Manual for Tali Forth 2 for the 65c02

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Tali Forth 2 is a bare-metal ANS(ish) Forth for the 65c02 8-bit MPU. It aims to be, roughly in order of importance, easy to try out (just run the included binary), simple (subroutine threading model), specific (for the 65c02 only), and standardized (ANS Forth).

Dedication

For the crew at 6502.org, who made this possible in more ways than one.

Introduction

But why?

> Forth is well suited to resource-constrained situations. It doesn't need lots of memory and doesn't have much overhead. [CHM1]
>
> — Charles H. Moore, redgate Hub 2009

The Big Picture

This section provides background information on Forth, the 6502 processor, and why anybody would want to combine the two. It can be skipped if you already know all those things.

The 6502 CPU

It is a well-established fact that humanity reached the apex of processor design with the 6502 in 1976.

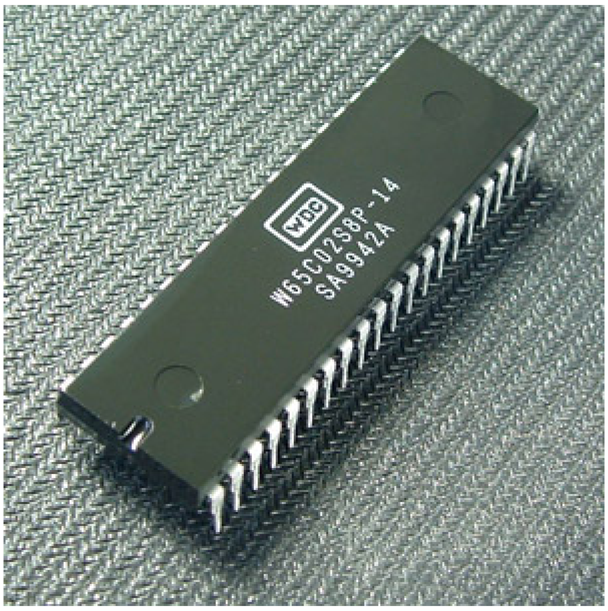


Figure 1. by Anthony King, public domain

Created by a team including Chuck Peddle and Bill Mensch, it was the engine that powered the 8-bit home computer revolution of the 1980s.[1] The VIC-20, Commodore PET, Apple II, and Atari 800 all used the 6502, among others.

More than 40 years later, the processor is still in production by the Western Design Center. Apart from commercial uses, there is an active hobbyist scene centered on the website 6502.org. A number of people have built their own 8-bit computers based on this chip and the instructions there, including a primer by Garth Wilson. It is for these systems that Tali Forth 2 was created.

The most important variant of the 6502 produced today is the 65c02, a CMOS chip with some additional instructions. It is for this chip that Tali Forth 2 was written.

But why program in 8-bit assembler at all? The 65c02 is fun to work with because of its clean instruction set architecture (ISA) This is not the place to explain the joys of assembler. The official handbook for the 65c02 is *Programming the 65816* [EnL].

> Garth Wilson answers this question in greater detail as part of his 6502 primer at http://wilsonminesco.com/6502primer/ .

Forth

> If C gives you enough rope to hang yourself, Forth is a flamethrower

> crawling with cobras. [EW]
>
> — Elliot Williams, Forth: The Hacker's language

Forth is the *enfant terrible* of programming languages. It was invented by Charles "Chuck" H. Moore in the 1960s to do work with radio astronomy, way before there were modern operating systems or programming languages.

A brief history of Forth can be found at https://www.forth.com/resources/forth-programming-language

As a language for people who actually need to get things done, it lets you run with scissors, play with fire, and cut corners until you've turned a square into a circle. Forth is not for the faint-hearted: It is trivial, for instance, to redefine `1` as `2` and `true` as `false`. Though you can do really, really clever things with few lines of code, the result can be hard for other people to understand, leading to the reputation of Forth begin a "write-only language". However, Forth excels when you positively, absolutely have to get something done with hardware that is really too weak for the job.

It should be no surprise that NASA is one of the organizations that uses Forth. The *Cassini* mission to Saturn used a Forth CPU, for instance. It is also perfect for small computers like the 8-bit 65c02. After a small boom in the 1980s, more powerful computers led to a decline of the language. The "Internet of Things" (IOT) with embedded small processors has led to a certain amount of renewed interest in the language. It helps that Forth is easy to implement: It is stack-based, uses Reverse Polish Notation (RPN) and a simple threaded interpreter model.

There is no way this document can provide an adequate introduction to Forth. There are quite a number of tutorials, however, such as *A Beginner's Guide to Forth* by J.V. Nobel[JVN] or the classic (but slightly dated) *Starting Forth* by Leo Brodie.[LB1] Gforth, one of the more powerful free Forths, comes with its own tutorial.

Once you have understood the basics of the language, do yourself a favor and read *Thinking Forth* by Brodie[LB2] which deals with the philosophy of the language. Even if you never code a line of Forth in your life, exposure to Forth will change the way you think about programming, much like Lisp.

Writing Your Own Forth

Even if the 65c02 is great and Forth is brilliant, why go to the effort of writing a new, bare-metal version of the languages? After almost 50 years, shouldn't there be a bunch of Forths around already?

FIG Forth

In fact, the classic Forth available for the whole group of 8-bit MPUs is FIG Forth. "FIG" stands for "Forth Interest Group". Ported to various architectures, it was original based on an incarnation for the 6502 written by Bill Ragsdale and Robert Selzer. There are PDFs of the 6502 version from September 1980 freely available — there is a tradition of placing Forth in the public domain — and more than one hobbyist has revised it to his machine.

However, Forth has changed a lot in the past three decades. There is now a standardized version called ANS Forth, which includes very basic changes such as how the `do` loop works. Learning the language with FIG Forth is like learning English with *The Canterbury Tales*.

A Modern Forth for the 65c02

Tali Forth was created to provide an easy to understand modern Forth written especially for the 65c02 that anybody can understand, adapt to their own use, and maybe actually work with. As part of that effort, the source code is heavily commented and this document tries to explain the internals in more detail.

[1] Rumor has it that there was another MPU called "Z80", but it ended up being a mere footnote.

User Guide

Installing Tali Forth

Downloading

Tali Forth 2 lives on GitHub at https://github.com/SamCoVT/TaliForth2. This is where you will always find the current version. You can either clone the code with git or simply download it. To just test Tali Forth using the py65mon simulator, all you need is the binary file `taliforth-py65mon.bin`.

