/ertl94l.ps.gz`.

4.19.1 Gforth locals

Locals can be defined with

```
{ local1 local2 ... -- comment }
```

or

```
{ local1 local2 ... }
```

E.g.,

```
: max { n1 n2 -- n3 }
 n1 n2 > if
   n1
 else
   n2
 endif ;
```

The similarity of locals definitions with stack comments is intended. A locals definition often replaces the stack comment of a word. The order of the locals corresponds to the order in a stack comment and everything after the `--` is really a comment.

This similarity has one disadvantage: It is too easy to confuse locals declarations with stack comments, causing bugs and making them hard to find. However, this problem can be avoided by appropriate coding conventions: Do not use both notations in the same program. If you do, they should be distinguished using additional means, e.g. by position.

The name of the local may be preceded by a type specifier, e.g., `F:` for a floating point value:

```
: CX* { F: Ar F: Ai F: Br F: Bi -- Cr Ci }
\ complex multiplication
 Ar Br f* Ai Bi f* f-
 Ar Bi f* Ai Br f* f+ ;
```

Gforth currently supports cells (`W:`, `W^`), doubles (`D:`, `D^`), floats (`F:`, `F^`) and characters (`C:`, `C^`) in two flavours: a value-flavoured local (defined with `W:`, `D:` etc.) produces its value and can be changed with `TO`. A variable-flavoured local (defined with `W^` etc.) produces its address (which becomes invalid when the variable's scope is left). E.g., the standard word `emit` can be defined in terms of `type` like this:

```
: emit { C^ char* -- }
    char* 1 type ;
```

A local without type specifier is a `W:` local. Both flavours of locals are initialized with values from the data or FP stack.

Currently there is no way to define locals with user-defined data structures, but we are working on it.

Gforth allows defining locals everywhere in a colon definition. This poses the following questions:

4.19.1.1 Where are locals visible by name?

Basically, the answer is that locals are visible where you would expect it in block-structured languages, and sometimes a little longer. If you want to restrict the scope of a local, enclose its definition in `SCOPE`...`ENDSCOPE`.

`scope` *compilation – scope ; run-time –* gforth "scope"

`endscope` *compilation scope – ; run-time –* gforth "endscope"

These words behave like control structure words, so you can use them with `CS-PICK` and `CS-ROLL` to restrict the scope in arbitrary ways.

If you want a more exact answer to the visibility question, here's the basic principle: A local is visible in all places that can only be reached through the definition of the local[26]. In other words, it is not visible in places that can be reached without going through the definition of the local. E.g., locals defined in `IF`...`ENDIF` are visible until the `ENDIF`, locals defined in `BEGIN`...`UNTIL` are visible after the `UNTIL` (until, e.g., a subsequent `ENDSCOPE`).

The reasoning behind this solution is: We want to have the locals visible as long as it is meaningful. The user can always make the visibility shorter by using explicit scoping. In a place that can only be reached through the definition of a local, the meaning of a local name is clear. In other places it is not: How is the local initialized at the control flow path that does not contain the definition? Which local is meant, if the same name is defined twice in two independent control flow paths?

This should be enough detail for nearly all users, so you can skip the rest of this section. If you really must know all the gory details and options, read on.

In order to implement this rule, the compiler has to know which places are unreachable. It knows this automatically after `AHEAD`, `AGAIN`, `EXIT` and `LEAVE`; in other cases (e.g., after most `THROW`s), you can use the word `UNREACHABLE` to tell the compiler that the control flow never reaches that place. If `UNREACHABLE` is not used where it could, the only consequence is that the visibility of some locals is more limited than the rule above says. If `UNREACHABLE` is used where it should not (i.e., if you lie to the compiler), buggy code will be produced.

`UNREACHABLE` – gforth "UNREACHABLE"

Another problem with this rule is that at `BEGIN`, the compiler does not know which locals will be visible on the incoming back-edge. All problems discussed in the following are due to this ignorance of the compiler (we discuss the problems using `BEGIN` loops as examples; the discussion also applies to `?DO` and other loops). Perhaps the most insidious example is:

```
AHEAD
BEGIN
  x
[ 1 CS-ROLL ] THEN
  { x }
  ...
UNTIL
```

This should be legal according to the visibility rule. The use of `x` can only be reached through the definition; but that appears textually below the use.

From this example it is clear that the visibility rules cannot be fully implemented without major headaches. Our implementation treats common cases as advertised and the exceptions are treated in a safe way: The compiler makes a reasonable guess about the locals visible after a `BEGIN`; if it is too pessimistic, the user will get a spurious error about the local not being defined; if the compiler is too optimistic, it will notice this later and issue a warning. In the case above the compiler would complain about `x` being undefined at its use. You can see from the obscure examples in this section that it takes quite unusual control structures to get the compiler into trouble, and even then it will often do fine.

If the `BEGIN` is reachable from above, the most optimistic guess is that all locals visible before the `BEGIN` will also be visible after the `BEGIN`. This guess is valid for all loops that

[26] In compiler construction terminology, all places dominated by the definition of the local.

are entered only through the BEGIN, in particular, for normal BEGIN...WHILE...REPEAT and BEGIN...UNTIL loops and it is implemented in our compiler. When the branch to the BEGIN is finally generated by AGAIN or UNTIL, the compiler checks the guess and warns the user if it was too optimistic:

```
IF
  { x }
BEGIN
  \ x ?
[ 1 cs-roll ] THEN
  ...
UNTIL
```

Here, x lives only until the BEGIN, but the compiler optimistically assumes that it lives until the THEN. It notices this difference when it compiles the UNTIL and issues a warning. The user can avoid the warning, and make sure that x is not used in the wrong area by using explicit scoping:

```
IF
  SCOPE
  { x }
  ENDSCOPE
BEGIN
[ 1 cs-roll ] THEN
  ...
UNTIL
```

Since the guess is optimistic, there will be no spurious error messages about undefined locals.

If the BEGIN is not reachable from above (e.g., after AHEAD or EXIT), the compiler cannot even make an optimistic guess, as the locals visible after the BEGIN may be defined later. Therefore, the compiler assumes that no locals are visible after the BEGIN. However, the user can use ASSUME-LIVE to make the compiler assume that the same locals are visible at the BEGIN as at the point where the top control-flow stack item was created.

ASSUME-LIVE *orig – orig* gforth "ASSUME-LIVE"

E.g.,

```
{ x }
AHEAD
ASSUME-LIVE
BEGIN
  x
[ 1 CS-ROLL ] THEN
  ...
UNTIL
```

Other cases where the locals are defined before the BEGIN can be handled by inserting an appropriate CS-ROLL before the ASSUME-LIVE (and changing the control-flow stack manipulation behind the ASSUME-LIVE).

Cases where locals are defined after the BEGIN (but should be visible immediately after the BEGIN) can only be handled by rearranging the loop. E.g., the "most insidious" example above can be arranged into:

```
BEGIN
  { x }
  ... 0=
WHILE
  x
REPEAT
```

4.19.1.2 How long do locals live?

The right answer for the lifetime question would be: A local lives at least as long as it can be accessed. For a value-flavoured local this means: until the end of its visibility. However, a variable-flavoured local could be accessed through its address far beyond its visibility scope. Ultimately, this would mean that such locals would have to be garbage collected. Since this entails un-Forth-like implementation complexities, I adopted the same cowardly solution as some other languages (e.g., C): The local lives only as long as it is visible; afterwards its address is invalid (and programs that access it afterwards are erroneous).

4.19.1.3 Programming Style

The freedom to define locals anywhere has the potential to change programming styles dramatically. In particular, the need to use the return stack for intermediate storage vanishes. Moreover, all stack manipulations (except `PICK`s and `ROLL`s with run-time determined arguments) can be eliminated: If the stack items are in the wrong order, just write a locals definition for all of them; then write the items in the order you want.

This seems a little far-fetched and eliminating stack manipulations is unlikely to become a conscious programming objective. Still, the number of stack manipulations will be reduced dramatically if local variables are used liberally (e.g., compare `max` in Section 4.19.1 [Gforth locals], page 97 with a traditional implementation of `max`).

This shows one potential benefit of locals: making Forth programs more readable. Of course, this benefit will only be realized if the programmers continue to honour the principle of factoring instead of using the added latitude to make the words longer.

Using `TO` can and should be avoided. Without `TO`, every value-flavoured local has only a single assignment and many advantages of functional languages apply to Forth. I.e., programs are easier to analyse, to optimize and to read: It is clear from the definition what the local stands for, it does not turn into something different later.

E.g., a definition using `TO` might look like this:

```
: strcmp { addr1 u1 addr2 u2 -- n }
 u1 u2 min 0
 ?do
   addr1 c@ addr2 c@ -
   ?dup-if
     unloop exit
   then
   addr1 char+ TO addr1
   addr2 char+ TO addr2
 loop
```

```
u1 u2 - ;
```

Here, `TO` is used to update `addr1` and `addr2` at every loop iteration. `strcmp` is a typical example of the readability problems of using `TO`. When you start reading `strcmp`, you think that `addr1` refers to the start of the string. Only near the end of the loop you realize that it is something else.

This can be avoided by defining two locals at the start of the loop that are initialized with the right value for the current iteration.

```
: strcmp { addr1 u1 addr2 u2 -- n }
 addr1 addr2
 u1 u2 min 0
 ?do { s1 s2 }
   s1 c@ s2 c@ -
   ?dup-if
     unloop exit
   then
   s1 char+ s2 char+
 loop
 2drop
 u1 u2 - ;
```

Here it is clear from the start that `s1` has a different value in every loop iteration.

4.19.1.4 Implementation

Gforth uses an extra locals stack. The most compelling reason for this is that the return stack is not float-aligned; using an extra stack also eliminates the problems and restrictions of using the return stack as locals stack. Like the other stacks, the locals stack grows toward lower addresses. A few primitives allow an efficient implementation:

`@local#` – *w* gforth "fetch-local-number"

`f@local#` – *r* gforth "f-fetch-local-number"

`laddr#` – *c-addr* gforth "laddr-number"

`lp+!#` – gforth "lp-plus-store-number"

used with negative immediate values it allocates memory on the local stack, a positive immediate argument drops memory from the local stack

`lp!` *c-addr* – gforth "lp-store"

`>l` *w* – gforth "to-l"

`f>l` *r* – gforth "f-to-l"

In addition to these primitives, some specializations of these primitives for commonly occurring inline arguments are provided for efficiency reasons, e.g., `@local0` as specialization of `@local#` for the inline argument 0. The following compiling words compile the right specialized version, or the general version, as appropriate:

`compile-@local` *n* – gforth "compile-fetch-local"

`compile-f@local` *n* – gforth "compile-f-fetch-local"

`compile-lp+!` *n* – gforth "compile-l-p-plus-store"

Combinations of conditional branches and `lp+!#` like `?branch-lp+!#` (the locals pointer is only changed if the branch is taken) are provided for efficiency and correctness in loops.

A special area in the dictionary space is reserved for keeping the local variable names. `{` switches the dictionary pointer to this area and `}` switches it back and generates the locals initializing code. `W:` etc. are normal defining words. This special area is cleared at the start of every colon definition.

A special feature of Gforth's dictionary is used to implement the definition of locals without type specifiers: every word list (aka vocabulary) has its own methods for searching etc. (see Section 4.11 [Word Lists], page 74). For the present purpose we defined a word list with a special search method: When it is searched for a word, it actually creates that word using `W:`. `{` changes the search order to first search the word list containing `}`, `W:` etc., and then the word list for defining locals without type specifiers.

The lifetime rules support a stack discipline within a colon definition: The lifetime of a local is either nested with other locals lifetimes or it does not overlap them.

At `BEGIN`, `IF`, and `AHEAD` no code for locals stack pointer manipulation is generated. Between control structure words locals definitions can push locals onto the locals stack. `AGAIN` is the simplest of the other three control flow words. It has to restore the locals stack depth of the corresponding `BEGIN` before branching. The code looks like this:

`lp+!#` current-locals-size − dest-locals-size
`branch` <begin>

`UNTIL` is a little more complicated: If it branches back, it must adjust the stack just like `AGAIN`. But if it falls through, the locals stack must not be changed. The compiler generates the following code:

`?branch-lp+!#` <begin> current-locals-size − dest-locals-size

The locals stack pointer is only adjusted if the branch is taken.

`THEN` can produce somewhat inefficient code:

`lp+!#` current-locals-size − orig-locals-size
<orig target>:
`lp+!#` orig-locals-size − new-locals-size

The second `lp+!#` adjusts the locals stack pointer from the level at the *orig* point to the level after the `THEN`. The first `lp+!#` adjusts the locals stack pointer from the current level to the level at the orig point, so the complete effect is an adjustment from the current level to the right level after the `THEN`.

In a conventional Forth implementation a dest control-flow stack entry is just the target address and an orig entry is just the address to be patched. Our locals implementation adds a word list to every orig or dest item. It is the list of locals visible (or assumed visible) at the point described by the entry. Our implementation also adds a tag to identify the kind of entry, in particular to differentiate between live and dead (reachable and unreachable) orig entries.

A few unusual operations have to be performed on locals word lists:

`common-list` *list1 list2 – list3* gforth-internal "common-list"

`sub-list?` *list1 list2 – f* gforth-internal "sub-list?"

`list-size` *list – u* gforth-internal "list-size"

Several features of our locals word list implementation make these operations easy to implement: The locals word lists are organised as linked lists; the tails of these lists are shared, if the lists contain some of the same locals; and the address of a name is greater than the address of the names behind it in the list.

Another important implementation detail is the variable `dead-code`. It is used by `BEGIN` and `THEN` to determine if they can be reached directly or only through the branch that they resolve. `dead-code` is set by `UNREACHABLE`, `AHEAD`, `EXIT` etc., and cleared at the start of a colon definition, by `BEGIN` and usually by `THEN`.

Counted loops are similar to other loops in most respects, but `LEAVE` requires special attention: It performs basically the same service as `AHEAD`, but it does not create a control-flow stack entry. Therefore the information has to be stored elsewhere; traditionally, the information was stored in the target fields of the branches created by the `LEAVE`s, by organizing these fields into a linked list. Unfortunately, this clever trick does not provide enough space for storing our extended control flow information. Therefore, we introduce another stack, the leave stack. It contains the control-flow stack entries for all unresolved `LEAVE`s.

Local names are kept until the end of the colon definition, even if they are no longer visible in any control-flow path. In a few cases this may lead to increased space needs for the locals name area, but usually less than reclaiming this space would cost in code size.

4.19.2 ANS Forth locals

The ANS Forth locals wordset does not define a syntax for locals, but words that make it possible to define various syntaxes. One of the possible syntaxes is a subset of the syntax we used in the Gforth locals wordset, i.e.:

```
{ local1 local2 ... -- comment }
```

or

```
{ local1 local2 ... }
```

The order of the locals corresponds to the order in a stack comment. The restrictions are:

- Locals can only be cell-sized values (no type specifiers are allowed).
- Locals can be defined only outside control structures.
- Locals can interfere with explicit usage of the return stack. For the exact (and long) rules, see the standard. If you don't use return stack accessing words in a definition using locals, you will be all right. The purpose of this rule is to make locals implementation on the return stack easier.
- The whole definition must be in one line.

Locals defined in this way behave like `VALUE`s (See Section 4.8.1 [Simple Defining Words], page 52). I.e., they are initialized from the stack. Using their name produces their value. Their value can be changed using `TO`.

Since this syntax is supported by Gforth directly, you need not do anything to use it. If you want to port a program using this syntax to another ANS Forth system, use '`compat/anslocal.fs`' to implement the syntax on the other system.

Note that a syntax shown in the standard, section A.13 looks similar, but is quite different in having the order of locals reversed. Beware!

The ANS Forth locals wordset itself consists of a word:

`(local)` *addr u* – local "paren-local-paren"

The ANS Forth locals extension wordset defines a syntax using `locals|`, but it is so awful that we strongly recommend not to use it. We have implemented this syntax to make porting to Gforth easy, but do not document it here. The problem with this syntax is that the locals are defined in an order reversed with respect to the standard stack comment notation, making programs harder to read, and easier to misread and miswrite. The only merit of this syntax is that it is easy to implement using the ANS Forth locals wordset.

4.20 Structures

This section presents the structure package that comes with Gforth. A version of the package implemented in ANS Forth is available in '`compat/struct.fs`'. This package was inspired by a posting on comp.lang.forth in 1989 (unfortunately I don't remember, by whom; possibly John Hayes). A version of this section has been published in ???. Marcel Hendrix provided helpful comments.

