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Overview

kForth is a computer program that may be used in various ways:

1. It may be used as a calculator.
2. It may be used to run computer programs written in the [Forth](#) language.
3. It may be embedded into another computer program to give that program the ability to understand and run Forth programs.

kForth, in its simplest mode of use, can evaluate arithmetic expressions typed in by the user. Expressions are entered in a manner similar to that used for RPN (reverse Polish notation) calculators, such as for Hewlett-Packard scientific calculators. Both integer and *floating point* calculations may be performed. Trigonometric and transcendental functions are provided. In addition, logic and bit operations may be performed, and the number base may be changed, i.e. numbers may be entered and displayed in hexadecimal (base 16) for example.

kForth is an implementation of the Forth programming language and environment. The user may write Forth programs with an editor, load these program files from kForth, and run them. kForth, like other implementations of Forth, provides an interactive environment, allowing the user to examine or define variables and execute or define individual *words*. Interactive use is one of the main advantages in using a Forth environment for writing and testing computer programs. kForth provides a significant *subset* of the ANS specification for the Forth language. It also provides some extensions and "non-standard" features which its authors have found to be useful. Experienced Forth users should consult the [Technical Information](#) section of the User's Guide for specific information on the differences between kForth and standard ANS Forth.

Some notable features of kForth are:

- kForth is reasonably fast for many applications.
- kForth detects and reports many kinds of programming mistakes, providing useful feedback to aid the user in correcting his/her Forth program.
- Detailed documentation about kForth's features is provided in the User's Guide. This guide contains a beginner's tutorial on using kForth, describes the function of each of kForth's intrinsic words, and provides technical details about kForth for intermediate and advanced users.
- A large collection of example Forth programs are bundled with kForth-32, many of which are complete and useful programs.
- kForth provides a set of Forth libraries for productive programming. Forth source libraries include:
 - String manipulation, standard file access, and console output control
 - Structures, lists, and simple objects
 - A subset of the [Forth Scientific Library](#) with many extras, and demos

- Operating system calls, sockets, signals, and shared library interface
- Assembler for x86 processors

The shared library interface supports bindings to pre-compiled external libraries of functions written in C and Fortran. Library bindings are provided for X-Windows programming (`libX11`), GNU Multiple Precision Arithmetic Library (`libgmp`), and the GNU Multi-precision Floating Point Library (`libmpfr`) .

- kForth's operating system interface, under Linux, makes it possible to write Forth programs for instrument control and data acquisition, e.g. to write Forth code for interfacing with a *device driver*, and to write *client-server* applications.
- kForth makes it easy to use the large amounts of memory available to the computer, through its *dynamic dictionary* design.
- kForth provides a large amount of test code, written in Forth, to validate its own operation. Tests for compliance to ANS-Forth specified behavior and validation of its floating point arithmetic are among the provided system tests.

In addition to being as a stand-alone computing environment, the kForth program was also written so that it may be easily embedded into another program. Advanced programmers, typically programming in the C and C++ languages, can use the kForth *source code* to make their own programs *user extensible*. In fact kForth was originally developed to allow users of [XYPLOT](#) for Linux to customize and add their own functions to the program. They can do this without modifying the XYPLOT program itself. Instead, they may write separate Forth modules and load them to extend XYPLOT's capabilities.

1. Installation

kForth is provided under the terms of the [GNU General Public License](#). New releases of this software will be posted at the [CCRE website](#), as they become available. This manual provides a guide to the use and documents the features of kForth.

The kForth source package is distributed as compressed tar (Unix Tape Archive) files:

- **kforth-x86-linux-x.y.z.tar.gz** (Linux version)

where `x.y.z` is the current version number, such as `1.5.3`. The source package unpacks to a directory of source files and a `Makefile` for building the executable(s). Difficulties with installation should be reported to: krishna.myneni@ccreweb.org

1.1 Installation under GNU/Linux

1.1.1 Required Packages

The following packages are required to build and maintain kForth from its source package, on a GNU/Linux system:

- **binutils**
- **gcc**
- **gcc-c++**
- **glibc**
- **glibc-devel**
- **libstdc++-devel**
- **make**
- **readline**
- **readline-devel**
- **ncurses**
- **ncurses-devel**
- **patchutils**

Note that some of the package names may be slightly different, depending on your GNU/Linux distribution. Some or all of these packages may already be installed on your GNU/Linux system, but if they are not, you should be able to install them manually for your distribution. You may use your system's graphical package manager to check for installation of the required packages, or use a command line query. For example, if your GNU/Linux system is `rpm`-based, you may verify that these packages have been installed by using the `rpm` command in the following way:

```
rpm -q package-name
```

The above command will return the version number of the package if it has been installed. The version of GNU C/C++ should be `3.2` or higher. On a Debian package-based system, the following command line query may be used:

`aptitude search package-name`

While it may be tedious to determine the necessary package names and install any needed packages on your system, this is a one-time procedure which will enable your system to be used for building software from its source code, and for software development.

1.1.2 64-bit Linux Systems

kForth is always built as a 32-bit application, even on 64-bit systems. If you are building on a 64-bit system (x86_64), the 32-bit versions of the C/C++ libraries and other libraries (ncurses, readline) must be installed. On a system such as CentOS 7, and other Red Hat Enterprise Linux 7 derived systems, additional packages are installed using

`sudo yum install package-name`

Installing the following additional packages will provide the needed libraries to build kForth on these systems:

- **`glibc-devel.i686`**
- **`libstdc++-devel.i686`**
- **`ncurses-devel.i686`**
- **`readline-devel.i686`**

1.1.3 Library Packages for Forth Programming

In addition to the packages needed to build kForth, additional libraries may be installed to allow Forth programs access to X11 graphics and multi-precision arithmetic. Various examples of Forth programs which use external libraries are provided in `forth-src/libs` and `forth-src/x11`. The following packages may be installed to run these examples (both 64-bit and 32-bit versions of the packages may coexist on a system).

- **`libX11.i686`**
- **`libXft.i686`**
- **`libXrender.i686`**
- **`xorg-x11-fonts-75dpi.noarch`**
- **`xorg-x11-fonts-100dpi.noarch`**
- **`xorg-x11-fonts-Type1.noarch`**
- **`xorg-x11-fonts-misc.noarch`**
- **`xorg-x11-fonts-ISO8859-1-75dpi.noarch`**
- **`gmp.i686`**
- **`mpfr.i686`**

1.2 Build and Configuration

Assuming your Linux system has the required packages, follow these steps to unpack, build, and install kForth:

1. Create a directory for the kForth source files, typically in your home directory, *e.g.*

```
mkdir ~/kforth
```

2. Move the kForth archive file into this directory:

```
mv kforth-x86-linux-x.y.z.tar.gz ~/kforth
```

3. Change to the `~/kforth` directory and extract the files:

```
cd ~/kforth
```

```
tar -zxvf kforth-x86-linux-x.y.z.tar.gz
```

After this step, a subdirectory will be created with the name **kforth-x.y.z**. This directory will contain all of the kForth source files, the **Makefile(s)**, as well as a **README** file with these same instructions.

4. Change to the `kforth-x.y.z` directory:

```
cd kforth-x.y.z
```

5. Build the kForth executable. There are several options for building kForth, but the simplest is to type:

```
make
```

All of the source files will be compiled/assembled and two executable files, named `kforth32` and `kforth32-fast`, will be generated.

6. At this point you should be able to run the executables from your `~/kforth/kforth-x.y.z` directory. If you wish to make kforth available to all users or to place the programs in the default search path, move the executables to a suitable directory (`/usr/local/bin/` is recommended) using:

```
sudo mv kforth32 /usr/local/bin/  
sudo mv kforth32-fast /usr/local/bin/
```

Any user should then be able to execute `kforth32` or `kforth32-fast`. You must have superuser privilege to do this last step.

7. Sample source code files are included in the archive. These files have extension `.4th`. Users may copy the example programs to their own directories.
8. You may specify a default directory in which `kforth` will search for `.4th` files not found in the current directory. The environment variable `KFORTH_DIR` must be set to this directory. For example, under the `BASH` shell, if you want the default directory to be `~/kforth/kforth-x.y.z`, add the following lines to your `.bash_profile` file:

```
KFORTH_DIR=~/kforth/kforth-x.y.z  
export KFORTH_DIR
```

9. The file `kforth.xpm` may be used to create a desktop icon for `kForth` under X Windows. For example, if you are using the KDE environment, copy `kforth.xpm` to the `/usr/share/icons` directory.

2. Using kForth

2.1 Basics

Type **kforth32** to start the program. Upon startup, kForth will inform you that it is ready to accept input by displaying

Ready!

You may type commands, a sequence of *words*, and press Enter. kForth will respond with the prompt

ok

after it finishes executing each line of input. To illustrate, try typing the following

2 5 + .

and press Enter. kForth will respond with

7 ok

You may now enter another sequence of words. One particularly useful word to know is

bye

kForth will respond by saying

Goodbye

and exiting. kForth is not *case sensitive* – you may enter words in lower case *or* upper case.

2.2 More Words

The word

words

will display a list of currently defined words in the *dictionary*. You may define your own words by typing them at the kForth prompt. For example, a word that counts from one to ten and displays each number counted may be defined by entering

```
: count_to_ten 10 0 do i 1+ . loop ;
```

The symbols ":" and ";" are very important – they indicate to the kForth compiler the beginning and ending of the definition of the word, called `count_to_ten` in this example. kForth will display the prompt `Ok` after the new word has been compiled into the dictionary.

You can verify that our newly defined word has been added to the dictionary by using `words`. Now, execute the word by typing

count_to_ten

and pressing `Enter`. kForth will display the output

```
1 2 3 4 5 6 7 8 9 10 ok
```

If you are entering a definition that requires several lines of typing, the `Ok` prompt will not be displayed until the end of the definition has been entered, *i.e.* until the compiler encounters a semicolon.

Although you can write Forth programs this way, it is much easier to create the definitions in a separate source file and then load them into kForth by issuing the command

include filename

For example, the definition of `count_to_ten` could have been entered into a plain text file called `prog1.4th`. Once kForth has been started, you can simply issue the command

include prog1

kForth will read the input from the specified file as though it was being entered from the keyboard. You may have noticed that the full filename was not entered in the `include` command. If no extension is specified, the file is assumed to have an extension of `.4th`.