Running

Tali currently supports two simulators, py65mon and c65. Py65mon will need to be downloaded separately (see below) and c65 comes with Tali in the c65 folder. If you have `gcc` and `make` installed, you can just type (in the main Tali folder):

```
make csim
```

This will compile the c65 simulator (if it hasn't been compiled yet) and run Tali Forth 2 in the simulator.

To exit, you can type `bye` or use CTRL-C to break out of the simulator.

Note: If running on Windows in a git bash shell, you will need to use winpty, eg. `winpty make csim`. This is only needed for the git bash shell. Running Tali in c65 from the Windows command prompt or Windows Subsystem for Linux (WSL) works fine.

Downloading the py65mon Simulator

Tali was written to run out of the box on the py65mon simulator from https://github.com/mnaberez/py65. This is a Python program that should run on various operating systems.

To install py65mon on Linux, use one of the following commands

```
# Install for only your user:
pip install -U py65 --user

# Install for all users:
sudo pip install -U py65
```

If you don't have `pip` installed, you will have to add it first with something like `sudo apt-get install python-pip` (Ubuntu Linux). Some systems use pip3 and you can run the above commands with pip3 instead of pip.

If you are on windows, you will need to download and install Python 3 first. Once Python is installed, the above commands should work from a Windows command prompt.

Running the Binary in py65mon

To start Tali in the py65mon simulator, run:

```
py65mon -m 65c02 -r taliforth-py65mon.bin
```

Note that the option `-m 65c02` is required, because Tali Forth makes extensive use of the additional commands of the CMOS version and will not run on a stock 6502 MPU.

If you downloaded the full Tali Forth 2 source code and have `make` installed, you can also just type:

```
make sim
```

to run Tali Forth 2 in the py65mon simulator (it will run the above command for you).

Installing on Your Own Hardware

The Tali Forth project started out as a way to run Forth on my own 65c02 computer, the Übersquirrel. Though it soon developed a life of its own, a central aim of the project is to provide a working, modern Forth that people can install on their projects.

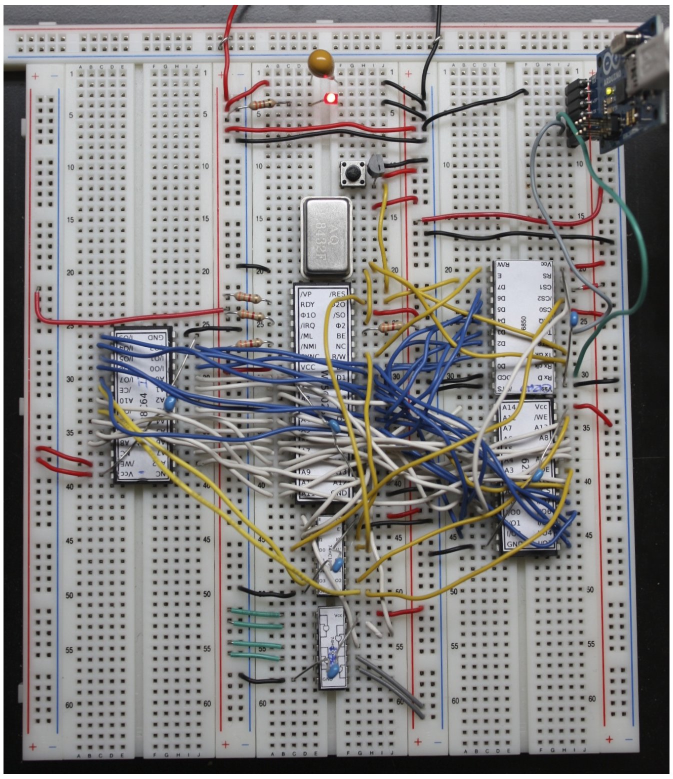


Figure 2. The functioning Übersquirrel Mark Zero prototype, August 2013. Photo by Scot W. Stevenson

The Platform Files

For this to work, you need to go to the `platform` folder and create your own kernel code to replace `platform-py65mon.asm`, the default kernel for use with the py65mon kernel. By convention, the name should start with `platform-`. See the `README.md` file in the the `platform` folder for details.

Once you have configured your platform file in the plaform folder, you can build a binary (typically programmed into an EEPROM) for your hardware with make. If you made a platform file named `platform-mycomp.asm`, then you should `cd` to the main Tali folder and run

```
make taliforth-mycomp.bin
```

The bin file will be created in the main folder. You should, of course, replace the "mycomp" portion of that command with whatever you named your platform.

Hardware Projects with Tali Forth 2

This is a list of projects known to run Tali Forth 2. Please let me know if you want to have your project added to the list.

- **Steckschwein** (https://steckschwein.de/) by Thomas Woinke and Marko Lauke. A multi-board 8 MHz 65c02 system. Platform file: `platform-steckschwein.asm` (26. Oct 2018)
- **SamCo's SBC** (https://github.com/SamCoVT/SBC) by Sam Colwell. A single-board computer running at 4MHz. Platform file: `platform-sbc.asm` (29. Oct 2018)
- **Neo6502** by Olimex LTD. A commercial offering that pairs a real 65C02 processor with an RP2040 to give HDMI output and USB keyboard support. Platform file: `platform-neo6502.asm` (28. Apr 2024)

There are various benchmarks of Tali Forth 2 running different hardware at *The Ultimate Forth Benchmark* (https://theultimatebenchmark.org/#sec-7).

Running Tali Forth

> One doesn't write programs in Forth. Forth is the program.
>
> — Charles Moore, Masterminds of Programming

Recommended Reading

If you are not familiar with Forth, now would be an excellent time to go and read Leo Brodie's excellent "Starting Forth", available for free online, before continuing through this manual. You can use Tali Forth 2 to run the examples given in the book.

You will also want to refer to Tali's Glossary for the list of words that Tali Forth 2 comes with. If you are just starting out, you will need to refer to this when deciding what words to use or to look up what a particular word does.

Booting

Out of the box, Tali Forth boots a minimal kernel to connect to the `py65mon` simulator. By default, this stage ends with a line such as

```
Tali Forth 2 default kernel for py65mon (18. Feb 2018)
```

When you port Tali Forth to your own hardware, you'll have to include your own kernel (and probably should print out a different line).