4.20.1 Why explicit structure support?

If we want to use a structure containing several fields, we could simply reserve memory for it, and access the fields using address arithmetic (see Section 4.6.5 [Address arithmetic], page 41). As an example, consider a structure with the following fields

`a` is a float

`b` is a cell

`c` is a float

Given the (float-aligned) base address of the structure we get the address of the field

`a` without doing anything further.

`b` with `float+`

`c` with `float+ cell+ faligned`

It is easy to see that this can become quite tiring.

Moreover, it is not very readable, because seeing a `cell+` tells us neither which kind of structure is accessed nor what field is accessed; we have to somehow infer the kind of structure, and then look up in the documentation, which field of that structure corresponds to that offset.

Finally, this kind of address arithmetic also causes maintenance troubles: If you add or delete a field somewhere in the middle of the structure, you have to find and change all computations for the fields afterwards.

So, instead of using `cell+` and friends directly, how about storing the offsets in constants:

```
0 constant a-offset
0 float+ constant b-offset
0 float+ cell+ faligned c-offset
```

Now we can get the address of field `x` with `x-offset +`. This is much better in all respects. Of course, you still have to change all later offset definitions if you add a field. You can fix this by declaring the offsets in the following way:

```
0 constant a-offset
a-offset float+ constant b-offset
b-offset cell+ faligned constant c-offset
```

Since we always use the offsets with `+`, we could use a defining word `cfield` that includes the `+` in the action of the defined word:

```
: cfield ( n "name" -- )
    create ,
does> ( name execution: addr1 -- addr2 )
    @ + ;

0 cfield a
0 a float+ cfield b
0 b cell+ faligned cfield c
```

Instead of `x-offset +`, we now simply write `x`.

The structure field words now can be used quite nicely. However, their definition is still a bit cumbersome: We have to repeat the name, the information about size and alignment is distributed before and after the field definitions etc. The structure package presented here addresses these problems.

4.20.2 Structure Usage

You can define a structure for a (data-less) linked list with:

```
struct
    cell% field list-next
end-struct list%
```

With the address of the list node on the stack, you can compute the address of the field that contains the address of the next node with `list-next`. E.g., you can determine the length of a list with:

```
: list-length ( list -- n )
\ "list" is a pointer to the first element of a linked list
\ "n" is the length of the list
    0 BEGIN ( list1 n1 )
        over
    WHILE ( list1 n1 )
        1+ swap list-next @ swap
    REPEAT
    nip ;
```

You can reserve memory for a list node in the dictionary with `list% %allot`, which leaves the address of the list node on the stack. For the equivalent allocation on the heap

you can use `list% %alloc` (or, for an `allocate`-like stack effect (i.e., with ior), use `list% %allocate`). You can get the the size of a list node with `list% %size` and its alignment with `list% %alignment`.

Note that in ANS Forth the body of a `created` word is `aligned` but not necessarily `faligned`; therefore, if you do a:

```
create name foo% %allot
```

then the memory alloted for `foo%` is guaranteed to start at the body of *name* only if `foo%` contains only character, cell and double fields.

You can include a structure `foo%` as a field of another structure, like this:

```
struct
...
    foo% field ...
...
end-struct ...
```

Instead of starting with an empty structure, you can extend an existing structure. E.g., a plain linked list without data, as defined above, is hardly useful; You can extend it to a linked list of integers, like this:[27]

```
list%
    cell% field intlist-int
end-struct intlist%
```

`intlist%` is a structure with two fields: `list-next` and `intlist-int`.

You can specify an array type containing *n* elements of type `foo%` like this:

```
foo% n *
```

You can use this array type in any place where you can use a normal type, e.g., when defining a `field`, or with `%allot`.

The first field is at the base address of a structure and the word for this field (e.g., `list-next`) actually does not change the address on the stack. You may be tempted to leave it away in the interest of run-time and space efficiency. This is not necessary, because the structure package optimizes this case and compiling such words does not generate any code. So, in the interest of readability and maintainability you should include the word for the field when accessing the field.

4.20.3 Structure Naming Convention

The field names that come to (my) mind are often quite generic, and, if used, would cause frequent name clashes. E.g., many structures probably contain a `counter` field. The structure names that come to (my) mind are often also the logical choice for the names of words that create such a structure.

Therefore, I have adopted the following naming conventions:

---

[27] This feature is also known as *extended records*. It is the main innovation in the Oberon language; in other words, adding this feature to Modula-2 led Wirth to create a new language, write a new compiler etc. Adding this feature to Forth just required a few lines of code.

- The names of fields are of the form *struct-field*, where *struct* is the basic name of the structure, and *field* is the basic name of the field. You can think of field words as converting the (address of the) structure into the (address of the) field.
- The names of structures are of the form *struct*`%`, where *struct* is the basic name of the structure.

This naming convention does not work that well for fields of extended structures; e.g., the integer list structure has a field `intlist-int`, but has `list-next`, not `intlist-next`.

4.20.4 Structure Implementation

The central idea in the implementation is to pass the data about the structure being built on the stack, not in some global variable. Everything else falls into place naturally once this design decision is made.

The type description on the stack is of the form *align size*. Keeping the size on the top-of-stack makes dealing with arrays very simple.

`field` is a defining word that uses `Create` and `DOES>`. The body of the field contains the offset of the field, and the normal `DOES>` action is simply:

```
+
```

i.e., add the offset to the address, giving the stack effect *addr1 – addr2* for a field.

This simple structure is slightly complicated by the optimization for fields with offset 0, which requires a different `DOES>`-part (because we cannot rely on there being something on the stack if such a field is invoked during compilation). Therefore, we put the different `DOES>`-parts in separate words, and decide which one to invoke based on the offset. For a zero offset, the field is basically a noop; it is immediate, and therefore no code is generated when it is compiled.

4.20.5 Structure Glossary

`%align` *align size –* gforth "%align"

Align the data space pointer to the alignment *align*.

`%alignment` *align size – align* gforth "%alignment"

The alignment of the structure.

`%alloc` *size align – addr* gforth "%alloc"

Allocate *size* address units with alignment *align*, giving a data block at *addr*; `throw` an ior code if not successful.

`%allocate` *align size – addr ior* gforth "%allocate"

Allocate *size* address units with alignment *align*, similar to `allocate`.

`%allot` *align size – addr* gforth "%allot"

Allot *size* address units of data space with alignment *align*; the resulting block of data is found at *addr*.

`cell%` *– align size* gforth "cell%"

`char%` *– align size* gforth "char%"

`dfloat%` *– align size* gforth "dfloat%"

`double%` – *align size* gforth "double%"

`end-struct` *align size* "*name*" – gforth "end-struct"

`name` execution: *addr1* – *addr1*+*offset1*
Create a field *name* with offset *offset1*, and the type given by *size align*. *offset2* is the offset of the next field, and *align2* is the alignment of all fields.

`field` *align1 offset1 align size* "*name*" – *align2 offset2* gforth "field"

`name` execution: *addr1* – *addr2*.

`float%` – *align size* gforth "float%"

`naligned` *addr1 n* – *addr2* gforth "naligned"

addr2 is the aligned version of *addr1* with respect to the alignment *n*.

`sfloat%` – *align size* gforth "sfloat%"

`%size` *align size* – *size* gforth "%size"

The size of the structure.

`struct` – *align size* gforth "struct"

An empty structure, used to start a structure definition.

4.21 Object-oriented Forth

Gforth comes with three packages for object-oriented programming: '`objects.fs`', '`oof.fs`', and '`mini-oof.fs`'; none of them is preloaded, so you have to `include` them before use. The most important differences between these packages (and others) are discussed in Section 4.21.3.4 [Comparison with other object models], page 127. All packages are written in ANS Forth and can be used with any other ANS Forth.

4.21.0.1 Why object-oriented programming?

Often we have to deal with several data structures (*objects*), that have to be treated similarly in some respects, but differently in others. Graphical objects are the textbook example: circles, triangles, dinosaurs, icons, and others, and we may want to add more during program development. We want to apply some operations to any graphical object, e.g., `draw` for displaying it on the screen. However, `draw` has to do something different for every kind of object.

We could implement `draw` as a big `CASE` control structure that executes the appropriate code depending on the kind of object to be drawn. This would be not be very elegant, and, moreover, we would have to change `draw` every time we add a new kind of graphical object (say, a spaceship).

What we would rather do is: When defining spaceships, we would tell the system: "Here's how you `draw` a spaceship; you figure out the rest".

This is the problem that all systems solve that (rightfully) call themselves object-oriented; the object-oriented packages presented here solve this problem (and not much else).

4.21.0.2 Object-Oriented Terminology

This section is mainly for reference, so you don't have to understand all of it right away. The terminology is mainly Smalltalk-inspired. In short:

class a data structure definition with some extras.

object an instance of the data structure described by the class definition.

instance variables
fields of the data structure.

selector (or *method selector*) a word (e.g., `draw`) that performs an operation on a variety of data structures (classes). A selector describes *what* operation to perform. In C++ terminology: a (pure) virtual function.

method the concrete definition that performs the operation described by the selector for a specific class. A method specifies *how* the operation is performed for a specific class.

selector invocation
a call of a selector. One argument of the call (the TOS (top-of-stack)) is used for determining which method is used. In Smalltalk terminology: a message (consisting of the selector and the other arguments) is sent to the object.

receiving object
the object used for determining the method executed by a selector invocation. In the '`objects.fs`' model, it is the object that is on the TOS when the selector is invoked. (*Receiving* comes from the Smalltalk *message* terminology.)

child class a class that has (*inherits*) all properties (instance variables, selectors, methods) from a *parent class*. In Smalltalk terminology: The subclass inherits from the superclass. In C++ terminology: The derived class inherits from the base class.

4.21.1 The '`objects.fs`' model

This section describes the '`objects.fs`' package. This material also has been published in *Yet Another Forth Objects Package* by Anton Ertl and appeared in Forth Dimensions 19(2), pages 37–43 (`http://www.complang.tuwien.ac.at/forth/objects/objects.html`).

This section assumes that you have read Section 4.20 [Structures], page 105.

The techniques on which this model is based have been used to implement the parser generator, Gray, and have also been used in Gforth for implementing the various flavours of word lists (hashed or not, case-sensitive or not, special-purpose word lists for locals etc.).

Marcel Hendrix provided helpful comments on this section. Andras Zsoter and Bernd Paysan helped me with the related works section.

4.21.1.1 Properties of the '`objects.fs`' model

- It is straightforward to pass objects on the stack. Passing selectors on the stack is a little less convenient, but possible.

- Objects are just data structures in memory, and are referenced by their address. You can create words for objects with normal defining words like `constant`. Likewise, there is no difference between instance variables that contain objects and those that contain other data.
- Late binding is efficient and easy to use.
- It avoids parsing, and thus avoids problems with state-smartness and reduced extensibility; for convenience there are a few parsing words, but they have non-parsing counterparts. There are also a few defining words that parse. This is hard to avoid, because all standard defining words parse (except `:noname`); however, such words are not as bad as many other parsing words, because they are not state-smart.
- It does not try to incorporate everything. It does a few things and does them well (IMO). In particular, this model was not designed to support information hiding (although it has features that may help); you can use a separate package for achieving this.
- It is layered; you don't have to learn and use all features to use this model. Only a few features are necessary (See Section 4.21.1.2 [Basic Objects Usage], page 111, See Section 4.21.1.3 [The Objects base class], page 112, See Section 4.21.1.4 [Creating objects], page 112.), the others are optional and independent of each other.
- An implementation in ANS Forth is available.

4.21.1.2 Basic '`objects.fs`' Usage

You can define a class for graphical objects like this:

```
object class \ "object" is the parent class
  selector draw ( x y graphical -- )
end-class graphical
```

This code defines a class `graphical` with an operation `draw`. We can perform the operation `draw` on any `graphical` object, e.g.:

```
100 100 t-rex draw
```

where `t-rex` is a word (say, a constant) that produces a graphical object.

How do we create a graphical object? With the present definitions, we cannot create a useful graphical object. The class `graphical` describes graphical objects in general, but not any concrete graphical object type (C++ users would call it an *abstract class*); e.g., there is no method for the selector `draw` in the class `graphical`.

For concrete graphical objects, we define child classes of the class `graphical`, e.g.:

```
graphical class \ "graphical" is the parent class
  cell% field circle-radius

:noname ( x y circle -- )
  circle-radius @ draw-circle ;
overrides draw

:noname ( n-radius circle -- )
  circle-radius ! ;
```

```
overrides construct

end-class circle
```

Here we define a class `circle` as a child of `graphical`, with field `circle-radius` (which behaves just like a field (see Section 4.20 [Structures], page 105); it defines (using `overrides`) new methods for the selectors `draw` and `construct` (`construct` is defined in `object`, the parent class of `graphical`).

Now we can create a circle on the heap (i.e., `allocate`d memory) with:

```
50 circle heap-new constant my-circle
```

`heap-new` invokes `construct`, thus initializing the field `circle-radius` with 50. We can draw this new circle at (100,100) with:

```
100 100 my-circle draw
```

Note: You can only invoke a selector if the object on the TOS (the receiving object) belongs to the class where the selector was defined or one of its descendents; e.g., you can invoke `draw` only for objects belonging to `graphical` or its descendents (e.g., `circle`). Immediately before `end-class`, the search order has to be the same as immediately after `class`.

4.21.1.3 The '`object.fs`' base class

When you define a class, you have to specify a parent class. So how do you start defining classes? There is one class available from the start: `object`. It is ancestor for all classes and so is the only class that has no parent. It has two selectors: `construct` and `print`.

4.21.1.4 Creating objects

You can create and initialize an object of a class on the heap with `heap-new` (... class – object) and in the dictionary (allocation with `allot`) with `dict-new` (... class – object). Both words invoke `construct`, which consumes the stack items indicated by "..." above.

If you want to allocate memory for an object yourself, you can get its alignment and size with `class-inst-size 2@` (class – align size). Once you have memory for an object, you can initialize it with `init-object` (... class object –); `construct` does only a part of the necessary work.

4.21.1.5 Object-Oriented Programming Style

This section is not exhaustive.

In general, it is a good idea to ensure that all methods for the same selector have the same stack effect: when you invoke a selector, you often have no idea which method will be invoked, so, unless all methods have the same stack effect, you will not know the stack effect of the selector invocation.

One exception to this rule is methods for the selector `construct`. We know which method is invoked, because we specify the class to be constructed at the same place. Actually, I defined `construct` as a selector only to give the users a convenient way to specify initialization. The way it is used, a mechanism different from selector invocation would be more natural (but probably would take more code and more space to explain).

4.21.1.6 Class Binding

Normal selector invocations determine the method at run-time depending on the class of the receiving object. This run-time selection is called *late binding*.

Sometimes it's preferable to invoke a different method. For example, you might want to use the simple method for `print`ing `object`s instead of the possibly long-winded `print` method of the receiver class. You can achieve this by replacing the invocation of `print` with:

```
[bind] object print
```

in compiled code or:

```
bind object print
```

in interpreted code. Alternatively, you can define the method with a name (e.g., `print-object`), and then invoke it through the name. Class binding is just a (often more convenient) way to achieve the same effect; it avoids name clutter and allows you to invoke methods directly without naming them first.

A frequent use of class binding is this: When we define a method for a selector, we often want the method to do what the selector does in the parent class, and a little more. There is a special word for this purpose: `[parent]`; `[parent]` *selector* is equivalent to `[bind]` *parent selector*, where *parent* is the parent class of the current class. E.g., a method definition might look like:

```
:noname
  dup [parent] foo \ do parent's foo on the receiving object
  ... \ do some more
; overrides foo
```

In *Object-oriented programming in ANS Forth* (Forth Dimensions, March 1997), Andrew McKewan presents class binding as an optimization technique. I recommend not using it for this purpose unless you are in an emergency. Late binding is pretty fast with this model anyway, so the benefit of using class binding is small; the cost of using class binding where it is not appropriate is reduced maintainability.

While we are at programming style questions: You should bind selectors only to ancestor classes of the receiving object. E.g., say, you know that the receiving object is of class `foo` or its descendents; then you should bind only to `foo` and its ancestors.