You may also load a source file upon startup of kForth by typing

```
kforth filename
```

2.3 Using the Stack

Forth provides a memory region called the *stack* in which data may be placed and operated upon by defined words. You may enter numbers onto the stack simply by typing them and pressing Enter. You can use the word `.S` to list the contents of the stack. For example, type the following and press Enter.

```
2 5
```

You have placed two numbers onto the stack. Now, type

```
.S
```

and press Enter. kForth will respond by listing the items on the stack:

```
5
2
```

Notice that 5 is on the top of the stack – items are placed into the stack in a *first-in, last-out* order. Stack operators (words) are a part of the Forth language. Examples include the arithmetic operators

```
+ - * /
```

These operate on the top two items on the stack and replace them with the result. Other words change the order of items on the stack or copy or remove items from the stack:

```
SWAP ROT DUP OVER TUCK DROP NIP
```

Each stack *cell* holds a single integer number. You may also place real numbers, also known as *floating point* numbers, onto the stack. These numbers must be input in a special way known as *exponential notation*. For example, to place the real number 3.14 onto the stack, type

```
3.14e0
```

and press Enter. The zero following the 'e' indicates the power of ten that is multiplied to the number (10 raised to the zero power is equal to 1). If the exponent is zero, as in this example, the entry can be shortened to simply

3.14e

Exponential format allows you to enter very small and very large numbers easily. To enter the fractional number representing one-billionth, 0.000000001, you may type

1e-9

and press Enter.

When you place a floating point number onto the stack and list the stack using **.S**, you will see two integer numbers printed instead of one real number. *A floating point number occupies two stack cells instead of one*, and **.S** lists the contents of each cell as though it were a single integer. You may print the floating point number occupying the top two cells of the stack with the word

F.

Use the words

F+ F- F* F/

to perform arithmetic on floating point numbers which have been placed onto the stack. For example,

3.14e 6.28e f+ f.

will print the result 9.42. Words to manipulate floating point numbers on the stack include

FSWAP FROT FDUP FOVER FDROP

2.4 Variables and Constants

An integer variable may be declared as follows:

variable name

Values may be stored and retrieved from the variable using the “store” (**!**) and “fetch” (**@**) operators. For example, if we want to define a variable called **counter** and initialize its value to 20, we enter the following:

**variable counter
20 counter !**

When you define a variable, memory is reserved at some *address* to hold an integer value, and the name of the variable becomes part of the dictionary. Typing the name `counter` at the Forth prompt and pressing enter will cause the memory address of `counter` to be placed onto the stack. Try the following:

```
counter  
.s
```

You will see a memory address on top of the stack.

To examine the value stored in the variable `counter`, we place the address of `counter` on the stack, then use the fetch operator to retrieve the value from that address onto the stack, as follows.

```
counter @
```

The number 20 will be on top of the stack. Of course to see the value, we must print it using the word "dot" (`.`), so entering

```
counter @ .
```

will print the value 20. Forth also has a built-in word, `?`, that performs the sequence '`@ .`'.

Now, let's say we want to increment the value of `counter` by ten. First we fetch the value stored in `counter` onto the stack, then add ten, and finally store the new value into the variable. This is accomplished by the sequence,

```
counter @ 10 + counter !
```

Actually, Forth provides a shorter way of doing the same thing:

```
10 counter +!
```

Floating point variables are defined in a similar way:

```
fvariable name
```

The corresponding operators for storing and retrieving floating point numbers into the variable are `f!` and `f@`. Let's define a floating point variable called `velocity` and initialize it to zero.

```
fvariable velocity  
0e velocity f!
```

Note that a floating point value of zero is entered as `0e` and we used the operator `f!` to store the value into `velocity`. If we now want to increment the value of `velocity` by 9.8, we can enter

```
velocity f@ 9.8e f+ velocity f!
```

kForth does not have a word called `f+!`, but with a little more familiarity with Forth, you may easily define such a word!. To print a floating point value on the stack, use the word `f.` as explained previously. For example,

```
velocity f@ f.
```

will print the value 9.8.

Integer constants are defined as follows

value constant name

To define a constant called `megabyte`, for example, type

```
1048576 constant megabyte
```

I often can't remember how many bytes there are in a megabyte, so I may have written instead

```
1024 1024 * constant megabyte
```

Now, type the name of the constant and print the top item on the stack

```
megabyte .
```

and you will see printed the value 1048576. Typing the name of the constant retrieves *its value* (not an address) onto the stack.

Floating point constants are defined in a similar fashion

fvalue fconstant name

To define a constant containing the acceleration due to gravity, 9.8 meters per second squared, type

```
9.8e fconstant g
```

The name of the constant is `g`. Typing

`g f.`

will print 9.8. Now, let's add the value of `g` to the value of `velocity` and print the result to illustrate the use of floating point variables and constants

`velocity f@ g f+ f.`

2.5 Stack Diagrams

The kForth [dictionary](#) contains many words that you may execute simply by typing them at the `OK` prompt. Some words expect values to have been placed on the stack when they begin executing. During execution of the word, these values may be removed from the stack and other values may be placed onto the stack. The values that are expected on the stack at the beginning of execution and those values that are returned on the stack at the end of execution are stated in the form of a *stack diagram* for the word. For example, the stack diagram for the word `NEGATE` is written as follows:

$$(\ n \ \ -- \ m \)$$

This diagram indicates that a single integer `n` must be on the stack prior to executing `NEGATE`. After `NEGATE` finishes executing, the original value `n` has been removed from the stack and is replaced by a new single integer `m`. Try typing

3 `negate`

Now, list the items on the stack using `.S`.

Words that do not expect any items to be on the stack, and which do not return anything on the stack (e.g. `CR` and `DECIMAL`) have a stack diagram that looks like

$$(\ \ -- \)$$

The word `@` has the stack diagram

$$(\ a \ \ -- \ n \)$$

with the meaning that `@` expects an address `a` on the stack and returns a single integer `n` on the stack. In contrast the word `!` has the stack diagram

$$(\ n \ a \ \ -- \)$$

with the meaning that `!` expects two items to be on the stack, a single integer `n` and an address `a`, with “`a`” being the *top* item on the stack. During execution, both `n` and `a` are removed from the stack, the word `!` using and dispensing with them. Nothing is returned on the stack.

2.6 Simple Word Examples

Now let us practice writing some simple and useful words.

Example 1: Compounding Interest

Suppose we invest \$1000 and we expect that it will grow with a yearly interest of 6%, which is compounded annually. What will be the final amount after 10 years?

We can determine the amount of interest accumulated after each year by taking 6% of the current amount and adding that to the current amount. For example, you can type the following to compute and print the amount at the end of the first year:

```
1000 dup 6 * 100 / + .
```

We placed the starting amount on the stack, then duplicated this value on the stack to compute 6% interest. Finally we add the top two numbers on the stack, the starting amount and the interest, and print the sum. If you are confused by the above example, it will help to print the contents of the stack using `.S` after you enter each word on a separate line,

```
1000 .S
dup .S
6 .S
* .S
100 .S
/ .S
+ .S
.
```

To solve the problem for 10 years, we simply need to repeat this calculation ten times. However, we must skip the first word, `1000` and the last word, `.`, in between years so that we can use the compounded amount from one year as the starting amount for the next year. The final result may be printed at the end.

Performing a repetitive calculation is easy in Forth – it is done with a `DO . . . LOOP`. The word `DO` expects two numbers on the stack. The difference between the two numbers is the number of times that the words between `DO` and `LOOP` will be executed. The smaller number should be on top of the stack. The following word illustrates using the `DO . . . LOOP` to solve this problem:


```
\ compound 6% interest on $1000 for 10 years and print answer
: compound10 ( -- )
  1000          \ starting amount
  10 0 do       \ do this for ten years
    dup 6 * 100 / \ compute 6% interest of current amount
    +           \ add interest to current amount
  loop         \ loop to next year
  .           \ finally print the result
;
```

Executing the word `compound10` will display the answer 1786.

Now let's generalize our word so that it is more useful. We want to be able to specify the starting amount, the interest, and the number of years to compound the interest. Finally, we want to print the result as before. The following word takes inputs from the stack, computes the final amount, and prints the answer:

```
: compound ( nstart npercent nyears -- )
  0 do \ do this for nyears
    2dup * 100 / \ compute interest on current amount
    rot + \ add interest to current amount
    swap \ swap items on stack to keep same order
  loop \ loop to next year
  drop . \ drop interest and print final amount
;
```

The word `compound` assumes that we have entered the starting amount, the percent interest per year, and the number of years onto the stack, as indicated in its stack diagram. Therefore, to solve the problem of our previous example using the more general word we would type

```
1000 6 10 compound
```

and press Enter. The same answer found previously will be displayed. But with our new word we can also determine the compounded growth after any number of years (except zero), at any interest rate, and for any starting amount. To see what our investment will grow to after 20 years, type:

```
1000 6 20 compound
```

To conclude this example, let's modify the word `compound` so that it prints a table of the accumulated amount at the end of each year:

```
: compound ( nstart npercent nyears -- )
  0 do
    2dup * 100 /
    rot +

    i 1+ 2 .r \ print year right-justified in 2 character field
    9 emit \ print a tab
    dup 6 .r \ print year-ending amount right justified in 6 char field
    cr \ advance to the next line
    swap
  loop
  2drop ;
```

Notice that we made use of the word **I** in the above example. **I** gets the *loop index* and places it on the stack. The loop index starts at the number on top of the stack when **DO** executes, which is 0 in this example. The loop index increments by one after each **LOOP**. You can look up in the dictionary other words that may not be familiar to you in this example, such as **1+**, **.R**, **EMIT**, and **CR**.

Finally, it is easy in kForth to send the output from the last example to a file instead of printing it on the screen. This is done by typing

```
>file interest.txt
1000 6 20 compound
console
```

The word **>FILE** redirects output from the screen (console) to the file name specified subsequently, `interest.txt` in the above example. The word **CONSOLE** closes the file and redirects output back to the screen. We used **>FILE** and **CONSOLE** to send the results of our interest calculations to a file, which can then be imported into a spreadsheet to make a chart!