Tali Forth itself boots next, and after setting up various internal things, compiles the high level words. This causes a slight delay, depending on the number and length of these words. As the last step, Forth should spit out a boot string like

```
Tali Forth 2 for the 65c02
Version ALPHA 24. December 2018
Copyright 2014-2018 Scot W. Stevenson
Tali Forth 2 comes with absolutely NO WARRANTY
Type 'bye' to exit
```

Because these are the last high-level commands Tali Forth executes, this functions as a primitive self-test. If you have modified the high level Forth words in either `forth_words.fs` or `user_words.fs`, the boot process might fail with a variant of the error message "unknown word". The built-in, native words should always work. For this `dump` is a built-in word — it is very useful for testing.

Command-Line History

Tali's command line includes a simple, eight-element history function. To access the previous entries, press `CONTROL-p`, to go forward to the next entry, press `CONTROL-n`.

Words

The Glossary contains a list of all the words Tali comes with, where they come from, their stack usage (as a stack comment), and a brief description of what each word does.

Tali Forth comes with the following Forth words out of the box:

```
drop dup swap ! @ over >r r> r@ nip rot -rot tuck , c@ c! +! 0 1 2 execute
emit type . u. u.r .r d. d.r m*/ ud. ud.r ? false true space 2dup ?dup + - 1-
1+ 2* 2/ abs dabs and or xor rshift lshift pick char [char] char+ chars cells
cell+ here = <> < u< u> > 0= 0<> 0> 0< min max 2drop 2swap 2over 2! 2@
2variable 2constant 2literal 2r@ 2r> 2>r invert negate dnegate c, bounds
spaces bl -trailing -leading /string refill accept input>r r>input unused
depth key key? allot create does> variable constant value to s>d d>s d- d+
erase blank fill find-name ' ['] name>int int>name name>string >body defer
latestxt latestnt parse-name parse execute-parsing source source-id : ;
:noname compile, [ ] literal sliteral ." s" s\" postpone immediate
compile-only never-native always-native allow-native nc-limit strip-underflow
abort abort" do ?do i j loop +loop exit unloop leave recurse quit begin again
state evaluate base digit? number >number hex decimal count m* um* * um/mod
sm/rem fm/mod / /mod mod */mod */ \ move cmove> cmove pad cleave hexstore
within >in <# # #s #> hold sign output input havekey cr page at-xy marker
words wordsize aligned align bell dump .s disasm compare search environment?
find word ( .( if then else repeat until while case of endof endcase defer@
defer! is action-of useraddr buffer: buffstatus buffblocknum blkbuffer scr
blk block-write block-write-vector block-read block-read-vector save-buffers
block update buffer empty-buffers flush load thru list block-c65-init
block-ramdrive-init definitions wordlist search-wordlist set-current
get-current set-order get-order root-wordlist assembler-wordlist
editor-wordlist forth-wordlist only also previous >order order forth see ed:
cold bye
```

This list might be outdated. To get the current list, run `words` from inside Tali Forth.

Though the list might look unsorted, it actually reflects the priority in the dictionary, that is, which words are found first. For instance, the native words — those coded in assembler — always start with `drop` and end with `bye`. `bye` is the last word that Tali will find in the dictionary. [1] The words before `drop` are those that are defined in high-level Forth. For more information on individual words, use the `see` command inside Tali Forth and refer to the Glossary.

To find out if a given word is available, you can use the sequence `s" myword" find-name 0<>` which will return a `true` or `false` flag.

Note that the built-in words are lower case. While Tali is not case sensitive — `KASUMI` is the same word as `Kasumi` — newly defined words will be lowercased as they are created and entered into the dictionary. There is a slight speed advantage during lookup to using lowercase words (because Tali doesn't have to lowercase the entered text), so all of the tests for Tali are in lowercase.

Numbers

If a word is not found in the dictionary, Tali Forth tries to turn it into a number using the current base. Only if it can't be turned into a number will Tali report an error. Tali supports the ANS standard prefix characters for specifying binary, decimal, and hex shown below. It is recommended to enter your numbers using these prefix characters when writing code that will be run later, as it makes the code insensitive to the current base.

```
%100 \ A binary number (decimal value 4)
#100 \ A decimal number (decimal value 100)
$100 \ A hexadecimal number (decimal value 256)
```

The ANS Standard

Tali Forth is orientated on ANS Forth, the standard defined by the American National Standards Institute (ANSI). See https://forth-standard.org/standard/alpha for the complete list of ANS Forth words.

Gforth

Tali also adopted some words from Gforth such as bounds or execute-parsing. In practical terms, Tali aims to be a subset of Gforth: If a program runs on Tali, it should run on Gforth the same way or have a very good reason not to. See https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Word-Index.html for a complete list of Gforth words.

Tali-Specific Words

In addition, there are words that are specific to Tali Forth.

0 (-- 0) - Push the number 0 on the Data Stack. Having this as an actual word speeds up processing because the interpreter doesn't have to convert the character "0" into the number 0.

1 (-- 1) - Push the number 1 on the Data Stack.

2 (-- 2) - Push the number 2 on the Data Stack.

allow-native (--) - Mark last word in dictionary to that it can be natively compiled if it is less than or equal to nc-limit in size.

always-native (--) - Mark last word in dictionary so that it is always natively compiled.

bell (--) - Ring the terminal bell (ASCII 07).

block-read (addr blk# --) - This is a vectored word the user can change to point to their own routine for reading 1K blocks into memory from storage.

block-read-vector (-- addr) - This is the address of the vector for block-read. Save the xt of your word here.

block-write (addr blk# --) - This is a vectored word the user can change to point to their own routine for writing 1K blocks from memory to storage.

block-write-vector (-- addr) - This is the address of the vector for block-write. Save the xt of your word here.

block-ramdrive-init (u --) - Create a RAM drive with the given number of blocks (numbered 0 to (u-1)) to allow use of the block words with no additional hardware. Because the blocks are only held in RAM, they will be lost when the hardware is powered down or the simulator is stopped.

cleave (addr u -- addr2 u2 addr1 u1) - Given a block of character memory with words separated by whitespace, split off the first sub-block and put it in TOS and NOS. Leave the rest lower down on the stack. This allows breaking off single words (or zero-terminated strings in memory, with a different delimiter) for further processing. Use with loops:

```
        : tokenize ( addr u -- )
            begin
                cleave
                cr type  \ <-- processing of single word
            dup 0= until
            2drop ;
```

For a string such as `s" emergency induction port"`, this gives us:

```
        emergency
        induction
        port
```

The payload of such a loop can be modified to process any `( addr u )`. For example, using the `execute-parsing` word, we can define a series of variables at run time:

```
        : make-variables ( addr u -- )
            begin
                cleave
                ['] variable execute-parsing  \ <-- new function
            dup 0= until
            2drop ;
```