4.21.1.7 Method conveniences

In a method you usually access the receiving object pretty often. If you define the method as a plain colon definition (e.g., with `:noname`), you may have to do a lot of stack gymnastics. To avoid this, you can define the method with `m: ... ;m`. E.g., you could define the method for `draw`ing a `circle` with

```
m: ( x y circle -- )
  ( x y ) this circle-radius @ draw-circle ;m
```

When this method is executed, the receiver object is removed from the stack; you can access it with `this` (admittedly, in this example the use of `m: ... ;m` offers no advantage). Note that I specify the stack effect for the whole method (i.e. including the receiver object),

not just for the code between `m:` and `;m`. You cannot use `exit` in `m: ... ;m`; instead, use `exitm`.[28]

You will frequently use sequences of the form `this` *field* (in the example above: `this circle-radius`). If you use the field only in this way, you can define it with `inst-var` and eliminate the `this` before the field name. E.g., the `circle` class above could also be defined with:

```
graphical class
  cell% inst-var radius

m: ( x y circle -- )
  radius @ draw-circle ;m
overrides draw

m: ( n-radius circle -- )
  radius ! ;m
overrides construct

end-class circle
```

`radius` can only be used in `circle` and its descendent classes and inside `m: ... ;m`.

You can also define fields with `inst-value`, which is to `inst-var` what `value` is to `variable`. You can change the value of such a field with `[to-inst]`. E.g., we could also define the class `circle` like this:

```
graphical class
  inst-value radius

m: ( x y circle -- )
  radius draw-circle ;m
overrides draw

m: ( n-radius circle -- )
  [to-inst] radius ;m
overrides construct

end-class circle
```

4.21.1.8 Classes and Scoping

Inheritance is frequent, unlike structure extension. This exacerbates the problem with the field name convention (see Section 4.20.3 [Structure Naming Convention], page 107): One always has to remember in which class the field was originally defined; changing a part of the class structure would require changes for renaming in otherwise unaffected code.

To solve this problem, I added a scoping mechanism (which was not in my original charter): A field defined with `inst-var` (or `inst-value`) is visible only in the class where

[28] Moreover, for any word that calls `catch` and was defined before loading `objects.fs`, you have to redefine it like I redefined `catch`: `: catch this >r catch r> to-this ;`

it is defined and in the descendent classes of this class. Using such fields only makes sense in `m:`-defined methods in these classes anyway.

This scoping mechanism allows us to use the unadorned field name, because name clashes with unrelated words become much less likely.

Once we have this mechanism, we can also use it for controlling the visibility of other words: All words defined after `protected` are visible only in the current class and its descendents. `public` restores the compilation (i.e. `current`) word list that was in effect before. If you have several `protected`s without an intervening `public` or `set-current`, `public` will restore the compilation word list in effect before the first of these `protected`s.

4.21.1.9 Object Interfaces

In this model you can only call selectors defined in the class of the receiving objects or in one of its ancestors. If you call a selector with a receiving object that is not in one of these classes, the result is undefined; if you are lucky, the program crashes immediately.

Now consider the case when you want to have a selector (or several) available in two classes: You would have to add the selector to a common ancestor class, in the worst case to `object`. You may not want to do this, e.g., because someone else is responsible for this ancestor class.

The solution for this problem is interfaces. An interface is a collection of selectors. If a class implements an interface, the selectors become available to the class and its descendents. A class can implement an unlimited number of interfaces. For the problem discussed above, we would define an interface for the selector(s), and both classes would implement the interface.

As an example, consider an interface `storage` for writing objects to disk and getting them back, and a class `foo` that implements it. The code would look like this:

```
interface
  selector write ( file object -- )
  selector read1 ( file object -- )
end-interface storage

bar class
  storage implementation

... overrides write
... overrides read
...
end-class foo
```

(I would add a word `read` *(file – object)* that uses `read1` internally, but that's beyond the point illustrated here.)

Note that you cannot use `protected` in an interface; and of course you cannot define fields.

In the Neon model, all selectors are available for all classes; therefore it does not need interfaces. The price you pay in this model is slower late binding, and therefore, added complexity to avoid late binding.

4.21.1.10 'objects.fs' Implementation

An object is a piece of memory, like one of the data structures described with `struct...end-struct`. It has a field `object-map` that points to the method map for the object's class.

The *method map*[29] is an array that contains the execution tokens (*xt*s) of the methods for the object's class. Each selector contains an offset into a method map.

`selector` is a defining word that uses `CREATE` and `DOES>`. The body of the selector contains the offset; the `does>` action for a class selector is, basically:

```
( object addr ) @ over object-map @ + @ execute
```

Since `object-map` is the first field of the object, it does not generate any code. As you can see, calling a selector has a small, constant cost.

A class is basically a `struct` combined with a method map. During the class definition the alignment and size of the class are passed on the stack, just as with `struct`s, so `field` can also be used for defining class fields. However, passing more items on the stack would be inconvenient, so `class` builds a data structure in memory, which is accessed through the variable `current-interface`. After its definition is complete, the class is represented on the stack by a pointer (e.g., as parameter for a child class definition).

A new class starts off with the alignment and size of its parent, and a copy of the parent's method map. Defining new fields extends the size and alignment; likewise, defining new selectors extends the method map. `overrides` just stores a new *xt* in the method map at the offset given by the selector.

Class binding just gets the *xt* at the offset given by the selector from the class's method map and `compile,`s (in the case of `[bind]`) it.

I implemented `this` as a `value`. At the start of an `m:...;m` method the old `this` is stored to the return stack and restored at the end; and the object on the TOS is stored `TO this`. This technique has one disadvantage: If the user does not leave the method via `;m`, but via `throw` or `exit`, `this` is not restored (and `exit` may crash). To deal with the `throw` problem, I have redefined `catch` to save and restore `this`; the same should be done with any word that can catch an exception. As for `exit`, I simply forbid it (as a replacement, there is `exitm`).

`inst-var` is just the same as `field`, with a different `DOES>` action:

```
@ this +
```

Similar for `inst-value`.

Each class also has a word list that contains the words defined with `inst-var` and `inst-value`, and its protected words. It also has a pointer to its parent. `class` pushes the word lists of the class and all its ancestors onto the search order stack, and `end-class` drops them.

An interface is like a class without fields, parent and protected words; i.e., it just has a method map. If a class implements an interface, its method map contains a pointer to the method map of the interface. The positive offsets in the map are reserved for class methods, therefore interface map pointers have negative offsets. Interfaces have offsets that

[29] This is Self terminology; in C++ terminology: virtual function table.

are unique throughout the system, unlike class selectors, whose offsets are only unique for the classes where the selector is available (invokable).

This structure means that interface selectors have to perform one indirection more than class selectors to find their method. Their body contains the interface map pointer offset in the class method map, and the method offset in the interface method map. The `does>` action for an interface selector is, basically:

```
( object selector-body )
2dup selector-interface @ ( object selector-body object interface-offset )
swap object-map @ + @ ( object selector-body map )
swap selector-offset @ + @ execute
```

where `object-map` and `selector-offset` are first fields and generate no code.

As a concrete example, consider the following code:

```
interface
  selector if1sel1
  selector if1sel2
end-interface if1

object class
  if1 implementation
  selector cl1sel1
  cell% inst-var cl1iv1

' m1 overrides construct
' m2 overrides if1sel1
' m3 overrides if1sel2
' m4 overrides cl1sel2
end-class cl1

create obj1 object dict-new drop
create obj2 cl1    dict-new drop
```

The data structure created by this code (including the data structure for `object`) is shown in the figure, assuming a cell size of 4.

4.21.1.11 'objects.fs' Glossary

`bind` ... "*class*" "*selector*" – ... objects "bind"

Execute the method for *selector* in *class*.

`<bind>` *class selector-xt* – *xt* objects "<bind>"

xt is the method for the selector *selector-xt* in *class*.

`bind'` "*class*" "*selector*" – *xt* objects "bind'"

xt is the method for *selector* in *class*.

`[bind]` *compile-time:* "*class*" "*selector*" – ; *run-time:* ... *object* – ... objects "[bind]"

Compile the method for *selector* in *class*.

`class` *parent-class – align offset* objects "class"

Start a new class definition as a child of *parent-class*. *align offset* are for use by *field* etc.

`class->map` *class – map* objects "class->map"

map is the pointer to *class*'s method map; it points to the place in the map to which the selector offsets refer (i.e., where *object-map*s point to).

`class-inst-size` *class – addr* objects "class-inst-size"

Give the size specification for an instance (i.e. an object) of *class*; used as `class-inst-size 2 ( class -- align size )`.

`class-override!` *xt sel-xt class-map –* objects "class-override!"

xt is the new method for the selector *sel-xt* in *class-map*.

`construct` *... object –* objects "construct"

Initialize the data fields of *object*. The method for the class *object* just does nothing: `( object -- )`.

`current'` `"`*selector*`"` *– xt* objects "current"'

xt is the method for *selector* in the current class.

`[current]` *compile-time:* `"`*selector*`"` *– ; run-time: ... object – ...* objects "[current]"

Compile the method for *selector* in the current class.

`current-interface` *– addr* objects "current-interface"

Variable: contains the class or interface currently being defined.

`dict-new` *... class – object* objects "dict-new"

`allot` and initialize an object of class *class* in the dictionary.

`drop-order` *class –* objects "drop-order"

Drop *class*'s wordlists from the search order. No checking is made whether *class*'s wordlists are actually on the search order.

`end-class` *align offset* `"`*name*`"` *–* objects "end-class"

name execution: `-- class`
End a class definition. The resulting class is *class*.

`end-class-noname` *align offset – class* objects "end-class-noname"

End a class definition. The resulting class is *class*.

`end-interface` `"`*name*`"` *–* objects "end-interface"

`name` execution: `-- interface`
End an interface definition. The resulting interface is *interface*.

`end-interface-noname` *– interface* objects "end-interface-noname"

End an interface definition. The resulting interface is *interface*.

`exitm` – objects "exitm"

`exit` from a method; restore old `this`.

`heap-new` *... class – object* objects "heap-new"

`allocate` and initialize an object of class *class*.

`implementation` *interface* – objects "implementation"

The current class implements *interface*. I.e., you can use all selectors of the interface in the current class and its descendents.

`init-object` ... *class object* – objects "init-object"

Initialize a chunk of memory (*object*) to an object of class *class*; then performs `construct`.

`inst-value` *align1 offset1* "*name*" – *align2 offset2* objects "inst-value"

name execution: `-- w`
w is the value of the field *name* in `this` object.

`inst-var` *align1 offset1 align size* "*name*" – *align2 offset2* objects "inst-var"

name execution: `-- addr`
addr is the address of the field *name* in `this` object.

`interface` – objects "interface"

Start an interface definition.

`;m` *colon-sys –; run-time:* – objects ";m"

End a method definition; restore old `this`.

`m:` – *xt colon-sys; run-time: object* – objects "m:"

Start a method definition; *object* becomes new `this`.

`method` *xt* "*name*" – objects "method"

`name` execution: `... object -- ...`
Create selector *name* and makes *xt* its method in the current class.

`object` – *class* objects "object"

the ancestor of all classes.

`overrides` *xt* "*selector*" – objects "overrides"

replace default method for *selector* in the current class with *xt*. `overrides` must not be used during an interface definition.

`[parent]` *compile-time:* "*selector*" – *; run-time: ... object* – ... objects "[parent]"

Compile the method for *selector* in the parent of the current class.

`print` *object* – objects "print"

Print the object. The method for the class *object* prints the address of the object and the address of its class.

`protected` – objects "protected"

Set the compilation wordlist to the current class's wordlist

`public` – objects "public"

Restore the compilation wordlist that was in effect before the last `protected` that actually changed the compilation wordlist.

`push-order` *class* – objects "push-order"

Add *class*'s wordlists to the head of the search-order.

`selector` `"`*name*`"` – objects "selector"

name execution: `... object -- ...`
Create selector *name* for the current class and its descendents; you can set a method for the selector in the current class with `overrides`.

`this` – *object* objects "this"

the receiving object of the current method (aka active object).

`<to-inst>` *w xt* – objects "<to-inst>"

store *w* into the field *xt* in `this` object.

`[to-inst]` *compile-time:* `"`*name*`"` – *; run-time:* *w* – objects "[to-inst]"

store *w* into field *name* in `this` object.

`to-this` *object* – objects "to-this"

Set `this` (used internally, but useful when debugging).

`xt-new` *... class xt – object* objects "xt-new"

Make a new object, using `xt ( align size -- addr )` to get memory.

4.21.2 The '`oof.fs`' model

This section describes the '`oof.fs`' package.

The package described in this section has been used in bigFORTH since 1991, and used for two large applications: a chromatographic system used to create new medicaments, and a graphic user interface library (MINOS).

You can find a description (in German) of '`oof.fs`' in *Object oriented bigFORTH* by Bernd Paysan, published in *Vierte Dimension* 10(2), 1994.

4.21.2.1 Properties of the '`oof.fs`' model

- This model combines object oriented programming with information hiding. It helps you writing large application, where scoping is necessary, because it provides class-oriented scoping.
- Named objects, object pointers, and object arrays can be created, selector invocation uses the "object selector" syntax. Selector invocation to objects and/or selectors on the stack is a bit less convenient, but possible.
- Selector invocation and instance variable usage of the active object is straightforward, since both make use of the active object.
- Late binding is efficient and easy to use.
- State-smart objects parse selectors. However, extensibility is provided using a (parsing) selector `postpone` and a selector `'`.
- An implementation in ANS Forth is available.

4.21.2.2 Basic 'oof.fs' Usage

This section uses the same example as for `objects` (see Section 4.21.1.2 [Basic Objects Usage], page 111).

You can define a class for graphical objects like this:

```
object class graphical \ "object" is the parent class
  method draw ( x y graphical -- )
class;
```

This code defines a class `graphical` with an operation `draw`. We can perform the operation `draw` on any `graphical` object, e.g.:

```
100 100 t-rex draw
```

where `t-rex` is an object or object pointer, created with e.g. `graphical : t-rex`.

How do we create a graphical object? With the present definitions, we cannot create a useful graphical object. The class `graphical` describes graphical objects in general, but not any concrete graphical object type (C++ users would call it an *abstract class*); e.g., there is no method for the selector `draw` in the class `graphical`.

For concrete graphical objects, we define child classes of the class `graphical`, e.g.:

```
graphical class circle \ "graphical" is the parent class
  cell var circle-radius
how:
  : draw ( x y -- )
    circle-radius @ draw-circle ;

  : init ( n-radius -- (
    circle-radius ! ;
class;
```

Here we define a class `circle` as a child of `graphical`, with a field `circle-radius`; it defines new methods for the selectors `draw` and `init` (`init` is defined in `object`, the parent class of `graphical`).

Now we can create a circle in the dictionary with:

```
50 circle : my-circle
```

`:` invokes `init`, thus initializing the field `circle-radius` with 50. We can draw this new circle at (100,100) with:

```
100 100 my-circle draw
```

Note: You can only invoke a selector if the receiving object belongs to the class where the selector was defined or one of its descendents; e.g., you can invoke `draw` only for objects belonging to `graphical` or its descendents (e.g., `circle`). The scoping mechanism will check if you try to invoke a selector that is not defined in this class hierarchy, so you'll get an error at compilation time.

4.21.2.3 The 'oof.fs' base class

When you define a class, you have to specify a parent class. So how do you start defining classes? There is one class available from the start: `object`. You have to use it as ancestor

for all classes. It is the only class that has no parent. Classes are also objects, except that they don't have instance variables; class manipulation such as inheritance or changing definitions of a class is handled through selectors of the class `object`.

`object` provides a number of selectors:

- `class` for subclassing, `definitions` to add definitions later on, and `class?` to get type informations (is the class a subclass of the class passed on the stack?).

  `class` "*name*" – oof "class"

  `definitions` – oof "definitions"

  `class?` *o* – *flag* oof "class-query"

- `init` and `dispose` as constructor and destructor of the object. `init` is invocated after the object's memory is allocated, while `dispose` also handles deallocation. Thus if you redefine `dispose`, you have to call the parent's dispose with `super dispose`, too.

  `init` ... – oof "init"

  `dispose` – oof "dispose"

- `new`, `new[]`, `:`, `ptr`, `asptr`, and `[]` to create named and unnamed objects and object arrays or object pointers.