2.7 Acting on Conditions

Nearly all computer programs, except for the simplest, will check to see if a specified condition is either true or false, and carry out different instructions based on the result. We have already seen how a **DO . . . LOOP** works in Forth. In this special case, the word **LOOP** adds 1 to the loop counter and then checks whether or not the condition that the loop counter is equal to the ending count of the loop is true or false. Often, we will want to instruct the computer to check conditions that are not related to loops and then execute one sequence of words if the condition is true, or another sequence of words if the condition is false. Let's see how we can do this in Forth.

To start with, let's look at how to test a condition and how the result of the test is represented. As an example, our condition to be tested is whether or not the variable **X** is greater than 2. In Forth, such a test would be written as

x @ 2 >

We fetch the value of **X** onto the stack, next place the integer 2 on the stack, and then use the word **>** to check whether or not the number buried one cell deep into the stack is greater than the number on the top of the stack. The stack diagram for **>** is

n1 n2 -- b

Therefore, **>** removes both numbers from the stack and leaves a *boolean flag*, written as "b" in the stack diagram above. The flag "b" is itself another number, but it is a number that is always either **0** or **-1**. The value of the flag represents one of two states: *true*, corresponding to the value **-1** and *false*, corresponding to the value **0**. As a convenience, Forth provides two predefined constants **TRUE** and **FALSE**. Try the following.

TRUE .

FALSE .

Now we have learned that the result of a test is a flag value, either *true* or *false*, placed on top of the stack. Although our example used the word `>`, other words in Forth can test for *equality* of two numbers, a *less than* condition, and perform several other comparisons.

A flag on top of the stack is used by the word `IF` to cause the computer to jump to different locations inside the executing word, based on the flag's value. This process is called *conditional branching* and all programming languages provide a way to do this. The word `IF` is part of a *control structure* made up of the words `IF . . . ELSE . . . THEN`, where . . . represents some arbitrary word sequences. Many other programming languages have a structure similar to this, but in Forth its use is slightly different. The word `IF` assumes the conditional test has already been performed and that there is a flag on top of the stack. Let's illustrate the use of the `IF . . . ELSE . . . THEN` structure with an example. Suppose we want to write a word that prints whether a number given to it is “even” or “odd”. We could define this word as follows

```
: parity ( n -- | print whether a number is even or odd )
  2 MOD 0=
  IF
    ." even"
  ELSE
    ." odd"
  THEN ;
```

In our definition of the word `parity`, the conditional test is given by the line

2 MOD 0=

The word `MOD` performs a division, except that it returns the *remainder* instead of the quotient. An “even” number divided by 2 has a zero remainder, so we check to see if the value returned by `MOD`, on top of the stack, is equal to zero. The word `0=` returns a true flag when the number on top of the stack is zero, a false flag otherwise. When `IF` examines this flag, if it finds the flag to be true, execution jumps to the word following `IF`. On the other hand, if the flag is false, execution branches to the word following `ELSE`. To see how it works, try typing a number followed by the word `parity`, e.g.

4 parity

A few other points to note about the `IF . . . ELSE . . . THEN` structure:

- When the word `IF` examines the flag on top of the stack, it treats *any* non-zero value as representing *true*. A zero value always corresponds to *false*. Therefore, we could define the word `parity` as:

```
: parity ( n -- ) 2 MOD IF ." odd" ELSE ." even" THEN ;
```

Notice the exchange of `." odd"` and `." even"` in the new version of `parity`.

- In some cases we may not want to do anything when the condition is false. For example, suppose we want to write a word that prints “odd” only when the number we give it is odd, but does nothing if the number is even. Then we can omit the `ELSE . . .` portion of the structure. For example, we can define

```
: odd? ( n -- ) 2 MOD IF ." odd" THEN ;
```

Try passing different numbers to the word `odd?`, e.g.

```
5 odd? .
```

- When the condition flag is *true*, the words enclosed between `IF` and `ELSE` are executed; when the flag is *false*, the words enclosed between `ELSE` and `THEN` are executed. After either branch is executed, the computer resumes execution after the word `THEN`. The two branches come back together again following `THEN` – this is a feature of *structured programming*, which makes it easier for a person to trace the possible paths a computer may take through a sequence of instructions.
- An `IF . . . ELSE . . . THEN` structure can be placed inside a branch of another `IF . . . ELSE . . . THEN` structure. This is called *nesting*, and you will see an example of nested structures in the next section.

2.8 The Return Stack

Because Forth words often use values on the stack for input data, it may become difficult to keep the items ordered exactly as needed during the calculation, especially when there are several input values required. While Forth provides several stack manipulation words such as `DUP` `SWAP` `ROT`, etc., sometimes the most convenient operation is to temporarily remove an item from the top of the stack, then place it back on the stack when needed. Of course we may use variables for this purpose, but Forth provides a simpler way to accomplish this by providing another stack, called the *return stack*. An item on the stack can be temporarily “pushed” onto the return stack by using the word `>R`. The item may be “popped” back from the return stack to the ordinary data stack with the word `R>`.

The following example also illustrates the use of the return stack.

```
: this_date ( -- day month year )  
  time&date >r >r >r 2drop drop r> r> r> ;
```

The word `this_date` returns today's date on the stack with the year on top. It does this by calling kForth's built-in word, `TIME&DATE`, which has the following stack diagram:

```
time&date ( -- secs mins hours day month year )
```

We want our word `this_date` to only return the day, month, and year, so we must remove `secs`, `mins`, and `hours` left on the stack by `TIME&DATE`. However, `day`, `month`, and `year` are on top and the three numbers we want to drop (`secs`, `mins`, and `hours`) are buried underneath. Using `>R` three times, we remove the year, month, and day from the stack, in that order. These numbers are pushed onto the return stack. Now we use `2DROP` and `DROP` to remove hours, mins, and secs from the stack. Finally, we use the word `R>` three times to pop the day, month, and year from the return stack back onto the data stack.

A word of caution to the novice Forth user: the return stack must be used with the following restrictions because Forth itself places items on the return stack at the beginning of executing a word and also when executing `DO` loops:

- Inside the definition of a word, every item pushed onto the return stack with `>R` must be popped from the return stack with a corresponding `R>` before the end of the word.
- There must also be a matching `R>` for every `>R` inside of a `DO . . . LOOP`.
- Inside of `DO` loops, the loop index words `I` and `J` must not be used when items have been pushed onto the return stack but not yet popped.

Example 2: Calculating Age

In this example, we will make use of what we have learned up to now to compute the age of a person given their birth date. Following good Forth practice, we will first define a few simple words which we anticipate will be helpful for writing the actual age calculator:

```
: this_year ( -- year )
    this_date >r 2drop r> ;

: this_month ( -- month )
    this_date drop nip ;

: this_day ( -- day )
    this_date 2drop ;
```

The words `this_year`, `this_month`, and `this_day` all use `this_date`, defined previously, and remove any extra items from the stack. A couple more words will be helpful in our calculation:

```
: date< ( day1 month1 day2 month2 -- flag )
    rot swap
    2dup          \ is month1 less than month2?
    < if
        2drop 2drop \ remove items on stack -- no further test needed
        true         \ leave true flag on the stack
    else
        = if         \ is month1 equal to month2?
        <             \ flag represents day1 less than day2
    else
```

```

        2drop      \ remove items on stack -- month1 > month2
        false      \ so return false flag
    then
then ;

```

Notice that we used two nested IF ... ELSE ... THEN structures in our definition of DATE<. The first IF examines the flag returned by <, which tests whether or not month1 is less than month2. If month1 is not less than month2, we must then check to see if month1 is equal to month2. The word = tests this condition and returns the appropriate flag, which is examined by the second IF.

```

\ test whether day and month are in future

: after_today ( day month -- b )
  this_day this_month 2swap date< ;

```

We are ready now to calculate a person's age, given their birth date.

```

: age ( day month year -- age | calculate age given birth date )
  this_year swap - \ number of years between birth year and this year
  -rot             \ move top item to bottom of stack
  after_today if   \ is birthday later than today?
    1-             \ yes, subtract one from number of years
  then ;

```

We may test our definition of AGE by typing

```

    day month year age .

```

where *day*, *month*, and *year* are the numbers for your birth day, month, and year. kForth will respond by printing your current age.

2.9 Factoring a Forth Program

You may have noticed that in our example of the age calculator, we defined several words, not just one. Breaking the calculation into individual short words is a way to make writing a program simpler, easier to understand, and easier to test when, as is inevitable, a program doesn't work like you imagined. Previously defined words can be used to write higher level words, making the higher level words more readable. Well-written Forth programs will often have short low-level words, each of which performs a single and simple computation matching well the name of that word. As an example, consider the game [tetrис.4th](#) written in Forth ([pure source](#)). Notice how the words defined towards the beginning of the program, such as `DRAW-PIT` and `UPDATE-SCORE` are short words with well-defined functions matching their names. Near the end of the program, various words are combined to define the higher level word, `PLAY-GAME`. Although the working of the lower level words may not be immediately apparent from reading their definitions, in a properly *factored* Forth program, the high level word(s), such as `PLAY-GAME`, are very readable and often times resemble a natural language description of the actions performed by the word. Good factoring is a skill acquired through practice with writing programs in any programming language, and often results in programs which are more easy to diagnose and repair when things don't work as expected.

2.9 Using Memory

2.9.1 Data Types

Earlier, in section 2.4, we learned how to create named integer and floating point variables using `VARIABLE` and `FVARIABLE`. These words *define* new words, which when executed, return the starting location (address) of the memory region containing their value. Different *data types* such as integers and floating point numbers require different amounts of memory for storing their values, and the words `VARIABLE` and `FVARIABLE` automatically reserve (`ALLOT`) the appropriate sized region.

In addition to the `VARIABLE` and `FVARIABLE` data types, Forth also provides `2VARIABLE` for a *double length* integer. Thus, `VARIABLE` will `allot` one *cell* (typically 4 bytes on a 32-bit system) and `2VARIABLE` will `allot` two cells of memory. To find out how many bytes of memory represent one cell in a Forth system, type

```
1 cells .
```

We would use `2VARIABLES`, for example, when we want to store integer numbers that are too large, or will become too large in the course of executing our program, to be represented by *single length* `VARIABLES`.