Running `s" tali garrus joker shepard" make-variables` will define those four words as variables, as `words` will show. More generally, we can use `cleave` to create a version of the `map` higher-order function in Forth.

```
        : map ( addr u xt -- )
            >r
            begin
                cleave
                r@ execute  \ <-- must consume ( addr u )
            dup 0= until
            2drop  r> drop ;
```

compile-only (--) - Mark last word in dictionary as compile-only.

digit? (char -- u true | char false) - If character is a digit, convert and set flag to `true`, otherwise return the offending character and a `false` flag.

ed (--) - Start the command-line editor. There is a whole chapter on this father down.

hexstore (addr u addr1 -- u2) - Store string of numbers in memory. Given a string with numbers of the current base seperated by spaces, store the numbers at the address `addr1`, returning the number of elements. Non-number elements are skipped, an zero-length string produces a zero output. Use as a poor man's assembler:

```
        hex  s" ca ca 95 00 74 01" myprog hexstore
        myprog swap execute
```

With this behavior, `hexstore` functions as a reverse `dump`. The names "store" or "numberstore" might have been more appropriate, but "hexstore" has the association of the Unix command `hexdump` and should be easier to understand.

input (--) - Return the address where the vector for the input routine is stored (not the vector itself). Used for input redirection for `emit` and others.

input>r (--) (R: -- n n n n) - Saves the current input state to the Return Stack. This is used for `evaluate`. ANS Forth does provide the word `save-input` (see https://forth-standard.org/standard/core/SAVE-INPUT), but it pushes the state to the Data Stack, not the Return Stack. The reverse operation is `r>input`.

int>name (xt -- nt) - Given the execution execution token (xt)* -, return the name token (nt)* -.

latestnt (-- nt) - Return the last used name token. The Gforth version of this word is called `latest`.

nc-limit (-- addr) - Return the address where the threshold value for native compiling native compiling is kept. To check the value of this parameter, use `nc-limit ?`. The default value is 20.

never-native (--) - Mark most recent word so it is never natively compiled.

number (addr u -- u | d) - Convert a string to a number. Gforth uses `s>number?` and returns a success flag as well.

output (-- addr) - Return the address where the vector for the output routine is stored (not the vector itself)* -. Used for output redirection for `emit` and others.

r>input (--) (R: n n n n --) - Restore input state from Return Stack. See `input>r` for details.

strip-underflow (-- addr) - Return the address where the flag is kept that decides if the underflow checks are removed during native compiling. To check the value of this flag, use `strip-underflow ?`.

useraddr (-- addr) - Return the base address of the block of memory holding the user variables.

wordsize (nt -- u) - Given the name token (`nt`) of a Forth word, return its size in bytes. Used to help tune native compiling. Note that `wordsize` expects the name token (`nt`) of a word, not the execution token (`xt`). This might be changed in future versions.

-leading (addr u -- addr1 u1) - Strip any leading whitespace. This is the other side of the ANS Forth string word `-trailing`.

Wordlists and Search Order

Tali Forth implements the optional Search-Order words, including the extended words. These words can be used to hide certain words or to rearrange the order the words are searched in, allowing configurable substitution in the case of words that have the same name but live in different wordlists.

On startup, only the FORTH-WORDLIST is in the search order, so only those words will be found. Tali also comes with an EDITOR-WORDLIST and an ASSEMBLER-WORDLIST, Room for 8 user wordlists is available, and the search order can also hold 8 wordlist identifiers. See https://forth-standard.org/standard/search for more information on wordlists and the search order.

The WORDLIST word will create a new wordlist (or print an error message if all 8 user wordlists have already been created). It puts the wordlist identifer (wid) on the stack. This is simply a number that uniquely identifes the wordlist, and it’s common practice to give it a name rather than use the number directly. An example might look like:

```
wordlist constant MY-WORDLIST
```

While this creates a new wordlist and gives it a name, the wordlist isn’t currently set up to be used. When Tali starts, only the FORTH-WORDLIST is set up in the search order and all compilation of new words goes into the FORTH-WORDLIST. After creating a new wordlist, you need to set it up for new words to be compiled to it using SET-CURRENT and you need to add it to the search order using SET-ORDER if you want the new words to be found.

```
\ Set up the new wordlist as the current (compilation) wordlist
\ New words are always put in the current wordlist.
MY-WORDLIST set-current

\ Put this wordlist in the search order so it will be searched
\ before the FORTH-WORDLIST.  To set the search order, put the
\ wids on the stack in reverse order (last one listed is seached
\ first), then the number of wids, and then SET-ORDER.
FORTH-WORDLIST MY-WORDLIST 2 set-order

: new-word s" This word is in MY-WORDLIST"

\ Go back to compiling into the FORTH-WORDLIST.
```

```
FORTH-WORDLIST set-current
```

See the Tutorial: Wordlists and the Search Order for an in-depth look at using wordlists.

Native Compiling

As the name says, subroutine threaded code encodes the words as a series of subroutine jumps. Because of the overhead caused by these jumps, this can make the code slow. Therefore, Tali Forth enables native compiling, where the machine code from the word itself is included instead of a subroutine jump. This is also called "inlining".

The parameter `nc-limit` sets the limit of how small words have to be to be natively compiled. To get the current value (usually 20), check the value of the system variable:

```
nc-limit ?
```

To set a new limit, save the maximal allowed number of bytes in the machine code like any other Forth variable:

```
40 nc-limit !
```

To completely turn off native compiling, set this value to zero.

Underflow Detection

When a word tries to access more words on the stack than it is holding, an "underflow" error occurs. Whereas Tali Forth 1 didn’t check for these errors, this version does.

However, this slows the program down. Because of this, the user can turn off underflow detection for words that are natively compiled into new words. To do this, set the system variable `strip-underflow` to `true`. Note this does not turn off underflow detection in the built-in words. Also, words with underflow detection that are not included in new words through native compiling will also retain their tests.

Restarting

Tali Forth has a non-standard word `cold` that resets the system. This doesn’t erase any data in memory, but just moves the pointers back. When in doubt, you might be better off quitting and restarting completely.

Gotchas

Some things to look out for when using Tali Forth.

Cell Size

Tali has a 16-bit cell size.

> Use `1 cells 8 * .` to get the cell size in bits with any Forth.