  `new` – *o* oof "new"

  `new[]` *n* – *o* oof "new-array"

  `:` "*name*" – oof "define"

  `ptr` "*name*" – oof "ptr"

  `asptr` *o* "*name*" – oof "asptr"

  `[]` *n* "*name*" – oof "array"

- `::` and `super` for explicit scoping. You should use explicit scoping only for super classes or classes with the same set of instance variables. Explicitly-scoped selectors use early binding.

  `::` "*name*" – oof "scope"

  `super` "*name*" – oof "super"

- `self` to get the address of the object

  `self` – *o* oof "self"

- `bind`, `bound`, `link`, and `is` to assign object pointers and instance defers.

  `bind` *o* "*name*" – oof "bind"

  `bound` *class addr* "*name*" – oof "bound"

  `link` "*name*" – *class addr* oof "link"

  `is` *xt* "*name*" – oof "is"

- `'` to obtain selector tokens, `send` to invocate selectors form the stack, and `postpone` to generate selector invocation code.

  `'` "*name*" – *xt* oof "tick"

  `postpone` "*name*" – oof "postpone"

- `with` and `endwith` to select the active object from the stack, and enable its scope. Using `with` and `endwith` also allows you to create code using selector `postpone` without being trapped by the state-smart objects.

`with` *o* – oof "with"
`endwith` – oof "endwith"

4.21.2.4 Class Declaration

- Instance variables
  `var` *size* – oof "var"
  Create an instance variable
- Object pointers
  `ptr` – oof "ptr"
  Create an instance pointer
  `asptr` *class* – oof "asptr"
  Create an alias to an instance pointer, cast to another class.
- Instance defers
  `defer` – oof "defer"
  Create an instance defer
- Method selectors
  `early` – oof "early"
  Create a method selector for early binding.
  `method` – oof "method"
  Create a method selector.
- Class-wide variables
  `static` – oof "static"
  Create a class-wide cell-sized variable.
- End declaration
  `how:` – oof "how-to"
  End declaration, start implementation
  `class;` – oof "end-class"
  End class declaration or implementation

4.21.2.5 Class Implementation

4.21.3 The '`mini-oof.fs`' model

Gforth's third object oriented Forth package is a 12-liner. It uses a mixture of the '`object.fs`' and the '`oof.fs`' syntax, and reduces to the bare minimum of features. This is based on a posting of Bernd Paysan in comp.arch.

4.21.3.1 Basic 'mini-oof.fs' Usage

There is a base class (`class`, which allocates one cell for the object pointer) plus seven other words: to define a method, a variable, a class; to end a class, to resolve binding, to allocate an object and to compile a class method.

`object` – *a-addr* mini-oof "object"

object is the base class of all objects.

`method` *m v* – *m' v* mini-oof "method"

Define a method.

`var` *m v size* – *m v'* mini-oof "var"

Define a variable with *size* bytes.

`class` *class* – *class methods vars* mini-oof "class"

Start the definition of a class.

`end-class` *class methods vars* – mini-oof "end-class"

End the definition of a class.

`defines` *xt class* "*name*" – mini-oof "defines"

Bind *xt* to the method *name* in class *class*.

`new` *class* – *o* mini-oof "new"

Create a new incarnation of the class *class*.

`::` *class* "*name*" – mini-oof "colon-colon"

Compile the method *name* of the class *class* (not immediate!).

4.21.3.2 Mini-OOF Example

A short example shows how to use this package. This example, in slightly extended form, is supplied as 'moof-exm.fs'

```
object class
  method init
  method draw
end-class graphical
```

This code defines a class `graphical` with an operation `draw`. We can perform the operation `draw` on any `graphical` object, e.g.:

```
100 100 t-rex draw
```

where `t-rex` is an object or object pointer, created with e.g. `graphical new Constant t-rex`.

For concrete graphical objects, we define child classes of the class `graphical`, e.g.:

```
graphical class
  cell var circle-radius
end-class circle \ "graphical" is the parent class

:noname ( x y -- )
  circle-radius @ draw-circle ; circle defines draw
:noname ( r -- )
```

```
circle-radius ! ; circle defines init
```

There is no implicit init method, so we have to define one. The creation code of the object now has to call init explicitely.

```
circle new Constant my-circle
50 my-circle init
```

It is also possible to add a function to create named objects with automatic call of `init`, given that all objects have `init` on the same place:

```
: new: ( .. o "name" -- )
    new dup Constant init ;
80 circle new: large-circle
```

We can draw this new circle at (100,100) with:

```
100 100 my-circle draw
```

4.21.3.3 'mini-oof.fs' Implementation

Object-oriented systems with late binding typically use a "vtable"-approach: the first variable in each object is a pointer to a table, which contains the methods as function pointers. The vtable may also contain other information.

So first, let's declare methods:

```
: method ( m v -- m' v ) Create  over , swap cell+ swap
  DOES> ( ... o -- ... )  over  +  execute ;
```

During method declaration, the number of methods and instance variables is on the stack (in address units). `method` creates one method and increments the method number. To execute a method, it takes the object, fetches the vtable pointer, adds the offset, and executes the *xt* stored there. Each method takes the object it is invoked from as top of stack parameter. The method itself should consume that object.

Now, we also have to declare instance variables

```
: var ( m v size -- m v' ) Create  over , +
  DOES> ( o -- addr )  + ;
```

As before, a word is created with the current offset. Instance variables can have different sizes (cells, floats, doubles, chars), so all we do is take the size and add it to the offset. If your machine has alignment restrictions, put the proper `aligned` or `faligned` before the variable, to adjust the variable offset. That's why it is on the top of stack.

We need a starting point (the base object) and some syntactic sugar:

```
Create object  1 cells , 2 cells ,
: class ( class -- class methods vars ) dup 2 ;
```

For inheritance, the vtable of the parent object has to be copied when a new, derived class is declared. This gives all the methods of the parent class, which can be overridden, though.

```
: end-class  ( class methods vars -- )
  Create  here >r , dup , 2 cells ?DO ['] noop , 1 cells +LOOP
  cell+ dup cell+ r> rot  2 cells /string move ;
```

The first line creates the vtable, initialized with `noop`s. The second line is the inheritance mechanism, it copies the xts from the parent vtable.

We still have no way to define new methods, let's do that now:

```
: defines ( xt class -- ) ' >body  + ! ;
```

To allocate a new object, we need a word, too:

```
: new ( class -- o )  here over  allot swap over ! ;
```

Sometimes derived classes want to access the method of the parent object. There are two ways to achieve this with Mini-OOF: first, you could use named words, and second, you could look up the vtable of the parent object.

```
: :: ( class "name" -- ) ' >body  +  compile, ;
```

Nothing can be more confusing than a good example, so here is one. First let's declare a text object (called `button`), that stores text and position:

```
object class
  cell var text
  cell var len
  cell var x
  cell var y
  method init
  method draw
end-class button
```

Now, implement the two methods, `draw` and `init`:

```
:noname ( o -- )
 >r r x  r y  at-xy  r text  r> len  type ;
 button defines draw
:noname ( addr u o -- )
 >r 0 r x ! 0 r y ! r len ! r> text ! ;
 button defines init
```

To demonstrate inheritance, we define a class `bold-button`, with no new data and no new methods:

```
button class
end-class bold-button

: bold   27 emit ." [1m" ;
: normal 27 emit ." [0m" ;
```

The class `bold-button` has a different draw method to `button`, but the new method is defined in terms of the draw method for `button`:

```
:noname bold [ button :: draw ] normal ; bold-button defines draw
```

Finally, create two objects and apply methods:

```
button new Constant foo
s" thin foo" foo init
page
foo draw
bold-button new Constant bar
s" fat bar" bar init
1 bar y !
bar draw
```

4.21.3.4 Comparison with other object models

Many object-oriented Forth extensions have been proposed (*A survey of object-oriented Forths* (SIGPLAN Notices, April 1996) by Bradford J. Rodriguez and W. F. S. Poehlman lists 17). This section discusses the relation of the object models described here to two well-known and two closely-related (by the use of method maps) models.

The most popular model currently seems to be the Neon model (see *Object-oriented programming in ANS Forth* (Forth Dimensions, March 1997) by Andrew McKewan) but this model has a number of limitations[30]:

- It uses a *selector object* syntax, which makes it unnatural to pass objects on the stack.
- It requires that the selector parses the input stream (at compile time); this leads to reduced extensibility and to bugs that are+ hard to find.
- It allows using every selector to every object; this eliminates the need for classes, but makes it harder to create efficient implementations.

Another well-known publication is *Object-Oriented Forth* (Academic Press, London, 1987) by Dick Pountain. However, it is not really about object-oriented programming, because it hardly deals with late binding. Instead, it focuses on features like information hiding and overloading that are characteristic of modular languages like Ada (83).

In *Does late binding have to be slow?* (Forth Dimensions 18(1) 1996, pages 31-35) Andras Zsoter describes a model that makes heavy use of an active object (like `this` in '`objects.fs`'): The active object is not only used for accessing all fields, but also specifies the receiving object of every selector invocation; you have to change the active object explicitly with `{ ... }`, whereas in '`objects.fs`' it changes more or less implicitly at `m: ... ;m`. Such a change at the method entry point is unnecessary with the Zsoter's model, because the receiving object is the active object already. On the other hand, the explicit change is absolutely necessary in that model, because otherwise no one could ever change the active object. An ANS Forth implementation of this model is available at `http://www.forth.org/fig/oopf.html`.

The '`oof.fs`' model combines information hiding and overloading resolution (by keeping names in various word lists) with object-oriented programming. It sets the active object implicitly on method entry, but also allows explicit changing (with `>o...o>` or with `with...endwith`). It uses parsing and state-smart objects and classes for resolving overloading and for early binding: the object or class parses the selector and determines the method from this. If the selector is not parsed by an object or class, it performs a call to the selector for the active object (late binding), like Zsoter's model. Fields are always accessed through the active object. The big disadvantage of this model is the parsing and the state-smartness, which reduces extensibility and increases the opportunities for subtle bugs; essentially, you are only safe if you never tick or `postpone` an object or class (Bernd disagrees, but I (Anton) am not convinced).

The '`mini-oof.fs`' model is quite similar to a very stripped-down version of the '`objects.fs`' model, but syntactically it is a mixture of the '`objects.fs`' and '`oof.fs`' models.

[30] A longer version of this critique can be found in *On Standardizing Object-Oriented Forth Extensions* (Forth Dimensions, May 1997) by Anton Ertl.

4.22 Passing Commands to the Operating System

Gforth allows you to pass an arbitrary string to the host operating system shell (if such a thing exists) for execution.

`sh` `"..."` – gforth "sh"

Parse a string and use `system` to pass it to the host operating system for execution in a sub-shell.

`system` *addr u* – gforth "system"

Pass the string specified by *c-addr, u* to the host operating system for execution in a sub-shell.

`$?` – *n* gforth "dollar-question"

VALUE: The exit status returned by the most recently executed `system` command.

`getenv` *c-addr1 u1* – *c-addr2 u2* gforth "getenv"

The string *c-addr1 u1* specifies an environment variable. The string *c-addr2 u2* is the host operating system's expansion of that environment variable. If the environment variable does not exist, *c-addr2 u2* specifies a string 0 characters in length.

4.23 Miscellaneous Words

These section lists the ANS Forth words that are not documented elsewhere in this manual. Ultimately, they all need proper homes.

`ms` *n* – facility-ext "ms"

`time&date` – *nsec nmin nhour nday nmonth nyear* facility-ext "time-and-date"

`[compile]` *compilation* `"`*name*`"` – *; run-time ? – ?* core-ext "bracket-compile"

The following ANS Forth words are not currently supported by Gforth (see Chapter 7 [ANS conformance], page 131):

`EDITOR EKEY EKEY>CHAR EKEY? EMIT? FORGET`

5 Error messages

A typical Gforth error message looks like this:

```
in file included from :-1
in file included from ./yyy.fs:1
./xxx.fs:4: Invalid memory address
bar
^^^
$400E664C @
$400E6664 foo
```

The message identifying the error is `Invalid memory address`. The error happened when text-interpreting line 4 of the file '`./xxx.fs`'. This line is given (it contains `bar`), and the word on the line where the error happened, is pointed out (with `^^^`).

The file containing the error was included in line 1 of '`./yyy.fs`', and '`yyy.fs`' was included from a non-file (in this case, by giving '`yyy.fs`' as command-line parameter to Gforth).

At the end of the error message you find a return stack dump that can be interpreted as a backtrace (possibly empty). On top you find the top of the return stack when the `throw` happened, and at the bottom you find the return stack entry just above the return stack of the topmost text interpreter.

To the right of most return stack entries you see a guess for the word that pushed that return stack entry as its return address. This gives a backtrace. In our case we see that `bar` called `foo`, and `foo` called `@` (and `@` had an *Invalid memory address* exception).

Note that the backtrace is not perfect: We don't know which return stack entries are return addresses (so we may get false positives); and in some cases (e.g., for `abort"`) we cannot determine from the return address the word that pushed the return address, so for some return addresses you see no names in the return stack dump.

The return stack dump represents the return stack at the time when a specific `throw` was executed. In programs that make use of `catch`, it is not necessarily clear which `throw` should be used for the return stack dump (e.g., consider one `throw` that indicates an error, which is caught, and during recovery another error happens; which `throw` should be used for the stack dump). Gforth presents the return stack dump for the first `throw` after the last executed (not returned-to) `catch`; this works well in the usual case.

`gforth` is able to do a return stack dump for throws generated from primitives (e.g., invalid memory address, stack empty etc.); `gforth-fast` is only able to do a return stack dump from a directly called `throw` (including `abort` etc.). This is the only difference (apart from a speed factor of between 1.15 (K6-2) and 1.6 (21164A)) between `gforth` and `gforth-fast`. Given an exception caused by a primitive in `gforth-fast`, you will typically see no return stack dump at all; however, if the exception is caught by `catch` (e.g., for restoring some state), and then `throw`n again, the return stack dump will be for the first such `throw`.

6 Tools

See also Chapter 10 [Emacs and Gforth], page 148.

6.1 'ans-report.fs': Report the words used, sorted by wordset

If you want to label a Forth program as ANS Forth Program, you must document which wordsets the program uses; for extension wordsets, it is helpful to list the words the program requires from these wordsets (because Forth systems are allowed to provide only some words of them).

The 'ans-report.fs' tool makes it easy for you to determine which words from which wordset and which non-ANS words your application uses. You simply have to include 'ans-report.fs' before loading the program you want to check. After loading your program, you can get the report with print-ans-report. A typical use is to run this as batch job like this:

```
gforth ans-report.fs myprog.fs -e "print-ans-report bye"
```

The output looks like this (for 'compat/control.fs'):

```
The program uses the following words
from CORE :
: POSTPONE THEN ; immediate ?dup IF 0=
from BLOCK-EXT :
\
from FILE :
(
```

6.1.1 Caveats

Note that 'ans-report.fs' just checks which words are used, not whether they are used in an ANS Forth conforming way!

Some words are defined in several wordsets in the standard. 'ans-report.fs' reports them for only one of the wordsets, and not necessarily the one you expect. It depends on usage which wordset is the right one to specify. E.g., if you only use the compilation semantics of S", it is a Core word; if you also use its interpretation semantics, it is a File word.

7 ANS conformance

To the best of our knowledge, Gforth is an

ANS Forth System

- providing the Core Extensions word set
- providing the Block word set
- providing the Block Extensions word set
- providing the Double-Number word set
- providing the Double-Number Extensions word set
- providing the Exception word set
- providing the Exception Extensions word set
- providing the Facility word set
- providing `MS` and `TIME&DATE` from the Facility Extensions word set
- providing the File Access word set
- providing the File Access Extensions word set
- providing the Floating-Point word set
- providing the Floating-Point Extensions word set
- providing the Locals word set
- providing the Locals Extensions word set
- providing the Memory-Allocation word set
- providing the Memory-Allocation Extensions word set (that one's easy)
- providing the Programming-Tools word set
- providing `;CODE`, `AHEAD`, `ASSEMBLER`, `BYE`, `CODE`, `CS-PICK`, `CS-ROLL`, `STATE`, `[ELSE]`, `[IF]`, `[THEN]` from the Programming-Tools Extensions word set
- providing the Search-Order word set
- providing the Search-Order Extensions word set
- providing the String word set
- providing the String Extensions word set (another easy one)

In addition, ANS Forth systems are required to document certain implementation choices. This chapter tries to meet these requirements. In many cases it gives a way to ask the system for the information instead of providing the information directly, in particular, if the information depends on the processor, the operating system or the installation options chosen, or if they are likely to change during the maintenance of Gforth.