2.9.2 CREATE and ALLOT

In writing our own Forth programs, we may need to store and retrieve data of different size than the sizes given by the data types discussed above. Examples are a paragraph of text, or an *array* of

integers. How do we go about reserving memory for, say, 100 single length integers? In addition to reserving the memory, we need to assign a name with which to refer to the memory region. These tasks are accomplished through the use of the words `CREATE` and `ALLOT`:

```
CREATE iarray 100 CELLS ALLOT
```

The above statement will create a new word in the dictionary, called `iarray`, and reserve 100 cells (400 bytes on a 32-bit system). Executing the word `iarray` will return the starting address of the memory region. The words `CREATE` and `ALLOT` are, in fact, primitive Forth words which may be used to *define* words such as `VARIABLE`, *e.g.*

```
: VAR CREATE 1 CELLS ALLOT ;
```

Example 3: Initializing and Printing an Array of Integers

In our example above, we reserved a memory region of 100 cells in size using `ALLOT`. Simply `allotting` this memory does not specify what is initially stored in this region. We might need to set the initial values of the 100 integers in `iarray` before using it in our computation. A word to set all of the 100 integers to zero could be defined in the following way.

```
: init-iarray ( -- | initialize iarray to zeros )  
  iarray 100 0 DO 0 over ! cell+ LOOP drop ;
```

Study the above example to see how the word performs the action of storing a zero in each of the 100 cells. You may look up the action of the word [CELL+](#) in the dictionary. A word to print the 100 integers stored in `iarray` may be defined as follows.

```
: print-iarray ( -- )  
  cr iarray  
  100 0 DO  
    dup @  
    6 .R i 1+ 8 mod 0= IF cr THEN \ nice output formatting  
    cell+  
  LOOP drop ;
```

Forth also provides the words, `FILL`, `BLANK`, and `ERASE`, to set all of the *bytes* in a memory region to a single byte value. Using `ERASE`, `init-iarray` may also be defined as

```
: init-iarray ( -- ) iarray 100 cells erase ;
```

Exercise: Try modifying our first definition of `init-iarray` so that it stores a running count from 1 to 100 in `iarray`, instead of initializing all the values to zero. The following output should be produced by `print-iarray`.

```
print-iarray
```


1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64
65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88
89	90	91	92	93	94	95	96
97	98	99	100	ok			

2.9.3 Viewing Memory with DUMP

In some applications, particularly those involving sending and receiving data between the computer and another device, it is often very useful to be able to view the individual bytes stored in a region of memory. Forth provides the word `DUMP` to allow the user to view the individual byte contents of a memory region. In kForth, the word `DUMP` is provided as a *source definition*, that is, a word defined using more primitive Forth words, within the file [dump.4th](#). To use the word `DUMP`, we must first `include` this file with

```
include dump
```

Then, typing `IARRAY 64 DUMP` should output something like

```
134969216 : 01 00 00 00 02 00 00 00 00 03 00 00 00 04 00 00 00 .....
134969232 : 05 00 00 00 06 00 00 00 00 07 00 00 00 08 00 00 00 .....
134969248 : 09 00 00 00 0A 00 00 00 00 0B 00 00 00 0C 00 00 00 .....
134969264 : 0D 00 00 00 0E 00 00 00 00 0F 00 00 00 10 00 00 00 ..... ok
```

At first glance, the above output does not seem too useful; however, if we look closely, the data stored previously in `iarray` may be seen – the running count starting from one can be seen in the successive groups of four bytes. Also, `DUMP` displays the individual bytes in base 16, or *hexadecimal*. This is not immediately apparent, until we see that the number 10 in `iarray` is displayed as the four-byte sequence " 0A 00 00 00". Engineers trying to debug programs communicating with hardware often find “hex” output to be more useful than the ordinary decimal representation because it allows them to visualize the bit-pattern represented by each hex character.

`DUMP` also shows the address of the first byte of each line on the left hand side, and shows additional characters on the right hand side. When the bytes in memory represent printable characters, also known as ASCII codes, the corresponding character is displayed on the right hand side. To see this, try `IARRAY 64 CELLS + 128 DUMP`. The following output will be shown by `DUMP`:

```
134969472 : 41 00 00 00 42 00 00 00 43 00 00 00 44 00 00 00 A...B...C...D...
134969488 : 45 00 00 00 46 00 00 00 47 00 00 00 48 00 00 00 E...F...G...H...
134969504 : 49 00 00 00 4A 00 00 00 4B 00 00 00 4C 00 00 00 I...J...K...L...
134969520 : 4D 00 00 00 4E 00 00 00 4F 00 00 00 50 00 00 00 M...N...O...P...
134969536 : 51 00 00 00 52 00 00 00 53 00 00 00 54 00 00 00 Q...R...S...T...
134969552 : 55 00 00 00 56 00 00 00 57 00 00 00 58 00 00 00 U...V...W...X...
134969568 : 59 00 00 00 5A 00 00 00 5B 00 00 00 5C 00 00 00 Y...Z...[...\...
134969584 : 5D 00 00 00 5E 00 00 00 5F 00 00 00 60 00 00 00 ]...^..._...`... ok
```

3. Dictionary

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2. [Word Lists and Search Order](#)
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Stack diagram notation:

	Data Type	Stack Cells
a	address	1
n	signed single integer	1
u	unsigned single integer	1
d	signed double length integer	2
ud	unsigned double length integer	2
t	signed triple length integer	3
ut	unsigned triple length integer	3
b	boolean flag: true or false (-1 or 0)	1
r	double precision floating point value	2
^str	counted string address	1

Word names shown in **BOLDFACE** are not standard in ANS Forth.

3.1 Dictionary Maintenance

FORGET	--	remove the next word in the input stream and later words from the dictionary
COLD	--	remove all non-intrinsic definitions from the dictionary
WORDS	--	list the defined words in the current search order

The word **FORGET** may be used to remove words from the dictionary. Typing

FORGET *name*

will remove *name* and all words defined after *name* from the dictionary.

The word **COLD** deletes all non-intrinsic definitions and strings, resets all stacks, and restarts the Forth environment in interpreter mode.

3.2 Word Lists and Search Order

Words in the dictionary are grouped into *word lists*. kForth provides the following built-in word lists:

Root Forth Assembler

New definitions are added to the current *compilation word list*, which is initially the **Forth** word list. When the compiler searches the dictionary for a word name, the search proceeds in a specified order through a specified series of word lists. This set of ordered word lists is known as the *search order*. The **Root** word list must always be a part of the search order; however, any other word lists may be added or removed from the search order. The user may create custom word lists to group new words added to the dictionary, and control their visibility to the Forth compiler.

ORDER	--	display the word lists in the search order. The word list at the beginning of the search order is displayed to the left, and the compilation word list is shown in brackets
GET-ORDER	-- awidn ... awid1 n	return the word list address identifiers, and the number of word lists awid1 is the first word list in the search order
SET-ORDER	awidn ... awid1 n --	set the search order to the specified sequence of word lists,

		where <code>awid1</code> is the first word list in the search order
<code>ONLY</code>	--	remove all word lists from the search order, except the minimal <code>Root</code> word list
<code>FORTH</code>	--	replace the first word list in the search order with the <code>Forth</code> word list
<code>ASSEMBLER</code>	--	replace the first word list in the search order with the <code>Assembler</code> word list
<code>GET-CURRENT</code>	-- <code>awid</code>	return the word list address for the current compilation word list
<code>SET-CURRENT</code>	<code>awid --</code>	set the compilation word list to be the word list identified by <code>awid</code>
<code>FORTH-WORDLIST</code>	-- <code>awid</code>	return the word list address identifying the <code>Forth</code> word list
<code>ALSO</code>	--	duplicate the word list at the beginning of the search order
<code>PREVIOUS</code>	--	remove the first word list in the search order
<code>DEFINITIONS</code>	--	set the first word list in the search order as the compilation word list
<code>WORDLIST</code>	-- <code>awid</code>	create a new empty word list and return its identifier address, <code>awid</code>
VOCABULARY	--	create a new named word list which, when executed, will replace the first word list in the search order
<code>SEARCH-WORDLIST</code>	<code>a u awid -- 0 axt n</code>	search the word list identified by <code>awid</code> for the word name in the string, a u. Return <code>n=0</code> if the word is not found in the word list, <code>n=1</code> if the word is found and is an immediate word <code>n=-1</code> if the word is found and is not an immediate word
<code>FIND</code>	<code>^str -- a n</code>	search all the word lists in the search order for the word specified by the counted string; <code>n</code> is 0 if not found, <code>n</code> is 1 if found and the word is an IMMEDIATE word, <code>n</code> is -1 if found and the word is not an immediate word, and <code>a</code> is a valid EXECUTE address if the word is found
[DEFINED]	-- <code>b</code>	parse a word name from the input stream, search for the name in the search order, and return a

		flag indicating whether or not the name was found (-1 if found).
[UNDEFINED]	-- b	parse a word name from the input stream, search for the name in the search order, and return a flag indicating whether or not the name was found (0 if found).

3.3 Compilation and Execution Words

IMMEDIATE	--	set the precedence during compilation of the most recently defined word
NONDEFERRED	--	set the precedence during interpretation of the most recently defined word
POSTPONE	--	append the run-time semantics of the next word to the current definition
LITERAL	n a --	compile a number or address on the stack into the current definition
2LITERAL	d --	compile a double number on the stack into the current definition
SLITERAL	a u --	compile a string address and count from the stack into the current definition
FLITERAL	r --	compile a floating point number on the stack into the current definition
'	-- a	returns the code field address (cfa) of the next word in the input stream
[']	--	immediate version of ' for use inside a word definition
>BODY	a1 -- a2	convert the cfa of a word to its parameter field address (pfa)
COMPILE,	a --	compile the execution semantics for the cfa of a word into the current definition
EXECUTE	a --	execute a word with its cfa given on the stack
EVALUATE	a u --	interpret and execute source code contained in a string
:	--	create a new word definition and enter the compilation state
;	--	
[--	enter interpretation state
]	--	enter compilation state
STATE	-- b	return true (-1) if compiling; false (0) otherwise

The words `'` (TICK), and `[']` may be used to search the dictionary for a specified word. These words behave according to the ANS Forth standard, and return an execution address on the stack. The word `EXECUTE` may be used to execute a word given the execution address on the stack. The word `NONDEFERRED` is a non-standard word which is used to set the enhanced *precedence* state of a word in kForth. For more information on the concept of precedence in kForth, refer to the Technical Information section of the user's guide.