This can trip up calculations when compared to the *de facto* standard Gforth with 64 bits. Take this example:

```
( Gforth )      decimal 1000 100 um* hex swap u. u.  ( returns 186a0 0  ok )
( Tali Forth)   decimal 1000 100 um* hex swap u. u.  ( returns 86a0 1  ok )
```

Tali has to use the upper cell of a double-celled number to correctly report the result, while Gforth doesn't. If the conversion from double to single is only via a `drop` instruction, this will produce different results.

There is a similar effect with the Gforth word `bounds`: Because of Tali's 16 bit address space, it wraps the upper address if we go beyond $FFFF:

```
( Gforth )      hex FFFF 2 bounds  swap u. u.  ( returns 10001 ffff  ok  )
( Tali )        hex FFFF 2 bounds  swap u. u.  ( returns     1 ffff  ok )
```

Delimiters During Parsing

Both `parse-name` and `parse` skip white space - defined as ASCII characters from 00 to 32 (SPACE) inclusive - when the standard talks about "spaces". Otherwise, Tali would choke on TABs during compiling, and the `ed` editor couldn't be used to edit programs because of the Line Feed characters. This is covered in the standard, see the footnote at https://forth-standard.org/standard/core/PARSE-NAME by Anton Ertl, referencing http://forth-standard.org/standard/usage#subsubsection.3.4.1.1 and http://forth-standard.org/standard/file#subsection.11.3.5 .

Negative `allot`

The ANSI standard does not define what happens if there is an attempt to free more memory with `allot` by passing a negative value than is available. Tali will let the user free memory up the beginning of RAM assigned to the Dictionary (marked with `cp0` in the code), even though this can mean that the Dictionary itself is compromised. This is Forth, you're the boss.

However, any attempt to free more memory than that will set the beginning of RAM to `cp0`. Also, the Dictionary Pointer `dp` will point to the *last native word* of the Dictionary, which is usually `drop`. Because of this, the high level words defined during boot will *not* be available. There will be an error message to document this. Realistically, you'll probably want to restart with `cold` if any of this happens.

[1] If you're going to quit anyway, speed can't be that important

Tutorials for Major Components

Tutorial: Working with Blocks

Tali supports the optional BLOCK word set. The 2012 Forth standard defines a block as 1024 bytes, and the buffers for them are the same size (as opposed to some older forths that had smaller buffers). Tali currently comes with one buffer.

Blocks are a simple system for dealing with non-volatile storage. Originally, the storage medium would have been a floppy disk drive, but hobbyists are more likely to attach I2C or SPI flash memory to their system. These storage devices often have more than 64K (the full address space of the 65C02) of storage, so the block words help to deal with the larger address space and the fact that there is a limited amount of RAM in the system.

The block words do not use a file system and expect to access the storage memory directly. The storage space is divided into 1K chunks, or "blocks", and each is given a number. On Tali, this allows for 64K blocks, or up to 64MB of storage. The user can request that a block is brought into RAM, operate on the data, and then request that the modified version be saved back to storage.

What the blocks hold is up to the user. They can hold text, Forth code, or binary data. Support for text and Forth code is provided by Tali, and the user can easily provide support for storing binary data in their programs, as demonstrated in this chapter.

First steps with blocks

In order to facilitate playing with blocks, Tali comes with a special word `block-ramdrive-init` that takes the number of blocks you want to use and allocates a RAM drive to simulate a mass-storage device. It also sets up the read and write vectors to routines that will move the data in and out of the allocated RAM. If you'd prefer persistent block storage in an external file you can use the c65 simulator (included with Tali) and try the `block-c65-init` word illustrated below.

If you have an actual storage device, such as a flash memory, you will need to write routines for transferring 1K from storage to RAM and from RAM to storage. Both of these should have the signature (addr blk# —). The addresses (xt) of these routines need to be placed in the existing variables `BLOCK-READ-VECTOR` and `BLOCK-WRITE-VECTOR`, respectively. If you had written routines named `mybockreader` and `myblockwriter`, That might look like:

```
' myblockreader BLOCK-READ-VECTOR !
' myblockwriter BLOCK-WRITE-VECTOR !
```

If you forget to initialize these vectors, you will see an error message about BLOCK-READ-VECTOR and BLOCK-WRITE-VECTOR when you try to use any of the block words.

Any System or Simulator

To get started on this tutorial, we will use the ramdrive with 4 blocks allocated. This can be used on any system or simulator, regardless of whether or not you have real storage. Because this is done in RAM, the contents will be lost when the system is reset or the simulator is stopped. If you have real storage and have installed the vectors to your read/write routines, you can skip this step.

```
4 block-ramdrive-init
```

This command takes a moment as all of the block memory is initialized to the value BLANK (a space) on the assumption you will be placing text there. When complete, you will have 4 blocks (numbered 0-3) available to play with. It also sets up the vectors to routines for reading and writing blocks in this ramdrive for you. If you want more blocks, you can change the number. Because they start at zero, the last valid block will always be one less than the number you provide.

Be careful about creating too many blocks, as they are 1K each. Four will be plenty for this tutorial. It's also worth noting that running `block-ramdrive-init` again will create another ramdrive and the existing one will be inaccessible while still taking up space in RAM.

c65 Simulator Only (comes with Tali)

If you want to simulate using persistent storage instead, create a writable file and start the c65 simulator as shown. Then, in forth, run `block-c65-init`. The `block-c65-init` word takes no arguments and returns true if block storage is available. You can read/write up to 65536 1K blocks in your file providing 64Mb of storage.

```
touch somefile.dat
c65/c65 -b somefile.dat -r taliforth-py65mon.bin
...
block-c65-init      ( -- f )
```

Using Blocks for Forth Code

When using blocks for text or Forth code, the 1K block is further divided into 16 lines of 64 characters each. Newlines are typically not used in blocks at all, and the unused space is filled with spaces to get to the next line. Blocks that have this type of text data in them are also called a "screen".

To see the contents of a block in screen format, you can use the built-in `list` command. It takes the block number (called a screen number when storing text) and displays the contents of that block. Typing the command `0 list` will list the contents of block 0.

```
0 list
Screen #   0
 0
 1
 2
 3
 4
 5
 6
 7
 8
 9
10
11
12
13
14
15
 ok
```

As you can see, this screen is currently blank. It’s actually 16 lines each containing 64 spaces.

Block 0 is special in that it is the only block you cannot load Forth code from. Because of this, block 0 is commonly used to hold a text description of what is in the other blocks.