7.1 The Core Words

7.1.1 Implementation Defined Options

(Cell) aligned addresses:
: processor-dependent. Gforth's alignment words perform natural alignment (e.g., an address aligned for a datum of size 8 is divisible by 8). Unaligned accesses usually result in a `-23 THROW`.

`EMIT` *and non-graphic characters:*
: The character is output using the C library function (actually, macro) `putc`.

character editing of `ACCEPT` *and* `EXPECT`*:*
: This is modeled on the GNU readline library (see section "Command Line Editing" in *The GNU Readline Library*) with Emacs-like key bindings. `Tab` deviates a little by producing a full word completion every time you type it (instead of producing the common prefix of all completions). See Section 2.3 [Command-line editing], page 13.

character set:
: The character set of your computer and display device. Gforth is 8-bit-clean (but some other component in your system may make trouble).

Character-aligned address requirements:
: installation-dependent. Currently a character is represented by a C `unsigned char`; in the future we might switch to `wchar_t` (Comments on that requested).

character-set extensions and matching of names:
: Any character except the ASCII NUL character can be used in a name. Matching is case-insensitive (except in `TABLE`s). The matching is performed using the C function `strncasecmp`, whose function is probably influenced by the locale. E.g., the `C` locale does not know about accents and umlauts, so they are matched case-sensitively in that locale. For portability reasons it is best to write programs such that they work in the `C` locale. Then one can use libraries written by a Polish programmer (who might use words containing ISO Latin-2 encoded characters) and by a French programmer (ISO Latin-1) in the same program (of course, `WORDS` will produce funny results for some of the words (which ones, depends on the font you are using)). Also, the locale you prefer may not be available in other operating systems. Hopefully, Unicode will solve these problems one day.

conditions under which control characters match a space delimiter:
: If `WORD` is called with the space character as a delimiter, all white-space characters (as identified by the C macro `isspace()`) are delimiters. `PARSE`, on the other hand, treats space like other delimiters. `PARSE-WORD` treats space like `WORD`, but behaves like `PARSE` otherwise. `(NAME)`, which is used by the outer interpreter (aka text interpreter) by default, treats all white-space characters as delimiters.

format of the control-flow stack:
: The data stack is used as control-flow stack. The size of a control-flow stack item in cells is given by the constant `cs-item-size`. At the time of this writing,

an item consists of a (pointer to a) locals list (third), an address in the code (second), and a tag for identifying the item (TOS). The following tags are used: `defstart`, `live-orig`, `dead-orig`, `dest`, `do-dest`, `scopestart`.

conversion of digits > 35

The characters `[\]^_'` are the digits with the decimal value 36–41. There is no way to input many of the larger digits.

display after input terminates in `ACCEPT` *and* `EXPECT`*:*

The cursor is moved to the end of the entered string. If the input is terminated using the ***`Return`*** key, a space is typed.

exception abort sequence of `ABORT"`*:*

The error string is stored into the variable `"error` and a `-2 throw` is performed.

input line terminator:

For interactive input, ***`C-m`*** (CR) and ***`C-j`*** (LF) terminate lines. One of these characters is typically produced when you type the ***`Enter`*** or ***`Return`*** key.

maximum size of a counted string:

`s" /counted-string" environment? drop ..` Currently 255 characters on all ports, but this may change.

maximum size of a parsed string:

Given by the constant `/line`. Currently 255 characters.

maximum size of a definition name, in characters:

31

maximum string length for `ENVIRONMENT?`*, in characters:*

31

method of selecting the user input device:

The user input device is the standard input. There is currently no way to change it from within Gforth. However, the input can typically be redirected in the command line that starts Gforth.

method of selecting the user output device:

`EMIT` and `TYPE` output to the file-id stored in the value `outfile-id` (`stdout` by default). Gforth uses unbuffered output when the user output device is a terminal, otherwise the output is buffered.

methods of dictionary compilation:

What are we expected to document here?

number of bits in one address unit:

`s" address-units-bits" environment? drop ..` 8 in all current ports.

number representation and arithmetic:

Processor-dependent. Binary two's complement on all current ports.

ranges for integer types:

Installation-dependent. Make environmental queries for `MAX-N`, `MAX-U`, `MAX-D` and `MAX-UD`. The lower bounds for unsigned (and positive) types is 0. The lower

bound for signed types on two's complement and one's complement machines machines can be computed by adding 1 to the upper bound.

read-only data space regions:
The whole Forth data space is writable.

size of buffer at `WORD`*:*
`PAD HERE - ..` 104 characters on 32-bit machines. The buffer is shared with the pictured numeric output string. If overwriting `PAD` is acceptable, it is as large as the remaining dictionary space, although only as much can be sensibly used as fits in a counted string.

size of one cell in address units:
`1 cells ..`

size of one character in address units:
`1 chars ..` 1 on all current ports.

size of the keyboard terminal buffer:
Varies. You can determine the size at a specific time using `lp@ tib - ..` It is shared with the locals stack and TIBs of files that include the current file. You can change the amount of space for TIBs and locals stack at Gforth startup with the command line option `-l`.

size of the pictured numeric output buffer:
`PAD HERE - ..` 104 characters on 32-bit machines. The buffer is shared with `WORD`.

size of the scratch area returned by `PAD`*:*
The remainder of dictionary space. `unused pad here - - ..`

system case-sensitivity characteristics:
Dictionary searches are case-insensitive (except in `TABLE`s). However, as explained above under *character-set extensions*, the matching for non-ASCII characters is determined by the locale you are using. In the default `C` locale all non-ASCII characters are matched case-sensitively.

system prompt:
`ok` in interpret state, `compiled` in compile state.

division rounding:
installation dependent. `s" floored" environment? drop ..` We leave the choice to `gcc` (what to use for `/`) and to you (whether to use `fm/mod`, `sm/rem` or simply `/`).

values of `STATE` *when true:*
-1.

values returned after arithmetic overflow:
On two's complement machines, arithmetic is performed modulo 2**bits-per-cell for single arithmetic and 4**bits-per-cell for double arithmetic (with appropriate mapping for signed types). Division by zero typically results in a `-55 throw` (Floating-point unidentified fault), although a `-10 throw` (divide by zero) would be more appropriate.

whether the current definition can be found after `DOES>`*:*
No.

7.1.2 Ambiguous conditions

a name is neither a word nor a number:
`-13 throw` (Undefined word). Actually, `-13 bounce`, which preserves the data and FP stack, so you don't lose more work than necessary.

a definition name exceeds the maximum length allowed:
`-19 throw` (Word name too long)

addressing a region not inside the various data spaces of the forth system:
The stacks, code space and header space are accessible. Machine code space is typically readable. Accessing other addresses gives results dependent on the operating system. On decent systems: `-9 throw` (Invalid memory address).

argument type incompatible with parameter:
This is usually not caught. Some words perform checks, e.g., the control flow words, and issue a `ABORT"` or `-12 THROW` (Argument type mismatch).

attempting to obtain the execution token of a word with undefined execution semantics:
`-14 throw` (Interpreting a compile-only word). In some cases, you get an execution token for `compile-only-error` (which performs a `-14 throw` when executed).

dividing by zero:
On better platforms, this produces a `-10 throw` (Division by zero); on other systems, this typically results in a `-55 throw` (Floating-point unidentified fault).

insufficient data stack or return stack space:
Depending on the operating system, the installation, and the invocation of Gforth, this is either checked by the memory management hardware, or it is not checked. If it is checked, you typically get a `-3 throw` (Stack overflow), `-5 throw` (Return stack overflow), or `-9 throw` (Invalid memory address) (depending on the platform and how you achieved the overflow) as soon as the overflow happens. If it is not checked, overflows typically result in mysterious illegal memory accesses, producing `-9 throw` (Invalid memory address) or `-23 throw` (Address alignment exception); they might also destroy the internal data structure of `ALLOCATE` and friends, resulting in various errors in these words.

insufficient space for loop control parameters:
like other return stack overflows.

insufficient space in the dictionary:
If you try to allot (either directly with `allot`, or indirectly with `,`, `create` etc.) more memory than available in the dictionary, you get a `-8 throw` (Dictionary overflow). If you try to access memory beyond the end of the dictionary, the results are similar to stack overflows.

interpreting a word with undefined interpretation semantics:
: For some words, we have defined interpretation semantics. For the others: `-14 throw` (Interpreting a compile-only word).

modifying the contents of the input buffer or a string literal:
: These are located in writable memory and can be modified.

overflow of the pictured numeric output string:
: `-17 throw` (Pictured numeric ouput string overflow).

parsed string overflow:
: `PARSE` cannot overflow. `WORD` does not check for overflow.

producing a result out of range:
: On two's complement machines, arithmetic is performed modulo 2**bits-per-cell for single arithmetic and 4**bits-per-cell for double arithmetic (with appropriate mapping for signed types). Division by zero typically results in a `-10 throw` (divide by zero) or `-55 throw` (floating point unidentified fault). `convert` and `>number` currently overflow silently.

reading from an empty data or return stack:
: The data stack is checked by the outer (aka text) interpreter after every word executed. If it has underflowed, a `-4 throw` (Stack underflow) is performed. Apart from that, stacks may be checked or not, depending on operating system, installation, and invocation. If they are caught by a check, they typically result in `-4 throw` (Stack underflow), `-6 throw` (Return stack underflow) or `-9 throw` (Invalid memory address), depending on the platform and which stack underflows and by how much. Note that even if the system uses checking (through the MMU), your program may have to underflow by a significant number of stack items to trigger the reaction (the reason for this is that the MMU, and therefore the checking, works with a page-size granularity). If there is no checking, the symptoms resulting from an underflow are similar to those from an overflow. Unbalanced return stack errors result in a variaty of symptoms, including `-9 throw` (Invalid memory address) and Illegal Instruction (typically `-260 throw`).

unexpected end of the input buffer, resulting in an attempt to use a zero-length string as a name:
: `Create` and its descendants perform a `-16 throw` (Attempt to use zero-length string as a name). Words like `'` probably will not find what they search. Note that it is possible to create zero-length names with `nextname` (should it not?).

`>IN` *greater than input buffer:*
: The next invocation of a parsing word returns a string with length 0.

`RECURSE` *appears after* `DOES>`*:*
: Compiles a recursive call to the defining word, not to the defined word.

argument input source different than current input source for `RESTORE-INPUT`*:*
: `-12 THROW`. Note that, once an input file is closed (e.g., because the end of the file was reached), its source-id may be reused. Therefore, restoring an input source specification referencing a closed file may lead to unpredictable results instead of a `-12 THROW`.

In the future, Gforth may be able to restore input source specifications from other than the current input source.

data space containing definitions gets de-allocated:
Deallocation with `allot` is not checked. This typically results in memory access faults or execution of illegal instructions.

data space read/write with incorrect alignment:
Processor-dependent. Typically results in a `-23 throw` (Address alignment exception). Under Linux-Intel on a 486 or later processor with alignment turned on, incorrect alignment results in a `-9 throw` (Invalid memory address). There are reportedly some processors with alignment restrictions that do not report violations.

data space pointer not properly aligned, `,`, `C,`*:*
Like other alignment errors.

less than u+2 stack items (`PICK` *and* `ROLL`*):*
Like other stack underflows.

loop control parameters not available:
Not checked. The counted loop words simply assume that the top of return stack items are loop control parameters and behave accordingly.

most recent definition does not have a name (`IMMEDIATE`*):*
`abort" last word was headerless"`.

name not defined by `VALUE` *used by* `TO`*:*
`-32 throw` (Invalid name argument) (unless name is a local or was defined by `CONSTANT`; in the latter case it just changes the constant).

name not found (`'`, `POSTPONE`, `['']`, `[COMPILE]`*):*
`-13 throw` (Undefined word)

parameters are not of the same type (`DO`, `?DO`, `WITHIN`*):*
Gforth behaves as if they were of the same type. I.e., you can predict the behaviour by interpreting all parameters as, e.g., signed.

`POSTPONE` *or* `[COMPILE]` *applied to* `TO`*:*
Assume `: X POSTPONE TO ; IMMEDIATE`. `X` performs the compilation semantics of `TO`.

String longer than a counted string returned by `WORD`*:*
Not checked. The string will be ok, but the count will, of course, contain only the least significant bits of the length.

u greater than or equal to the number of bits in a cell (`LSHIFT`, `RSHIFT`*):*
Processor-dependent. Typical behaviours are returning 0 and using only the low bits of the shift count.

word not defined via `CREATE`*:*
`>BODY` produces the PFA of the word no matter how it was defined.

`DOES>` changes the execution semantics of the last defined word no matter how it was defined. E.g., `CONSTANT DOES>` is equivalent to `CREATE , DOES>`.

words improperly used outside `<#` *and* `#>`*:*
Not checked. As usual, you can expect memory faults.

7.1.3 Other system documentation

nonstandard words using `PAD`*:*
None.

operator's terminal facilities available:
After processing the command line, Gforth goes into interactive mode, and you can give commands to Gforth interactively. The actual facilities available depend on how you invoke Gforth.

program data space available:
`UNUSED .` gives the remaining dictionary space. The total dictionary space can be specified with the `-m` switch (see Section 2.1 [Invoking Gforth], page 11) when Gforth starts up.

return stack space available:
You can compute the total return stack space in cells with `s" RETURN-STACK-CELLS" environment? drop .`. You can specify it at startup time with the `-r` switch (see Section 2.1 [Invoking Gforth], page 11).

stack space available:
You can compute the total data stack space in cells with `s" STACK-CELLS" environment? drop .`. You can specify it at startup time with the `-d` switch (see Section 2.1 [Invoking Gforth], page 11).

system dictionary space required, in address units:
Type `here forthstart - .` after startup. At the time of this writing, this gives 80080 (bytes) on a 32-bit system.

7.2 The optional Block word set

7.2.1 Implementation Defined Options

the format for display by `LIST`*:*
First the screen number is displayed, then 16 lines of 64 characters, each line preceded by the line number.

the length of a line affected by `\`*:*
64 characters.

7.2.2 Ambiguous conditions

correct block read was not possible:
Typically results in a `throw` of some OS-derived value (between -512 and -2048). If the blocks file was just not long enough, blanks are supplied for the missing portion.

I/O exception in block transfer:
Typically results in a `throw` of some OS-derived value (between -512 and -2048).

invalid block number:
`-35 throw` (Invalid block number)

a program directly alters the contents of `BLK`*:*
The input stream is switched to that other block, at the same position. If the storing to `BLK` happens when interpreting non-block input, the system will get quite confused when the block ends.

no current block buffer for `UPDATE`*:*
`UPDATE` has no effect.

7.2.3 Other system documentation

any restrictions a multiprogramming system places on the use of buffer addresses:
No restrictions (yet).

the number of blocks available for source and data:
depends on your disk space.

7.3 The optional Double Number word set

7.3.1 Ambiguous conditions

d outside of range of n in `D>S`*:*
The least significant cell of *d* is produced.

7.4 The optional Exception word set

7.4.1 Implementation Defined Options

`THROW`*-codes used in the system:*
The codes -256–-511 are used for reporting signals. The mapping from OS signal numbers to throw codes is -256–*signal*. The codes -512–-2047 are used for OS errors (for file and memory allocation operations). The mapping from OS error numbers to throw codes is -512–`errno`. One side effect of this mapping is that undefined OS errors produce a message with a strange number; e.g., `-1000 THROW` results in `Unknown error 488` on my system.

7.5 The optional Facility word set

7.5.1 Implementation Defined Options

encoding of keyboard events (`EKEY`):
: Not yet implemented.

duration of a system clock tick:
: System dependent. With respect to `MS`, the time is specified in microseconds. How well the OS and the hardware implement this, is another question.

repeatability to be expected from the execution of `MS`:
: System dependent. On Unix, a lot depends on load. If the system is lightly loaded, and the delay is short enough that Gforth does not get swapped out, the performance should be acceptable. Under MS-DOS and other single-tasking systems, it should be good.

7.5.2 Ambiguous conditions

`AT-XY` *can't be performed on user output device:*
: Largely terminal dependent. No range checks are done on the arguments. No errors are reported. You may see some garbage appearing, you may see simply nothing happen.