The following standard compilation words are provided in Forth source in [ans-words.4th](#) :

`TO` -- determine the body address of the next word and append the
run-time semantics to store a value at that address

3.4 Defining Words

In addition to ordinary "colon definitions" of the form,

`: NAME ... ;`

the following *defining words* are also provided:

`CREATE name`
`VARIABLE name`
`n CONSTANT name`
`2VARIABLE name`
`d 2CONSTANT name`
`FVARIABLE name`
`f FCONSTANT name`

`CREATE` can be used inside a word definition to make your own defining words. The word `DOES>`, as part of a `CREATE ... DOES>` expression, allows you to specify the run time behavior of words created by the defining word.

At present, kForth does not allow making a defining word with the use of `:"` inside the definition of a word -- use `CREATE ... DOES>` instead.

The following common Forth defining words have source code definitions, provided in [ans-words.4th](#):

`n VALUE name`
`DEFER name`

An existing word may be referred to by another name, using the non-standard word **ALIAS**.

ALIAS	xt --	create a new word which has the same execution behavior as xt
--------------	-------	---

It may be used as follows,

' name1 **ALIAS** *name2*

where *name1* is the name of an existing word in the search order, and *name2* is the new name.

3.5 Control Structures

The following control structures are provided in kForth:

```
DO ... LOOP
DO ... +LOOP
?DO ... LOOP
?DO ... +LOOP
IF ... THEN
IF ... ELSE ... THEN
BEGIN ... AGAIN
BEGIN ... UNTIL
BEGIN ... WHILE ... REPEAT
CASE ... OF ... ENDOF ... ENDCASE
```

All control structures may be nested. For DO loops the number of levels of nesting is only limited by return stack space. The following execution control words are also defined:

```
RECURSE
LEAVE
EXIT
QUIT
ABORT
ABORT"
```

RECURSE causes the currently executing word to be executed.

LEAVE removes the current loop parameters from the return stack, by calling UNLOOP, and causes an immediate jump out of the current loop. Execution resumes at the instruction following the loop.

EXIT causes an immediate return from the word currently being executed. Note that EXIT from within a loop requires that the loop parameters be discarded from the return stack explicitly with UNLOOP.

QUIT empties the return stack, terminates execution of the current word and returns kForth to the

interpreter mode.

ABORT empties the data stack and executes QUIT.

ABORT" examines the flag on top of the stack and if the flag is true, prints the message delimited by ", then executes ABORT.

The exception handling words CATCH and THROW are defined in source in ans-words.4th.

3.6 Stack Operations

DUP	n -- n n	duplicate
?DUP	n -- n n 0	dup if not zero
SWAP	n1 n2 -- n2 n1	swap
OVER	n1 n2 -- n1 n2 n1	over
ROT	n1 n2 n3 -- n2 n3 n1	rotate cw
-ROT	n1 n2 n3 -- n3 n1 n2	rotate ccw
DROP	n1 --	drop
NIP	n1 n2 -- n2	nip
TUCK	n1 n2 -- n2 n1 n2	tuck
PICK	... n -- ... m	copy nth item deep
ROLL	... n -- ... m	rotate nth item deep to top of stack
DEPTH	... -- ... n	stack depth
2DUP	n1 n2 -- n1 n2 n1 n2	
2SWAP	n1 n2 n3 n4 -- n3 n4 n1 n2	
2OVER	n1 n2 n3 n4 -- n1 n2 n3 n4 n1 n2	
2ROT	n1 n2 n3 n4 n5 n6 -- n3 n4 n5 n6 n1n2	
2DROP	n1 n2 --	
FDUP	r -- r r	duplicate a floating point number on top of the stack
FSWAP	r1 r2 -- r2 r1	swap two floating point numbers on the stack
FOVER	r1 r2 -- r1 r2 r1	copy the floating point number one deep onto top of stack
FROT	r1 r2 r3 -- r2 r3 r1	rotate the order of three fp numbers on the stack
FDROP	r --	drop a floating point number from the stack
F2DROP	r1 r2 --	drop two fp numbers from the stack
F2DUP	r1 r2 -- r1 r2 r1 r2	duplicate a pair of fp numbers on the stack

Return stack operations are:

>R	n --	push onto return stack
R>	-- n	pop from return stack
R@	-- n	copy from top of return stack
2>R	d --	push two stack cells onto return stack
2R>	-- d	pop two cells from return stack
2R@	-- d	copy two cells from top of return stack
I	-- n	current loop index
J	-- n	next outer loop index
UNLOOP	--	discard loop parameters from return stack

Note that 2>R is not equivalent to the sequence >R >R. The order of the two single length elements on top of the return stack is different for the two cases. 2>R pushes two items from the top of the stack so that they have the same order on the return stack. The sequence 2>R 2R>, however, is identical to the sequence >R >R R> R>.

3.7 Memory Operations

@	a -- n	fetch single
!	n a --	store single n to address a
2@	a -- d	fetch double number from address a
2!	d a --	store double number to address a
A@	a1 -- a2	fetch address from address a
C@	a -- n	fetch byte
C!	n a --	store byte
W@	a -- n	fetch signed word
W!	n a --	store signed word
SF@	a -- r	fetch single precision float
SF!	r a --	store r as single precision float
DF@	a -- r	fetch double precision float
DF!	r a --	store double precision float
F@	a -- r	same as DF@
F!	r a --	same as DF!
SP@	-- a	fetch data stack pointer
RP@	-- a	fetch return stack pointer
SP!	a --	set data stack pointer
RP!	a --	set return stack pointer
?	a --	fetch and print single; equivalent to @ .
ALLLOT	u --	allocates u bytes in the dictionary

?ALLOT	u -- a	allocates u bytes in the dictionary and returns starting address of the allocated region
ALLOCATE	u -- a n	reserve u bytes of system memory and return starting address of the allocated region and error code
FREE	a -- n	release memory previously reserved with ALLOCATE and return error code (0 = success)
RESIZE	a1 u -- a2 ior	change size of previously ALLOCATED region to u bytes; ior = 0 if success
C"	-- ^str	compile a counted string into the string table; the string is taken from the input stream and must be terminated by "
S"	-- a u	compile a string and return address and count
COUNT	^str -- a u	convert counted string address to character buffer address a and character count u
MOVE	a1 a2 u --	move u bytes from source a1 to dest a2; handle overlapping region
FILL	a u1 n2 --	fill u1 bytes with byte value n2 starting at a
ERASE	a u --	fill u bytes with zero starting at a

See also [String Operations](#).

The following standard memory words are provided in Forth source in [ans-words.4th](#) and [dump.4th](#):

PAD	-- a	return address of a scratch-pad in memory for temporary use	ans-words.4th
DUMP	a u --	output a hexadecimal display of the u bytes starting at address 'a'	dump.4th

The non-ANS standard word **A@** is needed because kForth performs type checking for operands involved in memory access. It is essentially identical to **@** except the type field is set to be an *address* for the retrieved value. Addresses may be stored in ordinary variables using **!**; however they should be retrieved with **A@**.

The behavior of **ALLOT** does not conform exactly to the ANS standard. **ALLOT** dynamically allocates the requested amount of memory and sets the parameter field address (PFA) of the last created word to the address of the allotted region. Thus, **ALLOT** should always be preceded by **CREATE**. In kForth, an attempt to **ALLOT** without first creating a named dictionary entry, using **CREATE**, will result in a virtual machine error. Thus kForth limits the use of **ALLOT**, but code written for kForth will be portable to ANS Forths.

The non-ANS standard word **?ALLOT** is provided because kForth contains no **HERE** address. **?ALLOT** should be preceded by **CREATE** as described above. All memory is dynamically allocated, and freed upon exiting kForth.

3.8 String Operations

-TRAILING	a u1 -- a u2	reduce string length to ignore trailing spaces
/STRING	a1 u1 n -- a2 u2	$a2 = a1 + n$, $u2 = u1 - n$
BLANK	a u --	fill u bytes with the blank-space character starting at a
CMOVE	a1 a2 u --	move u bytes from source a1 to dest a2
CMOVE>	a1 a2 u --	move u bytes from a1 to a2 in descending order
COMPARE	a1 u1 a2 u2 -- n	compare the strings a1 u1 and a2 u2. Return zero if they are equal.
SEARCH	a1 u1 a2 u2 -- a3 u3 b	search for the string a2 u2 within the string a1 u1; return <code>true</code> if found and the substring a3 u3
SLITERAL	a u --	compile a string address and count from the stack into the current definition

The following useful string words are provided in [strings.4th](#).

SCAN	a1 u1 n -- a2 u2	search for first occurrence of character value n in the string specified by a1 u1. Return the substring a2 u2 starting with the search character
SKIP	a1 u1 n -- a2 u2	search for first occurrence of character value not equal to n

See also [Memory Operations](#).