Editing a screen

In order to edit a block, we will need to bring in the screen editor. It lives in the EDITOR-WORDLIST, which is not in the search order when Tali starts. To add the editor words, run:

```
forth-wordlist editor-wordlist 2 set-order
( or the shorter version... )
editor-wordlist >order
```

This tells Tali to use both the editor words and the forth words.

You can only edit one screen at a time. To select a screen, simply `list` it. All further operations will edit that screen until a new screen is listed. The block number of the screen being edited is held in the `SCR` variable, and the `list` word simply saves the block number there before displaying it on the screen; many of the other editing words look in `SCR` to see which block is being edited.

The following words can be used to edit a screen:

list	`( scr# – )` List the block in screen (16 lines of 64 chars) format. This word also select the given block for futher editing if desired.
l	`( – )` List the current screen (previously listead with `list`)
el	`( line# – )` Erase a line on the previously listed screen.
o	`( line# – )` Overwrite an entire line on the previously listed screen. Enter the replacement text at the * prompt.
enter-screen	`( scr# – )` Prompt for all of the lines on the given screen number
erase-screen	`( scr# – )` Erase the given screen by filling with BLANK (spaces)

Because block 0 has already been listed above, we will simply add a message on line 2.

```
2 o
```

```
 2 * Load screen 2 to get a smiley!
```

Now if we list screen 0, we should see our message:

```
0 list
Screen #   0
 0
 1
 2 Load screen 2 to get a smiley!
 3
 4
 5
 6
 7
 8
 9
10
11
12
13
14
15
  ok
```

Now we will enter screen 2 using `enter-screen`. It will prompt line by line for the text. Pressing ENTER without typing any text will leave that line blank.

```
2 enter-screen
 0 * ( Make a smiley word and then run it!    SCC 2018-12 )
 1 * : smiley ." :)" ;
 2 *
 3 *
 4 *
 5 * smiley
 6 *
 7 *
 8 *
 9 *
10 *
11 *
12 *
13 *
14 *
15 *   ok
```

It is customary for the very first line to be a comment with a description, the programmer's initials, and the date. On line 1 we have entered the word definition, and on line 5 we are running the word.

To get Tali to run this code, we use the word `load` on the block number.

```
2 load :) ok
```

If your forth code doesn’t fit on one screen, you can spread it across contiguous screens and load all of them with the `thru` command. If you had filled screens 1-3 with forth code and wanted to load all of it, you would run:

```
1 3 thru
```

For reasons explained in the next chapter, the modified screen data is only saved back to the mass storage (in this case, our ramdrive) when the screen number is changed and accessed (typically with `list`). To force Tali to save any changes to the mass storage, you can use the `flush` command. It takes no arguments and simply saves any changes back to the mass storage.

```
flush
```

Working with Blocks

Blocks can also be used by applications to store data. The block words bring the blocks from mass storage into a 1K buffer where the data can be read or written. If changes are made to the buffer, the `update` word needs to be run to indicate that there are updates to the data and that it needs to be saved back to mass storage before another block can be brought in to the buffer.

Because the ANS spec does not specify how many buffers there are, portable Forth code needs to assume that there is only 1, and that the loading of any block might replace the buffered version of a previoly loaded block. This is a very good assumption for Tali, as it currently only has 1 block buffer.

The following words will be used to deal with blocks:

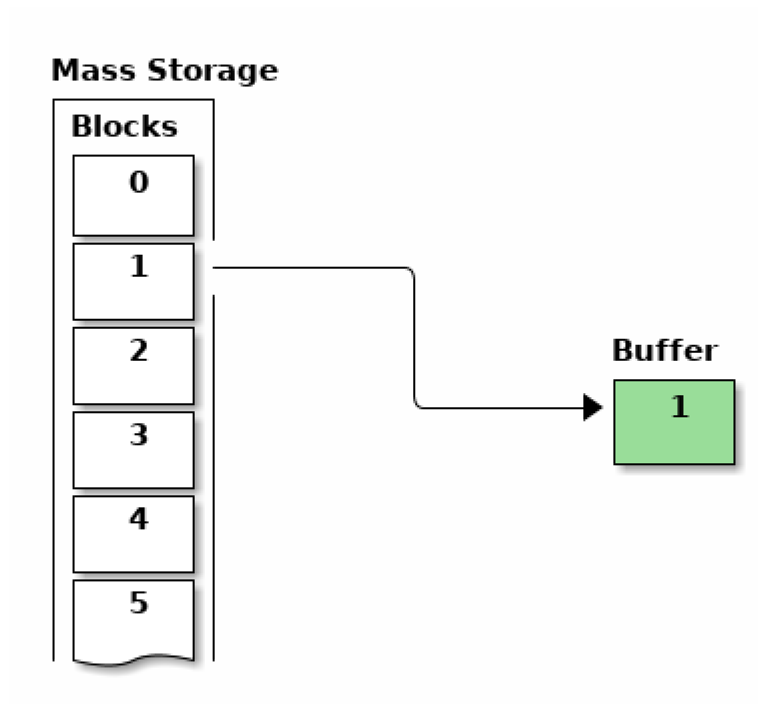
block	`( block# – addr )` Load the given block into a buffer. If the buffer has been updated, it will save the contents out to block storage before loading the new block. Returns the address of the buffer.
buffer	`( block# – addr )` Identical to block, except that it doesn’t actually load the block from storage. The contents in the buffer are undefined, but will be saved back to the given block number if updated. Returns the address of the buffer.
update	`( – )` Mark the most recent buffer as updated (dirty) so it will be saved back to storage at a later time.
flush	`( – )` Save any updated buffers to storage and mark all buffers empty.

save-buffers	`( — )` Save any updated buffers to storage.
empty-buffers	`( — )` Mark all buffers as empty, even if they have been updated and not saved. Can be used to abandon edits.
load	`( blk# — )` Interpret the contents of the given block.

The following variables are used with blocks:

BLK	The block number currently being interpreted by a `load` or `thru` command. BLK is 0 when interpreting from the keyboard or from a string.
SCR	The screen number currently being edited. Set by `list`, but you can set it yourself if you want.