7.6 The optional File-Access word set

7.6.1 Implementation Defined Options

file access methods used:
: `R/O`, `R/W` and `BIN` work as you would expect. `W/O` translates into the C file opening mode `w` (or `wb`): The file is cleared, if it exists, and created, if it does not (with both `open-file` and `create-file`). Under Unix `create-file` creates a file with 666 permissions modified by your umask.

file exceptions:
: The file words do not raise exceptions (except, perhaps, memory access faults when you pass illegal addresses or file-ids).

file line terminator:
: System-dependent. Gforth uses C's newline character as line terminator. What the actual character code(s) of this are is system-dependent.

file name format:
: System dependent. Gforth just uses the file name format of your OS.

information returned by `FILE-STATUS`:
: `FILE-STATUS` returns the most powerful file access mode allowed for the file: Either `R/O`, `W/O` or `R/W`. If the file cannot be accessed, `R/O BIN` is returned. `BIN` is applicable along with the returned mode.

input file state after an exception when including source:
: All files that are left via the exception are closed.

ior values and meaning:
: The *ior*s returned by the file and memory allocation words are intended as throw codes. They typically are in the range -512–-2047 of OS errors. The mapping from OS error numbers to *ior*s is -512–*errno*.

maximum depth of file input nesting:
: limited by the amount of return stack, locals/TIB stack, and the number of open files available. This should not give you troubles.

maximum size of input line:
: `/line`. Currently 255.

methods of mapping block ranges to files:
: By default, blocks are accessed in the file '`blocks.fb`' in the current working directory. The file can be switched with `USE`.

number of string buffers provided by `S"`*:*
: 1

size of string buffer used by `S"`*:*
: `/line`. currently 255.

7.6.2 Ambiguous conditions

attempting to position a file outside its boundaries:
: `REPOSITION-FILE` is performed as usual: Afterwards, `FILE-POSITION` returns the value given to `REPOSITION-FILE`.

attempting to read from file positions not yet written:
: End-of-file, i.e., zero characters are read and no error is reported.

file-id is invalid (`INCLUDE-FILE`*):*
: An appropriate exception may be thrown, but a memory fault or other problem is more probable.

I/O exception reading or closing file-id (`INCLUDE-FILE`, `INCLUDED`*):*
: The *ior* produced by the operation, that discovered the problem, is thrown.

named file cannot be opened (`INCLUDED`*):*
: The *ior* produced by `open-file` is thrown.

requesting an unmapped block number:
: There are no unmapped legal block numbers. On some operating systems, writing a block with a large number may overflow the file system and have an error message as consequence.

using `source-id` *when* `blk` *is non-zero:*
: `source-id` performs its function. Typically it will give the id of the source which loaded the block. (Better ideas?)

7.7 The optional Floating-Point word set

7.7.1 Implementation Defined Options

format and range of floating point numbers:
: System-dependent; the `double` type of C.

results of `REPRESENT` *when float is out of range:*
: System dependent; `REPRESENT` is implemented using the C library function `ecvt()` and inherits its behaviour in this respect.

rounding or truncation of floating-point numbers:
: System dependent; the rounding behaviour is inherited from the hosting C compiler. IEEE-FP-based (i.e., most) systems by default round to nearest, and break ties by rounding to even (i.e., such that the last bit of the mantissa is 0).

size of floating-point stack:
: `s" FLOATING-STACK" environment? drop .` gives the total size of the floating-point stack (in floats). You can specify this on startup with the command-line option `-f` (see Section 2.1 [Invoking Gforth], page 11).

width of floating-point stack:
: `1 floats`.

7.7.2 Ambiguous conditions

`df@` *or* `df!` *used with an address that is not double-float aligned:*
: System-dependent. Typically results in a `-23 THROW` like other alignment violations.

`f@` *or* `f!` *used with an address that is not float aligned:*
: System-dependent. Typically results in a `-23 THROW` like other alignment violations.

floating-point result out of range:
: System-dependent. Can result in a `-55 THROW` (Floating-point unidentified fault), or can produce a special value representing, e.g., Infinity.

`sf@` *or* `sf!` *used with an address that is not single-float aligned:*
: System-dependent. Typically results in an alignment fault like other alignment violations.

`base` *is not decimal (*`REPRESENT`, `F.`, `FE.`, `FS.`*):*
: The floating-point number is converted into decimal nonetheless.

Both arguments are equal to zero (`FATAN2`*):*
: System-dependent. `FATAN2` is implemented using the C library function `atan2()`.

Using `FTAN` *on an argument r1 where cos(r1) is zero:*
: System-dependent. Anyway, typically the cos of *r1* will not be zero because of small errors and the tan will be a very large (or very small) but finite number.

d cannot be presented precisely as a float in `D>F`*:*
: The result is rounded to the nearest float.

dividing by zero:
: `-55 throw` (Floating-point unidentified fault)

exponent too big for conversion (`DF!`, `DF@`, `SF!`, `SF@`*):*
: System dependent. On IEEE-FP based systems the number is converted into an infinity.

float<1 (`FACOSH`*):*
: `-55 throw` (Floating-point unidentified fault)

float=<-1 (`FLNP1`*):*
: `-55 throw` (Floating-point unidentified fault). On IEEE-FP systems negative infinity is typically produced for *float*=-1.

float=<0 (`FLN`, `FLOG`*):*
: `-55 throw` (Floating-point unidentified fault). On IEEE-FP systems negative infinity is typically produced for *float*=0.

float<0 (`FASINH`, `FSQRT`*):*
: `-55 throw` (Floating-point unidentified fault). `fasinh` produces values for these inputs on my Linux box (Bug in the C library?)

|float|>1 (`FACOS`, `FASIN`, `FATANH`*):*
: `-55 throw` (Floating-point unidentified fault).

integer part of float cannot be represented by d in `F>D`*:*
: `-55 throw` (Floating-point unidentified fault).

string larger than pictured numeric output area (`f.`, `fe.`, `fs.`*):*
: This does not happen.

7.8 The optional Locals word set

7.8.1 Implementation Defined Options

maximum number of locals in a definition:
: `s" #locals" environment? drop` .. Currently 15. This is a lower bound, e.g., on a 32-bit machine there can be 41 locals of up to 8 characters. The number of locals in a definition is bounded by the size of locals-buffer, which contains the names of the locals.

7.8.2 Ambiguous conditions

executing a named local in interpretation state:
: Locals have no interpretation semantics. If you try to perform the interpretation semantics, you will get a `-14 throw` somewhere (Interpreting a compile-only word). If you perform the compilation semantics, the locals access will be compiled (irrespective of state).

name not defined by `VALUE` *or* `(LOCAL)` *(*`TO`*):*
`-32 throw` (Invalid name argument)

7.9 The optional Memory-Allocation word set

7.9.1 Implementation Defined Options

values and meaning of ior:
The *ior*s returned by the file and memory allocation words are intended as throw codes. They typically are in the range -512–-2047 of OS errors. The mapping from OS error numbers to *ior*s is -512–*errno*.

7.10 The optional Programming-Tools word set

7.10.1 Implementation Defined Options

ending sequence for input following `;CODE` *and* `CODE`*:*
`END-CODE`

manner of processing input following `;CODE` *and* `CODE`*:*
The `ASSEMBLER` vocabulary is pushed on the search order stack, and the input is processed by the text interpreter, (starting) in interpret state.

search order capability for `EDITOR` *and* `ASSEMBLER`*:*
The ANS Forth search order word set.

source and format of display by `SEE`*:*
The source for `see` is the intermediate code used by the inner interpreter. The current `see` tries to output Forth source code as well as possible.

7.10.2 Ambiguous conditions

deleting the compilation word list (`FORGET`*):*
Not implemented (yet).

fewer than u+1 items on the control-flow stack (`CS-PICK`, `CS-ROLL`*):*
This typically results in an `abort"` with a descriptive error message (may change into a `-22 throw` (Control structure mismatch) in the future). You may also get a memory access error. If you are unlucky, this ambiguous condition is not caught.

name can't be found (`FORGET`*):*
Not implemented (yet).

name not defined via `CREATE`*:*
`;CODE` behaves like `DOES>` in this respect, i.e., it changes the execution semantics of the last defined word no matter how it was defined.

`POSTPONE` *applied to* `[IF]`*:*
: After defining `: X POSTPONE [IF] ; IMMEDIATE`. `X` is equivalent to `[IF]`.

reaching the end of the input source before matching `[ELSE]` *or* `[THEN]`*:*
: Continue in the same state of conditional compilation in the next outer input source. Currently there is no warning to the user about this.

removing a needed definition (`FORGET`*):*
: Not implemented (yet).

7.11 The optional Search-Order word set

7.11.1 Implementation Defined Options

maximum number of word lists in search order:
: `s" wordlists" environment? drop ..` Currently 16.

minimum search order:
: `root root`.

7.11.2 Ambiguous conditions

changing the compilation word list (during compilation):
: The word is entered into the word list that was the compilation word list at the start of the definition. Any changes to the name field (e.g., `immediate`) or the code field (e.g., when executing `DOES>`) are applied to the latest defined word (as reported by `last` or `lastxt`), if possible, irrespective of the compilation word list.

search order empty (`previous`*):*
: `abort" Vocstack empty"`.

too many word lists in search order (`also`*):*
: `abort" Vocstack full"`.

8 Model

This chapter has yet to be written. It will contain information, on which internal structures you can rely.

9 Integrating Gforth into C programs

This is not yet implemented.

Several people like to use Forth as scripting language for applications that are otherwise written in C, C++, or some other language.

The Forth system ATLAST provides facilities for embedding it into applications; unfortunately it has several disadvantages: most importantly, it is not based on ANS Forth, and it is apparently dead (i.e., not developed further and not supported). The facilities provided by Gforth in this area are inspired by ATLAST's facilities, so making the switch should not be hard.

We also tried to design the interface such that it can easily be implemented by other Forth systems, so that we may one day arrive at a standardized interface. Such a standard interface would allow you to replace the Forth system without having to rewrite C code.

You embed the Gforth interpreter by linking with the library `libgforth.a` (give the compiler the option `-lgforth`). All global symbols in this library that belong to the interface, have the prefix `forth_`. (Global symbols that are used internally have the prefix `gforth_`).

You can include the declarations of Forth types and the functions and variables of the interface with `#include <forth.h>`.

Types.

Variables.

Data and FP Stack pointer. Area sizes.

functions.

forth_init(imagefile) forth_evaluate(string) exceptions? forth_goto(address) (or forth_execute(xt)?) forth_continue() (a corountining mechanism)

Adding primitives.

No checking.

Signals?

Accessing the Stacks

10 Emacs and Gforth

Gforth comes with '`gforth.el`', an improved version of '`forth.el`' by Goran Rydqvist (included in the TILE package). The improvements are:

- A better (but still not perfect) handling of indentation.
- Comment paragraph filling (*M-q*)
- Commenting (*C-x *) and uncommenting (*C-u C-x *) of regions
- Removal of debugging tracers (*C-x ~*, see Section 4.16.1 [Debugging], page 91).

I left the stuff I do not use alone, even though some of it only makes sense for TILE. To get a description of these features, enter Forth mode and type *C-h m*.

In addition, Gforth supports Emacs quite well: The source code locations given in error messages, debugging output (from `~~`) and failed assertion messages are in the right format for Emacs' compilation mode (see section "Running Compilations under Emacs" in *Emacs Manual*) so the source location corresponding to an error or other message is only a few keystrokes away (*C-x `* for the next error, *C-c C-c* for the error under the cursor).

Also, if you `include` '`etags.fs`', a new '`TAGS`' file will be produced (see section "Tags Tables" in *Emacs Manual*) that contains the definitions of all words defined afterwards. You can then find the source for a word using *M-.*. Note that emacs can use several tags files at the same time (e.g., one for the Gforth sources and one for your program, see section "Selecting a Tags Table" in *Emacs Manual*). The TAGS file for the preloaded words is '`$(datadir)/gforth/$(VERSION)/TAGS`' (e.g., '`/usr/local/share/gforth/0.2.0/TAGS`').

To get all these benefits, add the following lines to your '`.emacs`' file:

```
(autoload 'forth-mode "gforth.el")
(setq auto-mode-alist (cons '("\\.fs\\'" . forth-mode) auto-mode-alist))
```

11 Image Files

An image file is a file containing an image of the Forth dictionary, i.e., compiled Forth code and data residing in the dictionary. By convention, we use the extension `.fi` for image files.

11.1 Image Licensing Issues

An image created with `gforthmi` (see Section 11.5.1 [gforthmi], page 151) or `savesystem` (see Section 11.3 [Non-Relocatable Image Files], page 150) includes the original image; i.e., according to copyright law it is a derived work of the original image.

Since Gforth is distributed under the GNU GPL, the newly created image falls under the GNU GPL, too. In particular, this means that if you distribute the image, you have to make all of the sources for the image available, including those you wrote. For details see [GNU General Public License (Section 3)], page 1.

If you create an image with `cross` (see Section 11.5.2 [cross.fs], page 151), the image contains only code compiled from the sources you gave it; if none of these sources is under the GPL, the terms discussed above do not apply to the image. However, if your image needs an engine (a gforth binary) that is under the GPL, you should make sure that you distribute both in a way that is at most a *mere aggregation*, if you don't want the terms of the GPL to apply to the image.

11.2 Image File Background

Our Forth system consists not only of primitives, but also of definitions written in Forth. Since the Forth compiler itself belongs to those definitions, it is not possible to start the system with the primitives and the Forth source alone. Therefore we provide the Forth code as an image file in nearly executable form. When Gforth starts up, a C routine loads the image file into memory, optionally relocates the addresses, then sets up the memory (stacks etc.) according to information in the image file, and (finally) starts executing Forth code.

The image file variants represent different compromises between the goals of making it easy to generate image files and making them portable.

Win32Forth 3.4 and Mitch Bradley's `cforth` use relocation at run-time. This avoids many of the complications discussed below (image files are data relocatable without further ado), but costs performance (one addition per memory access).

By contrast, the Gforth loader performs relocation at image load time. The loader also has to replace tokens that represent primitive calls with the appropriate code-field addresses (or code addresses in the case of direct threading).

There are three kinds of image files, with different degrees of relocatability: non-relocatable, data-relocatable, and fully relocatable image files.

These image file variants have several restrictions in common; they are caused by the design of the image file loader:

- There is only one segment; in particular, this means, that an image file cannot represent `ALLOCATE`d memory chunks (and pointers to them). The contents of the stacks are not represented, either.

- The only kinds of relocation supported are: adding the same offset to all cells that represent data addresses; and replacing special tokens with code addresses or with pieces of machine code.

  If any complex computations involving addresses are performed, the results cannot be represented in the image file. Several applications that use such computations come to mind:

  - Hashing addresses (or data structures which contain addresses) for table lookup. If you use Gforth's `table`s or `wordlist`s for this purpose, you will have no problem, because the hash tables are recomputed automatically when the system is started. If you use your own hash tables, you will have to do something similar.
  - There's a cute implementation of doubly-linked lists that uses `XOR`ed addresses. You could represent such lists as singly-linked in the image file, and restore the doubly-linked representation on startup.[1]
  - The code addresses of run-time routines like `docol:` cannot be represented in the image file (because their tokens would be replaced by machine code in direct threaded implementations). As a workaround, compute these addresses at run-time with `>code-address` from the executions tokens of appropriate words (see the definitions of `docol:` and friends in '`kernel.fs`').
  - On many architectures addresses are represented in machine code in some shifted or mangled form. You cannot put `CODE` words that contain absolute addresses in this form in a relocatable image file. Workarounds are representing the address in some relative form (e.g., relative to the CFA, which is present in some register), or loading the address from a place where it is stored in a non-mangled form.

11.3 Non-Relocatable Image Files

These files are simple memory dumps of the dictionary. They are specific to the executable (i.e., '`gforth`' file) they were created with. What's worse, they are specific to the place on which the dictionary resided when the image was created. Now, there is no guarantee that the dictionary will reside at the same place the next time you start Gforth, so there's no guarantee that a non-relocatable image will work the next time (Gforth will complain instead of crashing, though).

You can create a non-relocatable image file with

`savesystem` `"`*name*`"` – gforth "savesystem"

11.4 Data-Relocatable Image Files

These files contain relocatable data addresses, but fixed code addresses (instead of tokens). They are specific to the executable (i.e., '`gforth`' file) they were created with. For direct threading on some architectures (e.g., the i386), data-relocatable images do not work. You get a data-relocatable image, if you use '`gforthmi`' with a Gforth binary that is not doubly indirect threaded (see Section 11.5 [Fully Relocatable Image Files], page 151).