3.9 Logic and Bit Manipulation Operations

AND	n1 n2 -- n3	bitwise AND of n1 and n2
OR	n1 n2 -- n3	bitwise OR of n1 and n2
XOR	n1 n2 -- n3	bitwise exclusive OR of n1 and n2
NOT	n1 -- n2	one's complement of n1
INVERT	n1 -- n2	same as NOT
LSHIFT	n1 n2 -- n3	n3 is n1 shifted left by n2 bits
RSHIFT	n1 n2 -- n3	n3 is n1 shifted right by n2 bits

3.10 Arithmetic and Relational Operations

3.10.1 Single and Double Integer Operations

1+	n1 -- n2	increment ($n2 = n1 + 1$)
1-	n1 -- n2	decrement ($n2 = n1 - 1$)
2+	n1 -- n2	$n2 = n1 + 2$
2-	n1 -- n2	$n2 = n1 - 2$
2*	n1 -- n2	arithmetic left shift ($n2 = n1 * 2$)
2/	n1 -- n2	arithmetic right shift ($n2 = n1 / 2$)
CELLS	n1 -- n2	n2 is n1 times size in bytes of a cell (4)
CELL+	n1 -- n2	n2 is n1 plus the size in bytes of a cell
FLOATS	n1 -- n2	n2 is n1 times size of a floating point number
FLOAT+	n1 -- n2	n2 is n1 plus the size of a floating point number
DFLOATS	n1 -- n2	n2 is n1 times size of double precision fp number
DFLOAT+	n1 -- n2	n2 is n1 plus size of double precision fp number
SFLOATS	n1 -- n2	n2 is n1 times size of single precision fp number
SFLOAT+	n1 -- n2	n2 is n1 plus size of single precision fp number
CHAR+	n1 -- n2	same as 1+
+	n1 n2 -- n3	add
-	n1 n2 -- n3	subtract ($n3 = n1 - n2$)
*	n1 n2 -- n3	multiply
/	n1 n2 -- n3	divide ($n3 = n1 / n2$)
+	n a --	add n to value at address a
MOD	n1 n2 -- n3	modulus or remainder
/MOD	n1 n2 -- n3 n4	$n3 =$ remainder and $n4 =$ quotient for $n1 / n2$
* /	n1 n2 n3 -- n4	$n4 = n1 * n2 / n3$; intermediate value is 64 bit
* /MOD	n1 n2 n3 -- n4 n5	$n4$ and $n5$ are remainder and quotient for $n1 * n2 / n3$
M+	d1 n -- d2	add single to double integer
M*	n1 n2 -- d	multiply two singles and return signed double
M* /	d1 n1 +n2 -- d2	multiply d1 by n1 to obtain triple cell result; then divide result by $n2 > 0$ to give signed double d2
UM*	u1 u2 -- ud	multiply unsigned singles and return unsigned double
UM/MOD	ud u1 -- u2 u3	divide unsigned double number by unsigned single and return remainder (u2) and quotient (u3). Returns -1 -1 for u2 and u3 on division overflow
FM/MOD	d n1 -- n2 n3	divide double by single to give floored quotient n3 and <i>modulus</i> n2
SM/REM	d n1 -- n2 n3	divide double by single to give symmetric quotient n3 and <i>remainder</i> n2
DS*	d n -- t	multiply double and single to give signed triple length product
UDM*	ud u -- ut	multiply unsigned double and unsigned single to give unsigned triple length product

UTM/	ut u -- ud	divide unsigned triple by unsigned single to give unsigned double quotient
UTS/MOD	ut1 u1 -- ut2 u2	Divide unsigned triple ut1 by unsigned single u1 to give unsigned triple quotient ut2 and unsigned single remainder u2
STS/REM	t1 n1 -- t2 n2	Divide signed triple t1 by signed single n1 to give signed triple quotient t2 and signed remainder n2
D+	d1 d2 -- d3	double number addition
D-	d1 d2 -- d3	double number subtraction
ABS	n1 -- n2	absolute value
NEGATE	n1 -- n2	n2 = -n1
DABS	d1 -- d2	double number absolute value
DNEGATE	d1 -- d2	double number negation
MIN	n1 n2 -- n1 n2	minimum of n1 and n2
MAX	n1 n2 -- n1 n2	maximum of n1 and n2
DMIN	d1 d2 -- d1 d2	minimum of d1 and d2
DMAX	d1 d2 -- d1 d2	maximum of d1 and d2
=	n1 n2 -- b	test n1 equal to n2
<>	n1 n2 -- b	test n1 not equal to n2
<	n1 n2 -- b	test n1 less than n2
>	n1 n2 -- b	test n1 greater than n2
<=	n1 n2 -- b	test n1 less than or equal to n2
>=	n1 n2 -- b	test n1 greater than or equal to n2
U<	u1 u2 -- b	test unsigned u1 less than u2
U>	u1 u2 -- b	test unsigned u1 greater than u2
D=	d1 d2 -- b	test d1 equal to d2
D<	d1 d2 -- b	test d1 less than d2
DU<	ud1 ud2 -- b	test ud1 less than ud2
0<	n -- b	test n less than zero
0>	n -- b	test n greater than zero
0=	n -- b	test n equal to zero
0<>	n -- b	test n not equal to zero
D0=	d -- b	test d equal to zero
D2*	d1 -- d2	d2 is the arithmetic left shift of d1
D2/	d1 -- d2	d2 is the arithmetic right shift of d1
WITHIN	n1 u1 n2 u2 n3 u3 -- b	return TRUE if n2 u2 <= n1 u1 < n3 u3, given n2 u2 < n3 u3

kForth provides pre-defined constants TRUE (-1) and FALSE (0).

3.11 Floating Point Operations

3.11.1 Arithmetic and Relational Words

F+	r1 r2 -- r3	fadd
F-	r1 r2 -- r3	fsubtract (r3 = r1 - r2)
F*	r1 r2 -- r3	fmultiply
F/	r1 r2 -- r3	fdivide (r3 = r1/r2)
FABS	r1 -- r2	absolute value
FNEGATE	r1 -- r2	r2 = -r1
FROUND	r1 -- r2	round to nearest whole number
FTRUNC	r1 -- r2	truncate, towards zero, to whole number
FLOOR	r1 -- r2	truncate, towards minus infinity, to whole number
FMIN	r1 r2 -- r1 r2	minimum of r1 and r2
FMAX	r1 r2 -- r1 r2	maximum of r1 and r2
F0=	r -- b	test r equal to zero
F0<	r -- b	test r less than zero
F0>	r -- b	test r greater than zero
F=	r1 r2 -- b	test r1 equal to r2
F<>	r1 r2 -- b	test r1 not equal to r2
F<	r1 r2 -- b	test r1 less than r2
F>	r1 r2 -- b	test r1 greater than r2
F<=	r1 r2 -- b	test r1 less than or equal to r2
F>=	r1 r2 -- b	test r1 greater than or equal to r2

The following standard word is provided as Forth source in [ans-words.4th](#):

```
F~          r1 r2 r3 -- b      test r1 approximately equal to r2, within uncertainty r3;
                                if r3 = 0e, r1 and r2 must be exactly equal in their binary
                                representation
```

3.11.2 Floating Point Functions

F**	r1 r2 -- r3	r3 = r1 raised to power of r2
FSQRT	r1 -- r2	square root
FLOG	r1 -- r2	r2 = log base 10 of r1
FALOG	r1 -- r2	r2 = 10 raised to power of r1
FEXP	r1 -- r2	r2 = exp(r1)
FLN	r1 -- r2	r2 = log base e of r1
DEG>RAD	r1 -- r2	degrees to radians
RAD>DEG	r1 -- r2	radians to degrees

FSIN	r1 -- r2	$r2 = \sin(r1)$
FCOS	r1 -- r2	$r2 = \cos(r1)$
FSINCOS	r1 -- r2 r3	$r2 = \sin(r1); r3 = \cos(r1)$
FTAN	r1 -- r2	$r2 = \tan(r1)$
FASIN	r1 -- r2	arc sine
FACOS	r1 -- r2	arc cosine
FATAN	r1 -- r2	arc tangent
FATAN2	r1 r2 -- r3	r3 is arc tangent of r1/r2 with proper quadrant
FSINH	r1 -- r2	$r2 = \sinh(r1)$
FCOSH	r1 -- r2	$r2 = \cosh(r1)$
FTANH	r1 -- r2	$r2 = \tanh(r1)$
FASINH	r1 -- r2	inverse hyperbolic sine
FACOSH	r1 -- r2	inverse hyperbolic cosine
FATANH	r1 -- r2	inverse hyperbolic tangent

3.12 Number Conversion

S>D	n -- d	convert single integer to double length integer
D>S	d -- n	convert signed double integer to signed integer
S>F	n -- r	convert single integer to floating point number
D>F	d -- r	convert double length integer to fp number
FROUND>S	r -- n	convert floating point to integer by <i>rounding</i>
FTRUNC>S	r -- n	convert floating point to integer by <i>truncating</i> towards zero
F>D	r -- d	convert fp number to double integer by truncating towards zero
>FLOAT	a u -- r TRUE FALSE	convert string to floating point number return fp number and TRUE if successful, FALSE otherwise
>NUMBER	ud1 a1 u1 -- ud2 a2 u2	convert digits of string a1 u1 and add this number to ud1*base; result is ud2, and a2 u2 point to remaining part of string
NUMBER?	^str -- d b	convert counted string to signed double number b is TRUE if successful
<#	ud -- ud	begin conversion of unsigned double to a string
#	ud1 -- ud2	convert the least significant digit of ud1 to a character;
		concatenate character to conversion string.
#S	ud1 -- 0 0	convert all significant digits in ud1 to string
SIGN	n --	attach minus sign to conversion string if $n < 0$

HOLD	n --	attach character with ASCII code n to the conversion string
#>	ud -- a u	drop the double number and return the string address and count

Other useful conversion words for number to string conversion and vice-versa are given in Forth source in [strings.4th](#).

3.13 Input and Output

BASE	-- a	return the address containing current number base
DECIMAL	--	set the number base to ten
BINARY	--	set the number base to two
HEX	--	set the number base to sixteen
KEY	-- n	wait for key press and return key code
ACCEPT	a n1 -- n2	read up to n1 characters into buffer a from keyboard. n2 is actual number input.
BL	-- 32	return the ascii value for a blank space character
WORD	n -- ^str	parse a word from the input stream, delimited by character with ascii value n and return the address of a counted string containing the word
CHAR	-- n	parse the next word, delimited by a space and return the ascii value of its first character
[CHAR]	-- n	version of CHAR for use in compile state
.	n --	display top item on the stack in the current base
.R	n m --	display n in the current base in m-wide field
U.	u --	display unsigned single in current base
U.R	u m --	display u in the current base in m-wide field
D.	d --	display signed double length number
PRECISION	-- u	return the number of significant digits output by FS.
SET-PRECISION	u --	set the number of significant digits output by FS.
FS.	r --	display the floating point number using scientific notation, with the number of significant digits

		specified by PRECISION
F .	r --	display the floating point number on top of the stack, using an automatic format.
.S	n1 n2 ... -- n1 n2 ...	non-destructive display of the stack
. "	--	display text message; the message is read from the input stream and must be terminated by "
. (--	display text message from input stream; message is terminated by ')'. The word is executed immediately.
CR	--	output carriage return
SPACES	n --	output n spaces
EMIT	n --	output character with ascii value n
TYPE	a n --	display n characters from buffer at a
SOURCE	-- a u	return address and count of the input buffer
REFILL	-- b	attempt to read another line from the input source and return flag
>FILE	--	change output stream from the console to a file. The filename is the next word in the input stream
CONSOLE	--	reset output stream to the console