A simple block example

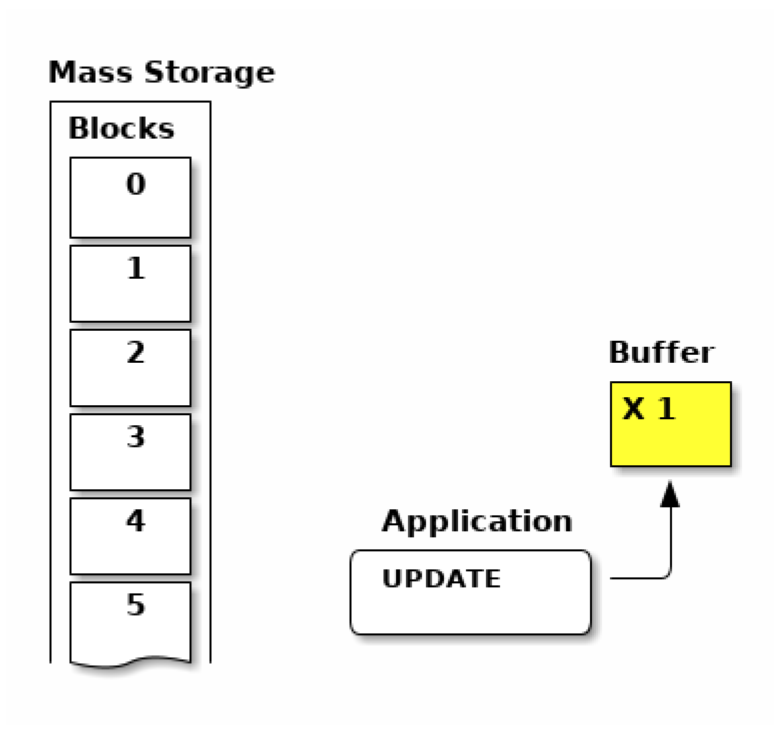


To load a block, just give the block number to the `block` word like so:

```
1 block
```

This will load the block into the buffer and return the address of the buffer on the stack. The buffer will be marked as "in-use" with block 1 and also marked as "clean". The address on the stack can be used to access the contents of the buffer. As long as the buffer has not been marked as "dirty" with the word `update`, you can call `block` again and it will simply replace the buffer with the new block data.

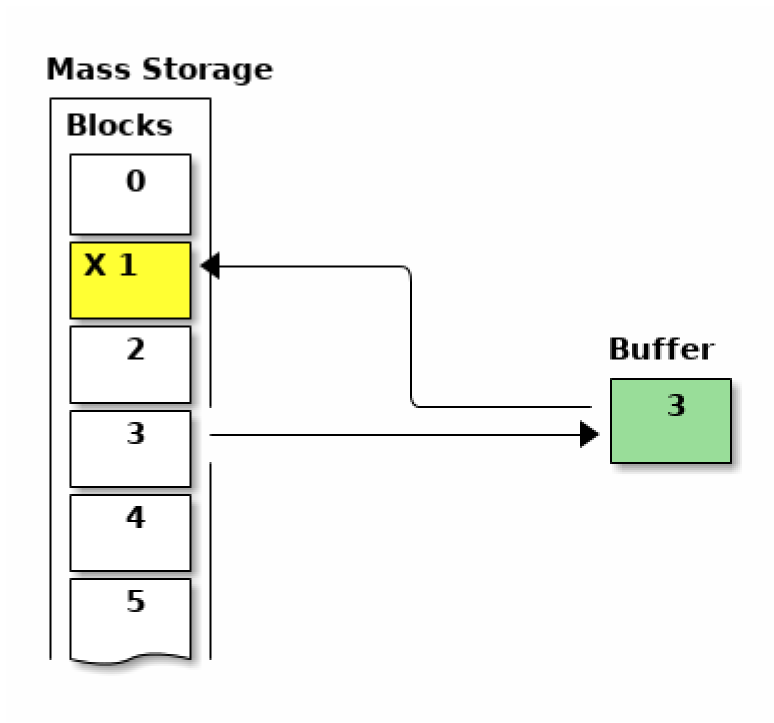
Note: On larger forths with multiple buffers, using block again may bring the requested block into a different buffer. Tali only has a single buffer, so the buffer contents will be replaced every time.



Let’s modify the data in block 1. The editor words handle the blocks behind the scenes, so we will use `move` to copy some strings into the buffer.

```
( Assuming "1 block" was recently run
)
( and buffer address is still there )
128 + ( Move to line 2)
s" Hello!"
rot swap move ( Copy Hello! into line
)
update ( Tell Tali it�s modified )
```

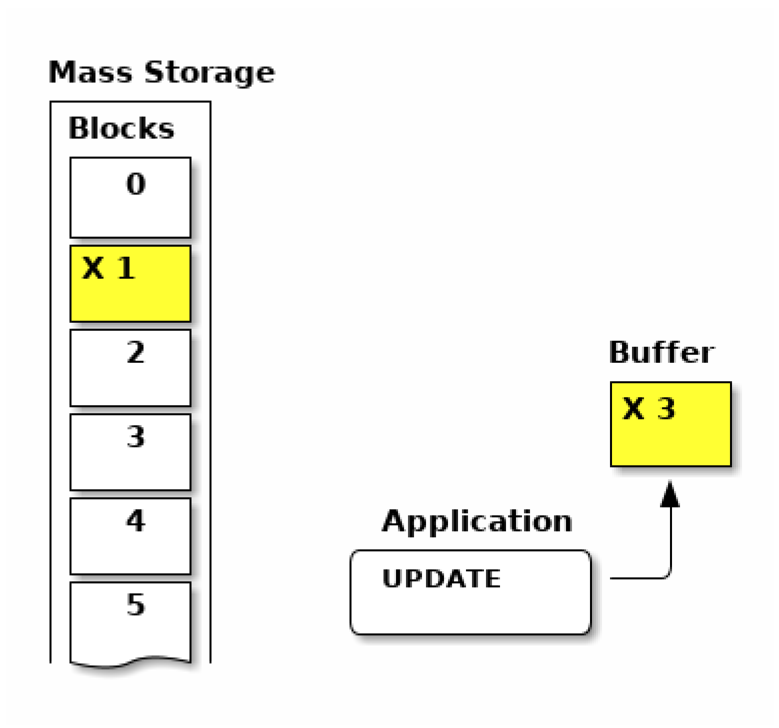
These commands put the string "Hello!" onto line 2, which can be seen by running `1 list` afterwards. The modification, however, hasn’t been transferred to storage yet. If power were lost or the processor reset at this point, the data would be lost.