[1] In my opinion, though, you should think thrice before using a doubly-linked list (whatever implementation).

11.5 Fully Relocatable Image Files

These image files have relocatable data addresses, and tokens for code addresses. They can be used with different binaries (e.g., with and without debugging) on the same machine, and even across machines with the same data formats (byte order, cell size, floating point format). However, they are usually specific to the version of Gforth they were created with. The files '`gforth.fi`' and '`kernl*.fi`' are fully relocatable.

There are two ways to create a fully relocatable image file:

11.5.1 'gforthmi'

You will usually use '`gforthmi`'. If you want to create an image *file* that contains everything you would load by invoking Gforth with `gforth` *options*, you simply say:

`gforthmi` *file options*

E.g., if you want to create an image '`asm.fi`' that has the file '`asm.fs`' loaded in addition to the usual stuff, you could do it like this:

```
gforthmi asm.fi asm.fs
```

'`gforthmi`' is implemented as a sh script and works like this: It produces two non-relocatable images for different addresses and then compares them. Its output reflects this: first you see the output (if any) of the two Gforth invocations that produce the nonrelocatable image files, then you see the output of the comparing program: It displays the offset used for data addresses and the offset used for code addresses; moreover, for each cell that cannot be represented correctly in the image files, it displays a line like the following one:

```
78DC          BFFFFA50          BFFFFA40
```

This means that at offset $78dc from `forthstart`, one input image contains $bffffa50, and the other contains $bffffa40. Since these cells cannot be represented correctly in the output image, you should examine these places in the dictionary and verify that these cells are dead (i.e., not read before they are written).

If you type '`gforthmi`' with no arguments, it prints some usage instructions.

There are a few wrinkles: After processing the passed *options*, the words `savesystem` and `bye` must be visible. A special doubly indirect threaded version of the '`gforth`' executable is used for creating the nonrelocatable images; you can pass the exact filename of this executable through the environment variable `GFORTHD` (default: '`gforth-ditc`'); if you pass a version that is not doubly indirect threaded, you will not get a fully relocatable image, but a data-relocatable image (because there is no code address offset). The normal '`gforth`' executable is used for creating the relocatable image; you can pass the exact filename of this executable through the environment variable `GFORTH`.

11.5.2 'cross.fs'

You can also use `cross`, a batch compiler that accepts a Forth-like programming language. This `cross` language has to be documented yet.

`cross` also allows you to create image files for machines with different data sizes and data formats than the one used for generating the image file. You can also use it to create

an application image that does not contain a Forth compiler. These features are bought with restrictions and inconveniences in programming. E.g., addresses have to be stored in memory with special words (`A!`, `A,`, etc.) in order to make the code relocatable.

11.6 Stack and Dictionary Sizes

If you invoke Gforth with a command line flag for the size (see Section 2.1 [Invoking Gforth], page 11), the size you specify is stored in the dictionary. If you save the dictionary with `savesystem` or create an image with '`gforthmi`', this size will become the default for the resulting image file. E.g., the following will create a fully relocatable version of '`gforth.fi`' with a 1MB dictionary:

```
gforthmi gforth.fi -m 1M
```

In other words, if you want to set the default size for the dictionary and the stacks of an image, just invoke '`gforthmi`' with the appropriate options when creating the image.

Note: For cache-friendly behaviour (i.e., good performance), you should make the sizes of the stacks modulo, say, 2K, somewhat different. E.g., the default stack sizes are: data: 16k (mod 2k=0); fp: 15.5k (mod 2k=1.5k); return: 15k(mod 2k=1k); locals: 14.5k (mod 2k=0.5k).

11.7 Running Image Files

You can invoke Gforth with an image file *image* instead of the default '`gforth.fi`' with the `-i` flag (see Section 2.1 [Invoking Gforth], page 11):

```
gforth -i image
```

If your operating system supports starting scripts with a line of the form `#! ...`, you just have to type the image file name to start Gforth with this image file (note that the file extension `.fi` is just a convention). I.e., to run Gforth with the image file *image*, you can just type *image* instead of `gforth -i` *image*. This works because every `.fi` file starts with a line of this format:

```
#! /usr/local/bin/gforth-0.4.0 -i
```

The file and pathname for the Gforth engine specified on this line is the specific Gforth executable that it was built against; i.e. the value of the environment variable `GFORTH` at the time that '`gforthmi`' was executed.

You can make use of the same shell capability to make a Forth source file into an executable. For example, if you place this text in a file:

```
#! /usr/local/bin/gforth

." Hello, world" CR
bye
```

and then make the file executable (chmod `+x` in Unix), you can run it directly from the command line. The sequence `#!` is used in two ways; firstly, it is recognised as a "magic sequence" by the operating system[2] secondly it is treated as a comment character by Gforth. Because of the second usage, a space is required between `#!` and the path to the executable.

[2] The Unix kernel actually recognises two types of files: executable files and files of data, where the data is processed by an interpreter that is specified on the "interpreter line" –

The disadvantage of this latter technique, compared with using '`gforthmi`', is that it is slower; the Forth source code is compiled on-the-fly, each time the program is invoked.

`#!` – gforth "hash-bang"

An alias for `\`

11.8 Modifying the Startup Sequence

You can add your own initialization to the startup sequence through the deferred word `'cold`. `'cold` is invoked just before the image-specific command line processing (by default, loading files and evaluating (`-e`) strings) starts.

A sequence for adding your initialization usually looks like this:

```
:noname
    Defers 'cold \ do other initialization stuff (e.g., rehashing wordlists)
    ... \ your stuff
; IS 'cold
```

You can make a turnkey image by letting `'cold` execute a word (your turnkey application) that never returns; instead, it exits Gforth via `bye` or `throw`.

You can access the (image-specific) command-line arguments through the variables `argc` and `argv`. `arg` provides convenient access to `argv`.

If `'cold` exits normally, Gforth processes the command-line arguments as files to be loaded and strings to be evaluated. Therefore, `'cold` should remove the arguments it has used in this case.

`'cold` – gforth "tick-cold"

`argc` – *addr* gforth "argc"

VARIABLE: The number of command-line arguments (including the command name).

`argv` – *addr* gforth "argv"

VARIABLE: A pointer to a vector of pointers to the command-line arguments (including the command-name). Each argument is represented as a C-style string.

`arg` *n* – *addr count* gforth "arg"

Return the string for the *n*th command-line argument.

---

the first line of the file, starting with the sequence #!. There may be a small limit (e.g., 32) on the number of characters that may be specified on the interpreter line.

12 Engine

Reading this chapter is not necessary for programming with Gforth. It may be helpful for finding your way in the Gforth sources.

The ideas in this section have also been published in the papers *ANS fig/GNU/??? Forth* (in German) by Bernd Paysan, presented at the Forth-Tagung '93 and *A Portable Forth Engine* by M. Anton Ertl, presented at EuroForth '93; the latter is available at `http://www.complang.tuwien.ac.at/papers/ertl93.ps.Z`.

12.1 Portability

An important goal of the Gforth Project is availability across a wide range of personal machines. fig-Forth, and, to a lesser extent, F83, achieved this goal by manually coding the engine in assembly language for several then-popular processors. This approach is very labor-intensive and the results are short-lived due to progress in computer architecture.

Others have avoided this problem by coding in C, e.g., Mitch Bradley (cforth), Mikael Patel (TILE) and Dirk Zoller (pfe). This approach is particularly popular for UNIX-based Forths due to the large variety of architectures of UNIX machines. Unfortunately an implementation in C does not mix well with the goals of efficiency and with using traditional techniques: Indirect or direct threading cannot be expressed in C, and switch threading, the fastest technique available in C, is significantly slower. Another problem with C is that it is very cumbersome to express double integer arithmetic.

Fortunately, there is a portable language that does not have these limitations: GNU C, the version of C processed by the GNU C compiler (see section "Extensions to the C Language Family" in *GNU C Manual*). Its labels as values feature (see section "Labels as Values" in *GNU C Manual*) makes direct and indirect threading possible, its `long long` type (see section "Double-Word Integers" in *GNU C Manual*) corresponds to Forth's double numbers[1]. GNU C is available for free on all important (and many unimportant) UNIX machines, VMS, 80386s running MS-DOS, the Amiga, and the Atari ST, so a Forth written in GNU C can run on all these machines.

Writing in a portable language has the reputation of producing code that is slower than assembly. For our Forth engine we repeatedly looked at the code produced by the compiler and eliminated most compiler-induced inefficiencies by appropriate changes in the source code.

However, register allocation cannot be portably influenced by the programmer, leading to some inefficiencies on register-starved machines. We use explicit register declarations (see section "Variables in Specified Registers" in *GNU C Manual*) to improve the speed on some machines. They are turned on by using the configuration flag `--enable-force-reg` (`gcc` switch `-DFORCE_REG`). Unfortunately, this feature not only depends on the machine, but

[1] Unfortunately, long longs are not implemented properly on all machines (e.g., on alpha-osf1, long longs are only 64 bits, the same size as longs (and pointers), but they should be twice as long according to see section "Double-Word Integers" in *GNU C Manual*). So, we had to implement doubles in C after all. Still, on most machines we can use long longs and achieve better performance than with the emulation package.

also on the compiler version: On some machines some compiler versions produce incorrect code when certain explicit register declarations are used. So by default `-DFORCE_REG` is not used.

12.2 Threading

GNU C's labels as values extension (available since `gcc-2.0`, see section "Labels as Values" in *GNU C Manual*) makes it possible to take the address of *label* by writing `&&`*label*. This address can then be used in a statement like `goto *`*address*. I.e., `goto *&&x` is the same as `goto x`.

With this feature an indirect threaded `NEXT` looks like:

```
cfa = *ip++;
ca = *cfa;
goto *ca;
```

For those unfamiliar with the names: `ip` is the Forth instruction pointer; the `cfa` (code-field address) corresponds to ANS Forths execution token and points to the code field of the next word to be executed; The `ca` (code address) fetched from there points to some executable code, e.g., a primitive or the colon definition handler `docol`.

Direct threading is even simpler:

```
ca = *ip++;
goto *ca;
```

Of course we have packaged the whole thing neatly in macros called `NEXT` and `NEXT1` (the part of `NEXT` after fetching the cfa).

12.2.1 Scheduling

There is a little complication: Pipelined and superscalar processors, i.e., RISC and some modern CISC machines can process independent instructions while waiting for the results of an instruction. The compiler usually reorders (schedules) the instructions in a way that achieves good usage of these delay slots. However, on our first tries the compiler did not do well on scheduling primitives. E.g., for `+` implemented as

```
n=sp[0]+sp[1];
sp++;
sp[0]=n;
NEXT;
```

the `NEXT` comes strictly after the other code, i.e., there is nearly no scheduling. After a little thought the problem becomes clear: The compiler cannot know that `sp` and `ip` point to different addresses (and the version of `gcc` we used would not know it even if it was possible), so it could not move the load of the cfa above the store to the TOS. Indeed the pointers could be the same, if code on or very near the top of stack were executed. In the interest of speed we chose to forbid this probably unused "feature" and helped the compiler in scheduling: `NEXT` is divided into the loading part (`NEXT_P1`) and the goto part (`NEXT_P2`). `+` now looks like:

```
n=sp[0]+sp[1];
sp++;
```

```
NEXT_P1;
sp[0]=n;
NEXT_P2;
```

This can be scheduled optimally by the compiler.

This division can be turned off with the switch `-DCISC_NEXT`. This switch is on by default on machines that do not profit from scheduling (e.g., the 80386), in order to preserve registers.

12.2.2 Direct or Indirect Threaded?

Both! After packaging the nasty details in macro definitions we realized that we could switch between direct and indirect threading by simply setting a compilation flag (`-DDIRECT_THREADED`) and defining a few machine-specific macros for the direct-threading case. On the Forth level we also offer access words that hide the differences between the threading methods (see Section 4.18 [Threading Words], page 96).

Indirect threading is implemented completely machine-independently. Direct threading needs routines for creating jumps to the executable code (e.g. to `docol` or `dodoes`). These routines are inherently machine-dependent, but they do not amount to many source lines. Therefore, even porting direct threading to a new machine requires little effort.

The default threading method is machine-dependent. You can enforce a specific threading method when building Gforth with the configuration flag `--enable-direct-threaded` or `--enable-indirect-threaded`. Note that direct threading is not supported on all machines.

12.2.3 DOES>

One of the most complex parts of a Forth engine is `dodoes`, i.e., the chunk of code executed by every word defined by a `CREATE...DOES>` pair. The main problem here is: How to find the Forth code to be executed, i.e. the code after the `DOES>` (the `DOES>`-code)? There are two solutions:

In fig-Forth the code field points directly to the `dodoes` and the `DOES>`code address is stored in the cell after the code address (i.e. at *CFA* `cell+`). It may seem that this solution is illegal in the Forth-79 and all later standards, because in fig-Forth this address lies in the body (which is illegal in these standards). However, by making the code field larger for all words this solution becomes legal again. We use this approach for the indirect threaded version and for direct threading on some machines. Leaving a cell unused in most words is a bit wasteful, but on the machines we are targeting this is hardly a problem. The other reason for having a code field size of two cells is to avoid having different image files for direct and indirect threaded systems (direct threaded systems require two-cell code fields on many machines).

The other approach is that the code field points or jumps to the cell after `DOES>`. In this variant there is a jump to `dodoes` at this address (the `DOES>`-handler). `dodoes` can then get the `DOES>`-code address by computing the code address, i.e., the address of the jump to dodoes, and add the length of that jump field. A variant of this is to have a call to `dodoes` after the `DOES>`; then the return address (which can be found in the return register

on RISCs) is the DOES>-code address. Since the two cells available in the code field are used up by the jump to the code address in direct threading on many architectures, we use this approach for direct threading on these architectures. We did not want to add another cell to the code field.

12.3 Primitives

12.3.1 Automatic Generation

Since the primitives are implemented in a portable language, there is no longer any need to minimize the number of primitives. On the contrary, having many primitives has an advantage: speed. In order to reduce the number of errors in primitives and to make programming them easier, we provide a tool, the primitive generator ('prims2x.fs'), that automatically generates most (and sometimes all) of the C code for a primitive from the stack effect notation. The source for a primitive has the following form:

Forth-name stack-effect category [*pronounc.*]
[""*glossary entry*""]
C code
[:
Forth code]

The items in brackets are optional. The category and glossary fields are there for generating the documentation, the Forth code is there for manual implementations on machines without GNU C. E.g., the source for the primitive + is:

```
+    n1 n2 -- n    core    plus
n = n1+n2;
```

This looks like a specification, but in fact n = n1+n2 is C code. Our primitive generation tool extracts a lot of information from the stack effect notations[2]: The number of items popped from and pushed on the stack, their type, and by what name they are referred to in the C code. It then generates a C code prelude and postlude for each primitive. The final C code for + looks like this:

```
I_plus:  /* + ( n1 n2 -- n ) */  /* label, stack effect */
/*  */                          /* documentation */
{
DEF_CA                          /* definition of variable ca (indirect threading) */
Cell n1;                        /* definitions of variables */
Cell n2;
Cell n;
n1 = (Cell) sp[1];              /* input */
n2 = (Cell) TOS;
sp += 1;                        /* stack adjustment */
NAME("+")                       /* debugging output (with -DDEBUG) */
{
n = n1+n2;                      /* C code taken from the source */
```

[2] We use a one-stack notation, even though we have separate data and floating-point stacks; The separate notation can be generated easily from the unified notation.

```
}
NEXT_P1;                        /* NEXT part 1 */
TOS = (Cell)n;                  /* output */
NEXT_P2;                        /* NEXT part 2 */
}
```

This looks long and inefficient, but the GNU C compiler optimizes quite well and produces optimal code for `+` on, e.g., the R3000 and the HP RISC machines: Defining the `n`s does not produce any code, and using them as intermediate storage also adds no cost.

There are also other optimizations that are not illustrated by this example: assignments between simple variables are usually for free (copy propagation). If one of the stack items is not used by the primitive (e.g. in `drop`), the compiler eliminates the load from the stack (dead code elimination). On the other hand, there are some things that the compiler does not do, therefore they are performed by '`prims2x.fs`': The compiler does not optimize code away that stores a stack item to the place where it just came from (e.g., `over`).

While programming a primitive is usually easy, there are a few cases where the programmer has to take the actions of the generator into account, most notably `?dup`, but also words that do not (always) fall through to `NEXT`.