The following standard terminal control words, and more, are provided in Forth source in [ansi.4th](#):

PAGE	--	clear the screen and put cursor at top left
AT-XY	n1 n2 --	position cursor at column n1 and row n2, origin is (0,0)

3.13 File Access

OPEN	<code>^name n1 -- n2</code>	open file specified by counted string <code>^name</code> in mode <code>n1</code> , which can be the following: 0 read-only (R/O) 1 write-only (W/O) 2 read-write (R/W) <code>n2</code> is the file descriptor, a non-negative integer if successful.
LSEEK	<code>n1 n2 n3 -- n4</code>	change current position in opened file <code>n1</code> is the file descriptor <code>n2</code> is the offset, and <code>n3</code> is the mode with the following meaning: 0 offset is relative to start of file 1 offset is relative to current position 2 offset is relative to end of file <code>n4</code> is the resulting offset from the beginning of the file, or -1 if error.
READ	<code>n1 a n2 -- n3</code>	read <code>n2</code> bytes into buffer address <code>a</code> , from file with descriptor <code>n1</code> . <code>n3</code> is the number of bytes actually read.
WRITE	<code>n1 a n2 -- n3</code>	write <code>n2</code> bytes from buffer address <code>a</code> to file with descriptor <code>n1</code> . <code>n3</code> is the number of bytes actually written.
CLOSE	<code>n1 -- n2</code>	close file with descriptor <code>n1</code> and return status <code>n2</code> (0 if successful, -1 if error).
INCLUDE	<code>--</code>	read and process the specified Forth source file
INCLUDED	<code>a u -- ?</code>	set the input stream for the interpreter to the specified file and process it line by line

The following ANS standard file access words are provided as Forth definitions in `files.4th`:

R/O	<code>-- n</code>	"read-only" file access method
W/O	<code>-- n</code>	"write-only" file access method
R/W	<code>-- n</code>	"read-write" file access method
CREATE-FILE	<code>a u n1 -- n2 n3</code>	create a file with name specified by string address and count <code>a u</code> , and access method <code>n1</code> . Return file descriptor <code>n2</code> and result code <code>n3</code>
OPEN-FILE	<code>a u n1 -- n2 n3</code>	open an existing file and return file descriptor <code>n2</code> and result code <code>n3</code>

CLOSE-FILE	n1 -- n2	close the file with descriptor n1 and return result code n2
READ-FILE	a u1 n1 -- u2 n2	read u1 bytes into buffer at address 'a' from file with descriptor n1 and return actual number of bytes read u2 and result code n2
WRITE-FILE	a u n1 -- n2	write u bytes from buffer 'a' to file with descriptor n1; return result code n2
FILE- POSITION	n1 -- ud n2	return the current file position ud and result code n2
REPOSITION- FILE	ud n1 -- n2	set file position to ud for file with descriptor n1 and return result code n2
FILE-SIZE	n1 -- ud n2	return the size of the file ud and the result code n2
FILE-EXISTS	^str -- b	return TRUE if the specified file exists
DELETE-FILE	a u -- n	delete the file specified by string a u, and return result code n (not in Cygwin)
READ-LINE	a u1 n1 -- u2 b n2	read a line of text, with at most u1 bytes, from file with descriptor n1 into the buffer 'a'; return actual bytes read u2, success flag, and result code n2
WRITE-LINE	a u n1 -- n2	write a line of text having u bytes from buffer 'a' into file with descriptor n1, and return result code n2

3.14 Operating System Interface

SYSTEM	^str -- n	execute a shell command; ^str is the command line passed to the shell. Return code n is -1 on error, or the return value from the command.
SYSCALL	n1 ... nm m ncall -- nerr	perform system call ncall, with arguments n1 to nm, where $0 \leq m \leq 6$ (not functional under Cygwin)
BYE	--	close the Forth environment and exit to the system.
CHDIR	^path -- n	change the current directory to the one specified in the counted string ^path; n is OS dependent return code
IOCTL	n1 n2 a -- n3	send device control request n2 to file with descriptor n1. Additional parameters are passed through buffer at address a. n3 is the status (0 if successful, -1 if error).
TIME&DAY	-- sec min hr day mo yr	return the local time
MS	u --	wait for at least u milliseconds
MS@	-- u	return number of milliseconds elapsed since start of kForth
DLOPEN	azstr bflag -- nhandle	load the dynamic library file
DLERROR	-- azstr	return address of null terminated error string
DLSYM	nhandle azsym -- addr	return address of symbol in library
DLCLOSE	nhandle -- nerr	close the dynamic library
FORTH-SIGNAL	a n -- aold	install Forth word as handler for signal n
RAISE	n -- ior	assert signal n
SET-ITIMER	n1 a1 a2 -- n2	set up timer signals
GET-ITIMER	n a -- n2	get timer countdown count
USLEEP	u --	wait for at least u microseconds (For Windows version, resolution is 1000)

Numerous operating system functions are defined as Forth words in [syscalls.4th](#).

3.14 Miscellaneous

CALL	a --	call machine language subroutine at address a
-------------	-------------	---

4. Technical Information

1. [ANS Forth Compliance](#)
2. [Threading Model](#)
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Release Specifications

The current [kForth-32](#) release is version 1.6.0.

4.1 ANS Forth Compliance

kForth is specified as a subset of the ANS Forth standard, given in [DPANS94](#). Code written for kForth is portable to ANS-compliant Forth systems with the use of trivially defined extensions (see the *Special Features* section below). The compliance with ANS Forth may be checked using John Hayes' suite of tests for the core words of an ANS Forth system: `tester.4th` and `core.4th`. Tests involving unsupported words such as `HERE` and `,` and `C,` have been commented out, as well as tests involving the `BEGIN ... WHILE ... WHILE ... REPEAT ... THEN` structure, and some weird variants of `CREATE` and `DOES>` usage. Compliance with the ANS Forth extension words for working with double length numbers may be checked using `dbltest.4th`. Tests are commented out for words which are not implemented in kForth.

4.2 Threading Model

kForth is an *indirect threaded code* (ITC) system. The kForth compiler/interpreter parses the input stream into a vector of pseudo op-codes or Forth Byte Code. Upon execution, the vector of byte codes is passed on to a *virtual machine* which looks up the execution address of the words and performs either a *call* or an *indirect jump* to the next execution address. The type of threading used in the virtual machine is a **hybrid** of *indirect call threading* and *indirect jump threading*. The kForth virtual machine is implemented as a mixture of assembly language, C, and C++ functions. Only the assembly language portion of the virtual machine utilizes indirect jump threading.

4.3 Signed Integer Division

kForth versions 1.2.10 and earlier implement *symmetric integer division*. An alternative form of signed integer division is called *floored integer division*. Both symmetric and floored division yield identical results when the two operands, dividend and divisor, are either both positive integers or

both negative integers. However, when the two operands differ in sign, symmetric and floored integer division can give different results. For example,

Floored Division: -8 3 / . -3 ok

Symmetric Division: -8 3 / . 2 ok

Similarly, the word MOD yields different results on floored and symmetric division systems. Under floored division, MOD is truly a *modulus* operator (*i.e.* the result of $n1\ n2\ MOD$ is a number in the range $[0, n2)$), while under symmetric division, MOD simply returns a remainder. The following paper provides a discussion of integer division in computing languages: [*Division and Modulus for Computer Scientists*](#) by Daan Leijen.

Floored integer division was guaranteed by the Forth-83 standard. However, the DPANS94 standard revoked this guarantee and allowed system implementors to choose either symmetric or floored integer division. The rationale in revoking a fixed standard was to allow Forth systems to implement whatever form of integer division was best supported by the microprocessor hardware. Most microprocessors which provide signed integer division implement symmetric division. In kForth, the original rationale for using symmetric division was simply to maintain consistency with the GNU C implementation, which mandates the use of symmetric integer division per the ISO C99 standard (the symmetric version of MOD corresponds to the % operator in C). In general, floored division is considered by computer scientists and mathematicians to be the more useful form of signed integer division.

A significant problem with the DPANS94 standard is that, in practice, implementors of ANS-compliant Forth systems for a single hardware platform such as Intel x86 have chosen to use different forms of division. Consider the behavior of the Forth systems below, all running under Linux on a Intel PII:

```
gforth:    -8 3 MOD .    -2 ok
pfe:       -8 3 MOD .     1 ok
kforth:    -8 3 MOD .    -2 ok
iforth:    -8 3 MOD .    -2 ok
bigforth:  -8 3 MOD .     1 ok
```

Therefore, a Forth program using signed integer division words (/ MOD /MOD */MOD) may produce different outputs under two different ANS-compliant Forth systems. The DPANS94 standard addresses the portability issue by calling for use of the explicit floored and symmetric division words FM/MOD and SM/REM whenever it is important to explicitly specify the type of division. However, it is highly likely that Forth programmers will casually use signed integer division words such as MOD without always remembering the portability issue.

4.4 Double Numbers

kForth supports working with signed and unsigned double length numbers, and implements nearly all of the optional double number word set specified by DPANS94, either intrinsically or in the form of Forth source definitions (see `ans-words.4th` for the latter). In addition to the ANS Forth tests involving double numbers given in `core.4th`, further tests of double number words implemented in kForth are given in `system-test/dbltest.4th`.

4.4.1 Double Number Entry

One significant departure in kForth from typical Forth systems which provide double numbers is the method of entry of double length numbers. Traditional Forth recognizes the decimal point as a marker for a double number, e.g.

`234.`

is interpreted as a double number. *kForth does not permit double number entry in this manner.* The rationale behind this restriction is that such entries may easily be confused with floating point numbers. Such confusion will likely be common for new Forth users who have previously used other computer languages such as C. Even experienced Forth users who make frequent use of floating point calculations are also susceptible to such confusion. Since kForth uses the data stack to hold floating point numbers, and since a floating point number also occupies two stack cells (see next section), mistakes arising from misinterpreting entries with a decimal point may not be as readily apparent, leading to hard-to-find bugs.