12.3.2 TOS Optimization

An important optimization for stack machine emulators, e.g., Forth engines, is keeping one or more of the top stack items in registers. If a word has the stack effect *in1...inx -- out1...outy*, keeping the top *n* items in registers

- is better than keeping *n-1* items, if *x*>=*n* and *y*>=*n*, due to fewer loads from and stores to the stack.
- is slower than keeping *n-1* items, if *x*<>*y* and *x*<*n* and *y*<*n*, due to additional moves between registers.

In particular, keeping one item in a register is never a disadvantage, if there are enough registers. Keeping two items in registers is a disadvantage for frequent words like `?branch`, constants, variables, literals and `i`. Therefore our generator only produces code that keeps zero or one items in registers. The generated C code covers both cases; the selection between these alternatives is made at C-compile time using the switch `-DUSE_TOS`. `TOS` in the C code for `+` is just a simple variable name in the one-item case, otherwise it is a macro that expands into `sp[0]`. Note that the GNU C compiler tries to keep simple variables like `TOS` in registers, and it usually succeeds, if there are enough registers.

The primitive generator performs the TOS optimization for the floating-point stack, too (`-DUSE_FTOS`). For floating-point operations the benefit of this optimization is even larger: floating-point operations take quite long on most processors, but can be performed in parallel with other operations as long as their results are not used. If the FP-TOS is kept in a register, this works. If it is kept on the stack, i.e., in memory, the store into memory has to wait for the result of the floating-point operation, lengthening the execution time of the primitive considerably.

The TOS optimization makes the automatic generation of primitives a bit more complicated. Just replacing all occurrences of `sp[0]` by `TOS` is not sufficient. There are some special cases to consider:

- In the case of `dup ( w -- w w )` the generator must not eliminate the store to the original location of the item on the stack, if the TOS optimization is turned on.
- Primitives with stack effects of the form `--` *out1...outy* must store the TOS to the stack at the start. Likewise, primitives with the stack effect *in1...inx* `--` must load the TOS from the stack at the end. But for the null stack effect `--` no stores or loads should be generated.

12.3.3 Produced code

To see what assembly code is produced for the primitives on your machine with your compiler and your flag settings, type `make engine.s` and look at the resulting file '`engine.s`'.

12.4 Performance

On RISCs the Gforth engine is very close to optimal; i.e., it is usually impossible to write a significantly faster engine.

On register-starved machines like the 386 architecture processors improvements are possible, because `gcc` does not utilize the registers as well as a human, even with explicit register declarations; e.g., Bernd Beuster wrote a Forth system fragment in assembly language and hand-tuned it for the 486; this system is 1.19 times faster on the Sieve benchmark on a 486DX2/66 than Gforth compiled with `gcc-2.6.3` with `-DFORCE_REG`.

However, this potential advantage of assembly language implementations is not necessarily realized in complete Forth systems: We compared Gforth (direct threaded, compiled with `gcc-2.6.3` and `-DFORCE_REG`) with Win32Forth 1.2093, LMI's NT Forth (Beta, May 1994) and Eforth (with and without peephole (aka pinhole) optimization of the threaded code); all these systems were written in assembly language. We also compared Gforth with three systems written in C: PFE-0.9.14 (compiled with `gcc-2.6.3` with the default configuration for Linux: `-O2 -fomit-frame-pointer -DUSE_REGS -DUNROLL_NEXT`), ThisForth Beta (compiled with `gcc-2.6.3 -O3 -fomit-frame-pointer`; ThisForth employs peephole optimization of the threaded code) and TILE (compiled with `make opt`). We benchmarked Gforth, PFE, ThisForth and TILE on a 486DX2/66 under Linux. Kenneth O'Heskin kindly provided the results for Win32Forth and NT Forth on a 486DX2/66 with similar memory performance under Windows NT. Marcel Hendrix ported Eforth to Linux, then extended it to run the benchmarks, added the peephole optimizer, ran the benchmarks and reported the results.

We used four small benchmarks: the ubiquitous Sieve; bubble-sorting and matrix multiplication come from the Stanford integer benchmarks and have been translated into Forth by Martin Fraeman; we used the versions included in the TILE Forth package, but with bigger data set sizes; and a recursive Fibonacci number computation for benchmarking calling performance. The following table shows the time taken for the benchmarks scaled by the time taken by Gforth (in other words, it shows the speedup factor that Gforth achieved over the other systems).

```
relative      Win32-    NT       eforth       This-
  time  Gforth Forth Forth eforth  +opt   PFE Forth  TILE
sieve     1.00  1.39  1.14   1.39  0.85  1.58  3.18  8.58
```

```
bubble    1.00  1.31  1.41   1.48  0.88  1.50        3.88
matmul    1.00  1.47  1.35   1.46  0.74  1.58        4.09
fib       1.00  1.52  1.34   1.22  0.86  1.74  2.99  4.30
```

You may be quite surprised by the good performance of Gforth when compared with systems written in assembly language. One important reason for the disappointing performance of these other systems is probably that they are not written optimally for the 486 (e.g., they use the `lods` instruction). In addition, Win32Forth uses a comfortable, but costly method for relocating the Forth image: like `cforth`, it computes the actual addresses at run time, resulting in two address computations per `NEXT` (see Section 11.2 [Image File Background], page 149).

Only Eforth with the peephole optimizer has a performance that is comparable to Gforth. The speedups achieved with peephole optimization of threaded code are quite remarkable. Adding a peephole optimizer to Gforth should cause similar speedups.

The speedup of Gforth over PFE, ThisForth and TILE can be easily explained with the self-imposed restriction of the latter systems to standard C, which makes efficient threading impossible (however, the measured implementation of PFE uses a GNU C extension: see section "Defining Global Register Variables" in *GNU C Manual*). Moreover, current C compilers have a hard time optimizing other aspects of the ThisForth and the TILE source.

The performance of Gforth on 386 architecture processors varies widely with the version of `gcc` used. E.g., `gcc-2.5.8` failed to allocate any of the virtual machine registers into real machine registers by itself and would not work correctly with explicit register declarations, giving a 1.3 times slower engine (on a 486DX2/66 running the Sieve) than the one measured above.

Note that there have been several releases of Win32Forth since the release presented here, so the results presented above may have little predictive value for the performance of Win32Forth today.

In *Translating Forth to Efficient C* by M. Anton Ertl and Martin Maierhofer (presented at EuroForth '95), an indirect threaded version of Gforth is compared with Win32Forth, NT Forth, PFE, and ThisForth; that version of Gforth is 2%–8% slower on a 486 than the direct threaded version used here. The paper available at `http://www.complang.tuwien.ac.at/papers/ertl&maierhofer95.ps.gz`; it also contains numbers for some native code systems. You can find a newer version of these measurements at `http://www.complang.tuwien.ac.at/forth/performance.html`. You can find numbers for Gforth on various machines in '`Benchres`'.

13 Binding to System Library

14 Cross Compiler

Cross Compiler

14.1 Using the Cross Compiler

14.2 How the Cross Compiler Works

Appendix A Bugs

Known bugs are described in the file 'BUGS' in the Gforth distribution.

If you find a bug, please send a bug report to bug-gforth@gnu.org. A bug report should include this information:

- The Gforth version used (it is announced at the start of an interactive Gforth session).
- The machine and operating system (on Unix systems uname -a will report this information).
- The installation options (send the file 'config.status').
- A complete list of changes (if any) you (or your installer) have made to the Gforth sources.
- A program (or a sequence of keyboard commands) that reproduces the bug.
- A description of what you think constitutes the buggy behaviour.

For a thorough guide on reporting bugs read section "How to Report Bugs" in *GNU C Manual*.

Appendix B Authors and Ancestors of Gforth

B.1 Authors and Contributors

The Gforth project was started in mid-1992 by Bernd Paysan and Anton Ertl. The third major author was Jens Wilke. Lennart Benschop (who was one of Gforth's first users, in mid-1993) and Stuart Ramsden inspired us with their continuous feedback. Lennart Benshop contributed '`glosgen.fs`', while Stuart Ramsden has been working on automatic support for calling C libraries. Helpful comments also came from Paul Kleinrubatscher, Christian Pirker, Dirk Zoller, Marcel Hendrix, John Wavrik, Barrie Stott, Marc de Groot, and Jorge Acerada. Since the release of Gforth-0.2.1 there were also helpful comments from many others; thank you all, sorry for not listing you here (but digging through my mailbox to extract your names is on my to-do list). Since the release of Gforth-0.4.0 Neal Crook worked on the manual.

Gforth also owes a lot to the authors of the tools we used (GCC, CVS, and autoconf, among others), and to the creators of the Internet: Gforth was developed across the Internet, and its authors did not meet physically for the first 4 years of development.

B.2 Pedigree

Gforth descends from bigFORTH (1993) and fig-Forth. Gforth and PFE (by Dirk Zoller) will cross-fertilize each other. Of course, a significant part of the design of Gforth was prescribed by ANS Forth.

Bernd Paysan wrote bigFORTH, a descendent from TurboForth, an unreleased 32 bit native code version of VolksForth for the Atari ST, written mostly by Dietrich Weineck.

VolksForth descends from F83. It was written by Klaus Schleisiek, Bernd Pennemann, Georg Rehfeld and Dietrich Weineck for the C64 (called UltraForth there) in the mid-80s and ported to the Atari ST in 1986.

Henry Laxen and Mike Perry wrote F83 as a model implementation of the Forth-83 standard. !! Pedigree? When?

A team led by Bill Ragsdale implemented fig-Forth on many processors in 1979. Robert Selzer and Bill Ragsdale developed the original implementation of fig-Forth for the 6502 based on microForth.

The principal architect of microForth was Dean Sanderson. microForth was FORTH, Inc.'s first off-the-shelf product. It was developed in 1976 for the 1802, and subsequently implemented on the 8080, the 6800 and the Z80.

All earlier Forth systems were custom-made, usually by Charles Moore, who discovered (as he puts it) Forth during the late 60s. The first full Forth existed in 1971.

A part of the information in this section comes from *The Evolution of Forth* by Elizabeth D. Rather, Donald R. Colburn and Charles H. Moore, presented at the HOPL-II conference and preprinted in SIGPLAN Notices 28(3), 1993. You can find more historical and genealogical information about Forth there.

Appendix C Other Forth-related information

C.1 Internet resources

There is an active newsgroup (comp.lang.forth) discussing Forth and Forth-related issues. A frequently-asked-questions (FAQ) list is posted to the newsgroup regulary, and archived at these sites:

- `ftp://rtfm.mit.edu/pub/usenet-by-group/comp.lang.forth/`
- `ftp://ftp.forth.org/pub/Forth/FAQ/`

The FAQ list should be considered mandatory reading before posting to the newsgroup.

Here are some other web sites holding Forth-related material:

- `http://www.taygeta.com/forth.html` – Skip Carter's Forth pages.
- `http://www.jwdt.com/~paysan/gforth.html` – the Gforth home page.
- `http://www.minerva.com/uathena.htm` – home of ANS Forth Standard.
- `http://dec.bournemouth.ac.uk/forth/index.html` – the Forth Research page, including links to the Journal of Forth Application and Research (JFAR) and a searchable Forth bibliography.

C.2 Books

As the Standard is relatively new, there are not many books out yet. It is not recommended to learn Forth by using Gforth and a book that is not written for ANS Forth, as you will not know your mistakes from the deviations of the book. However, books based on the Forth-83 standard should be ok, because ANS Forth is primarily an extension of Forth-83.

The definite reference if you want to write ANS Forth programs is, of course, the ANS Forth document. It is available in printed form from the National Standards Institute Sales Department (Tel.: USA (212) 642-4900; Fax.: USA (212) 302-1286) as document *X3.215-1994* for about $200. You can also get it from Global Engineering Documents (Tel.: USA (800) 854-7179; Fax.: (303) 843-9880) for about $300.

dpANS6, the last draft of the standard, which was then submitted to ANSI for publication is available electronically and for free in some MS Word format, and it has been converted to HTML (`http://www.taygeta.com/forth/dpans.html`; this is my favourite format); this HTML version also includes the answers to Requests for Interpretation (RFIs). Some pointers to these versions can be found through
`http://www.complang.tuwien.ac.at/projects/forth.html`.

Forth: The New Model by Jack Woehr (Prentice-Hall, 1993) is an introductory book based on a draft version of the standard. It does not cover the whole standard. It also contains interesting background information (Jack Woehr was in the ANS Forth Technical Committee). It is not appropriate for complete newbies, but programmers experienced in other languages should find it ok.

Forth Programmer's Handbook by Edward K. Conklin, Elizabeth D. Rather and the technical staff of Forth, Inc. (Forth, Inc., 1997; ISBN 0-9662156-0-5) contains little introductory material. The majority of the book is similar to Chapter 4 [Words], page 27, but the book covers most of the standard words and some non-standard words (whereas this manual is quite incomplete). In addition, the book contains a chapter on programming style. The major drawback of this book is that it usually does not identify what is standard and what is specific to the Forth system described in the book (probably one of Forth, Inc.'s systems). Fortunately, many of the non-standard programming practices described in the book work in Gforth, too. Still, this drawback makes the book hardly more useful than a pre-ANS book.

C.3 The Forth Interest Group

The Forth Interest Group (FIG) is a world-wide, non-profit, member-supported organisation. It publishes a regular magazine, *FORTH Dimensions*, and offers other benefits of membership. You can contact the FIG through their office email address: `office@forth.org` or by visiting their web site at `http://www.forth.org/`. This web site also includes links to FIG chapters in other countries and American cities (`http://www.forth.org/chapters.html`).

C.4 Conferences

There are several regular conferences related to Forth. They are all well-publicised in *FORTH Dimensions* and on the comp.lang.forth news group:

- FORML – the Forth modification laboratory convenes every year near Monterey, California.
- The Rochester Forth Conference – an annual conference traditionally held in Rochester, New York.
- EuroForth – this European conference takes place annually.

Word Index

This index is a list of Forth words that have "glossary" entries within this manual. Each word is listed with its stack effect and wordset.

!

! *w a-addr* -- core 40

#

ud1 -- *ud2* core 85
#! -- gforth 153
#> *xd* -- *addr u* core 85
#s *ud* -- *0 0* core 85
#tib -- *a-addr* core-ext 66

$

$? -- *n* gforth 128

%

%align *align size* -- gforth 108
%alignment *align size* -- *align* gforth 108
%alloc *size align* -- *addr* gforth 108
%allocate *align size* -- *addr ior* gforth 108
%allot *align size* -- *addr* gforth 108
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'

' "*name*" -- *xt* core 73
' "*name*" -- *xt* oof 122
'cold -- gforth 153

(

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(local) *addr u* -- local 105

)

) -- gforth 93

*

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*/ *n1 n2 n3* -- *n4* core 31
*/mod *n1 n2 n3* -- *n4 n5* core 31

,

, *w* -- core 39

-

- *n1 n2* -- *n* core 29
-DO *compilation* -- *do-sys ; run-time n1 n2* -- *| loop-sys* gforth 47
-LOOP *compilation do-sys* -- *; run-time loop-sys1 u* -- *| loop-sys2* gforth 48
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-trailing *c-addr u1* -- *c-addr u2* string 43

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." *compilation 'ccc"'* -- *; run-time* -- core 88
.fpath -- gforth 80
.path *path-addr* -- gforth 81
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.s -- tools 91

/

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: "*name*" -- *colon-sys* core 56
:: "*name*" -- oof 122
:: *class* "*name*" -- mini-oof 124
:noname -- *xt colon-sys* core-ext 61

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;m *colon-sys* --*; run-time:* -- objects 119
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?DUP-IF *compilation -- orig ; run-time n -- n|* gforth ... 47
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[current] *compile-time: "selector" -- ; run-time: ... object -- ...* objects ... 118
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[IFDEF] *"<spaces>name" --* gforth ... 71
[IFUNDEF] *"<spaces>name" --* gforth ... 71
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]

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]L *compilation: n -- ; run-time: -- n* gforth ... 70

~

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+

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0

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0>= n -- f gforth 31
0< n -- f core 30
0<= n -- f gforth 30
0<> n -- f core-ext 30

1

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1/f r1 -- r2 gforth 33
1+ n1 -- n2 core 29

2

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Concept and Word Index

Not all entries listed in this index are present verbatim in the text. This index also duplicates, in abbreviated form, all of the words listed in the Word Index (only the names are listed for the words here).

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