4.4.2 kForth Method

The prohibition on standard double number entry in kForth demands that an alternate method be provided for entry of double numbers. This may be easily accomplished by using a string to double number conversion word. There are two ways to accomplish this. The first method is simple, but it is specific to kForth, while the second is more complex, but portable to other ANS systems. In the simple method, we may make use of the non-standard word, `NUMBER?`, to convert a counted string to a signed double length number, as follows.

```
c" -20123456789" NUMBER? DROP
```

`NUMBER?` actually returns a flag indicating whether or not the conversion succeeded, but we drop the flag in the above example for simplicity. If the conversion did not succeed, a double length zero will result.

4.4.3 ANS Forth Compatible Method

The second method should be used if it is desired to port the code to other ANS Forth systems. ANS Forth provides `>NUMBER` for converting a string to an unsigned double number. A more general string to double number conversion word, handling both signed and unsigned double numbers, may be written as follows.

variable dsign

```
: >d ( a u -- d|ud | convert string to a signed/unsigned double )
  0 0 2SWAP
  \ skip leading spaces and tabs
  BEGIN OVER C@ DUP BL = SWAP 9 = OR WHILE 1 /STRING REPEAT
  ?DUP IF
    FALSE dsign !
    OVER C@
    CASE
      [char] - OF TRUE dsign ! 1 /STRING ENDOF
      [char] + OF 1 /STRING ENDOF
    ENDCASE
    >NUMBER 2DROP
    dsign @ IF DNEGATE THEN
  ELSE DROP THEN ;
```

Using the above definition of >D, examples of double number entry are:

```
s" 20123456789" >d
s" -20123456789" >d
s" +20123456789" >d
```

Note that the method used above is not needed if the double number being entered fits within the bounds of a *signed* single number. Most cases of double number entry fit this scenario. In such a case, we may simply enter the single number, followed by S>D, e.g.

```
-234          S>D
2147483647    S>D
-2147483649   S>D
```

4.5 Floating Point Implementation

The ANS Forth specification allows floating point numbers to be stored either on the *data stack* or on a separate *floating point stack*. kForth uses the *data stack* for holding floating point numbers. Even though many current Forth systems for PCs feature a separate floating point stack, the rationale for using the data stack for floating point operations in kForth was to allow legacy code written for earlier Forth systems (in particular the Forths from Laboratory Microsystems Inc.) to run without significant modifications under kForth. In kForth, a floating point number on the stack occupies two cells. Thus, under 32-bit Windows or Linux, floating point numbers are 64-bit double-precision numbers (equivalent to C's double).

The quality of the floating point arithmetic in kForth may be checked using the program, `paranoia.4th`, and other floating point tests provided in `forth-src/system-test`.

4.6 Special Features

Special features of kForth are described in a two-part article in [Forthwrite](#) magazine, issues **116** and **117**. These features are:

- The kForth dictionary is *dynamically allocated* as new definitions are added. Thus kForth does not implement a monolithic, fixed size dictionary, but can use as much memory as provided by the host operating system. Several side effects result from using dynamic memory allocation to grow the dictionary:
 - There is no **HERE** address in kForth.
 - There is no **,** (comma operator) in kForth.
 - There is no **C,** operator in kForth.

Owing to the fact that **HERE** does not exist, the word **ALLLOT** not only allocates the requested amount of memory, but also has the non-standard behavior that it assigns the address of the new memory region to the *parameter field address* (PFA) of the last defined word. In kForth, the use of **ALLLOT** must always be preceded by the use of **CREATE**. A variant of **ALLLOT**, named **?ALLLOT** is also provided. **?ALLLOT** has the same behavior as **ALLLOT** plus it returns the start address of the dynamically allocated region on the parameter stack. **?ALLLOT** has the following equivalent definition under ANS Forth:

```
: ?ALLLOT ( u -- a ) HERE SWAP ALLLOT ;
```

?ALLLOT is particularly useful in writing *defining words* in the absence of **HERE** and the comma operators. For example, to write your own integer constant defining word:

```
: CONST ( n -- ) CREATE 4 ?ALLLOT ! DOES> @ ;
```

or to write an address constant defining word (see below):

```
: PTR ( a -- ) CREATE 4 ?ALLLOT ! DOES> A@ ;
```

- kForth maintains *type stacks* corresponding to both the data and return stacks. The type stacks contain a type code for each corresponding data stack cell or return stack cell. This allows kForth to perform some rudimentary type checking, for example when an address is being accessed kForth verifies that the value's type is that of an address. Address values that are stored in variables must be retrieved with the word **A@** instead of **@** so that the type can be validated. Code written for kForth may be ported to other ANS Forth implementations by defining **A@** as follows:

```
: A@ @ ;
```

- Unlike a conventional Forth interpreter which executes each token as it is interpreted, kForth continues to build up a vector of byte codes, until a keyword or end of line in the input stream necessitates execution. *Deferred execution* in interpreter mode is implemented by

extending the normal concept of *precedence* in Forth. Instead of a single precedence-bit associated with each word, kForth uses a precedence-*byte* having *two* significant bits to describe the behavior of each word in both compiled and interpreted modes. Thus, a word may have one of four possible precedence values:

```
0 not IMMEDIATE DEFERRED
1 IMMEDIATE      DEFERRED
2 not IMMEDIATE NONDEFERRED
3 IMMEDIATE      NONDEFERRED
```

To understand the execution behavior of a word in each of these states, it is helpful to view a table of execution modes for each precedence value and for the two compilation states: *interpret* and *compile*. We define the following execution modes:

- E0 – no execution, the opcode for the word is compiled into the opcode vector.
- E1 – execute current opcode vector up to and including current opcode.
- E2 – execute only current opcode and remove it from the opcode vector.

Precedence	Interpret	Compile
0	E0	E0
1	E2	E2
2	E1	E0
3	E1	E2

The ability to defer execution in interpreter mode allows "one-liners" to be executed from the kForth prompt without having to define a word. For example, the following line can be typed directly at the kForth prompt:

```
10 0 do i . loop
```

Ordinary Forth interpreters do not allow *do-loop*, *begin-while-repeat*, and *if-then* structures to occur outside of word definitions. kForth can interpret and execute such structures as long as they are completed on a single line of input.

Words which are **NONDEFERRED** are those for which interpretation of the rest of the input line will depend on the execution of the word. Thus, the following intrinsic words in kForth have the nondeferred precedence attribute:

\	. (BINARY	DECIMAL	HEX
WORD	'	CREATE	FORGET	COLD

ALLOT ?ALLOT CONSTANT FCONSTANT VARIABLE
FVARIABLE CHAR >FILE CONSOLE

Only in very special cases will it be necessary for a programmer to use the **NONDEFERRED** keyword to set explicitly the interpretation precedence of a word. This is due to the automatic inheritance of the nondeferred attribute: if a word definition includes a nondeferred word, then the new word is automatically nondeferred also. Thus, for example, any word which has a definition including **WORD** is also a nondeferred word. Another example is a defining word, i.e. one which uses **CREATE**. Since **CREATE** is nondeferred the new defining word is also nondeferred.

The most common case in which the **NONDEFERRED** keyword should be explicitly used is in the definition of a word which changes the number base. For example,

```
DECIMAL  
: BASE3 3 BASE ! ; NONDEFERRED  
BASE3 21
```

If **BASE3** was not declared to be a nondeferred word, then **21** in the above line would be interpreted as decimal 21 rather than as decimal 7 (which is 21 in base 3).

- kForth can be started up in *debug mode* using the command line switch **-D**. Compiled op-codes and other debugging information are displayed in this mode. It is useful primarily for programmers interested in extending and debugging their own versions of kForth.

4.7 Benchmarks and Tests

Versions of standard benchmark programs for measuring kForth execution speed may be found in the subdirectory, **forth-src/benchmarks**. Forth source files in **forth-src/system-test** provide tests for ANS compliance of core and standard extension words in Forth-94, for words which are specific to kForth, and for floating point arithmetic. The tests require one of the following test harnesses: **ttester.4th** or **tester.4th**.

```
core.4th  
coreplus.4th  
memorytest.4th  
filetest.4th  
searchordertest.4th  
stringtest.4th  
dbltest.4th  
to-float-test.4th
```

regress.4th
asm-x86-test.4th
divtest.4th
fatan2-test.4th
ieee-fprox-test.4th
ieee-arith-test.4th
fpzero-test.4th
fpio-test.4th
paranoia.4th

4.8 VM Error Codes

Non-zero return codes from the virtual machine (VM) indicate the following conditions:

1. Value on the stack did not have type `addr`.
2. Value on the stack did not have type `ival`.
3. Value on the stack has unknown type.
4. Division by zero.
5. Return stack has been corrupted.
6. Invalid kForth op-code encountered.
7. Stack underflow.
8. Return code for `QUIT` (not seen by user).
9. Attempted to re-`ALLOT` memory for a word.
10. Failed on `CREATE` (bad word name).
11. End of string not found.
12. No matching `DO`.
13. No matching `BEGIN`.
14. `ELSE` without matching `IF`.
15. `THEN` without matching `IF`.
16. `ENDOF` without matching `OF`.
17. `ENDCASE` without matching `CASE`.
18. Cannot open file.
19. Address outside of stack space.
20. Division overflow.

Executing the word `ABORT` will reset the stack pointers. This procedure should be used to recover from VM errors 5 and 7, and whenever there is a suspicion that the stacks have been corrupted.

4.9 Source Code Map

Source code for kForth-32 consists of the following C++, C, and assembly language files:

```
kforth.cpp
ForthCompiler.cpp
ForthVM.cpp
vmc.c
vm32-common.s
vm32.s
vm32-fast.s
fbc.h
ForthWords.h
ForthCompiler.h
ForthVM.h
kfmacros.h
```

The source code is made available to users under the [GNU General Public License](#). The Linux version is provided as source code only and must be built locally on the user's machine (see [installation](#)). Under Linux, the standard GNU assembler, GNU C and C++ compilers, and the C++ Standard Template Library (STL) are required to build the executable. The Windows 95/98/NT console application was built using the free [Cygwin](#) port of the GNU development tools.

4.10 Embedding kForth

The file `kforth.cpp` serves as a skeleton C++ program to illustrate how the kForth compiler and virtual machine may be embedded in a standalone program. [XYPLOT](#) is a more complex GUI program which embeds kForth to allow user extensibility. The file `xyp1ot.cpp` shows how to set up hooks for calling C++ functions in the host program from the embedded kForth interpreter and vice-versa.