We also want to make a change to block 3, so we will bring that block in next.

```
3 block
```

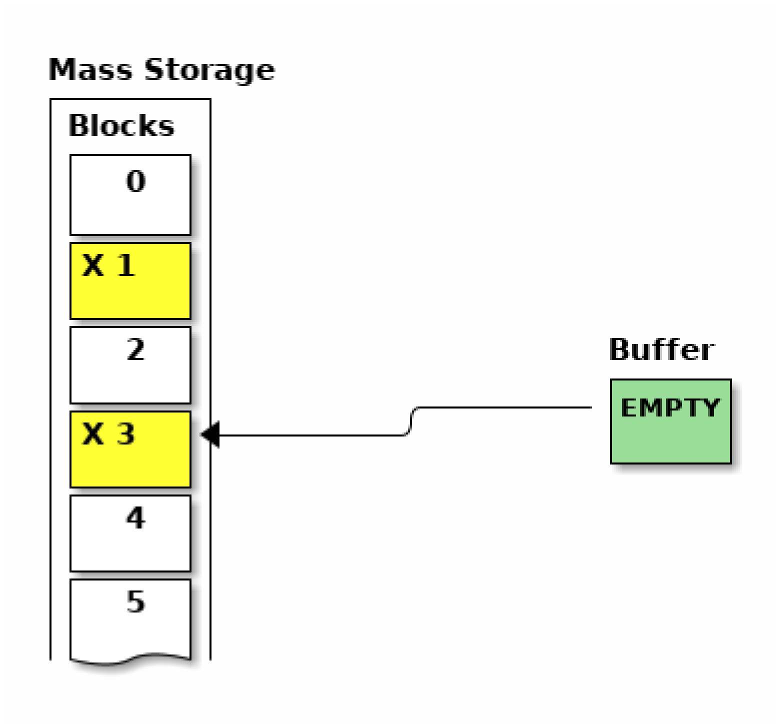
The block-handling built-in to Forth will see that the buffer is in use and is no longer a clean copy because it has been updated. This will cause Tali to write block 1 back to mass storage before bringing in block 3. Once block 3 is in the buffer, it will be marked as "in-use" with block 3 and "clean".



Let’s modify the data in block 3 now.

```
( Assuming "3 block" was recently run
)
( and buffer address is still there )
256 + ( Move to line 4)
s" Hi there!"
rot swap move ( Copy string into line
)
update ( Tell Tali it�s modified )
```

After this code is run, the buffer will be modified, marked as updated/dirty, but once again it won’t actually be saved back to mass storage right at this point.



To force the updated version of block 3 to be written back to mass storage, we can use the command:

```
flush
```

If the buffer is in use and dirty, it will be written back to mass storage. Then the buffer will be marked empty. Flush should be called before shutting down (when using blocks) and before swapping storage media.

If you want to write the changes but keep the block in the buffer, you can use the command `save-buffers` instead of flush. That would be useful in a situation where you want to save the block changes right now, but also want to keep making changes in the buffer.

If you want to abandon the changes in the buffer, you can use the command `empty-buffers`. This will not save even a dirty buffer, and marks the buffer as empty.

Storing Binary Data in Blocks

While Tali comes built-in with support for text and Forth code in blocks, users may also want to use blocks to hold binary data. A user might want to do this because the block memory space is much larger that the normal 65C02 memory space, so a much larger dataset can be stored here than the 65C02 would be able to support in RAM. It may also be desirable for the data to be saved even in the absence of power, and when block storage is implemented on a non-volatile meory, such as EEPROM or FLASH, this is possible.

Because the format of the binary data is up to the user, Forth doesn't directly support the initializing, entering, retrieval, or display of binary data. Instead, the user is expected to use the provided block words to create the functionality needed for the application.

Unless all of the blocks in the system are used with binary data, there will often be a mix of text and binary data blocks. Because using some of the words designed for text blocks, such as `list`, on a binary block could emit characters that can mess up terminals, it is recommended to "reserve" binary blocks. This is done by simply adding a note in block 0 with the block numbers being used to hold binary data, so that users of the system will know to avoid performing text operations on those blocks. Block 0 is also a good place to inform the user if the routines for accessing the binary data are also stored (as Forth code) in block storage.

In this example, we will create some words to make non-volatile arrays stored on a flash device. While this example can be run with the block ramdrive, using 7 blocks, it won't be non-volatile in that case.

To get started, we will add a note to block 0 indicating the blocks we are going to use. The following shows an example Forth session adding this note.

```
0 list
Screen #   0
 0 ( Welcome to this EEPROM! )
 1
 2 ( There are 128 blocks on this EEPROM )
 3
 4
 5
 6
 7
 8
 9
10
11
12
13
14
15
 ok
editor-wordlist >order  ok
4 o
 4 * ( Blocks 3-6 contain binary data )  ok
5 o
 5 * ( Blocks 1-2 contain the routines to access this data )  ok
l
Screen #   0
 0 ( Welcome to this EEPROM! )
 1
 2 ( There are 128 blocks on this EEPROM )
 3
 4 ( Blocks 3-6 contain binary data )
 5 ( Blocks 1-2 contain the routines to access this data )
 6
 7
 8
 9
10
11
12
13
14
15
 ok
```

In this session, screen 0 is listed to locate a couple of empty lines for the message. Then the editor-wordlist is added to the search order to get the word `o`, which is used to overwrite lines 4 and 5 on the current screen. Finally, `l` (also from the editor-wordlist) is used to list the current screen again to see the changes.

Now that the blocks have been reserved, we will put our code in blocks 1 and 2. It is recommended to put the access words for the binary data into the same block storage device so that the data can be recovered on a different system if needed.

```
1 enter-screen
 0 * ( Block Binary Data Words  1/2                 SCC 2018-12 )
 1 * ( Make a defining word to create block arrays. )
 2 * : block-array: ( base_block# "name" -- ) ( index -- addr )
 3 *   create ,     ( save the base block# )
 4 *   does> @ swap ( base_block# index )
 5 *     cells      ( Turn index into byte index )
 6 *     1024 /MOD  ( base_block# offset_into_block block# )
 7 *     rot +      ( offset_into_block real_block# )
 8 *     block      ( offset_into_block buffer_address )
 9 *     + ;
10 * ( Create the array starting at block 3           )
11 * ( With 4 blocks, max index is 2047 - not checked )
12 * 3 block-array: myarray
13 * ( Some helper words for accessing elements )
14 * : myarray@ ( index -- n ) myarray @ ;
15 * : myarray! ( n index -- ) myarray ! update ;  ok
2 enter-screen
 0 * ( Block Binary Data Words cont. 2/2           SCC 2018-12 )
 1 * ( Note: For both words below, end-index is one past the )
 2 * ( last index you want to use.                          )
 3 *
 4 * ( A helper word to initialize values in block arrays to 0 )
 5 * : array-zero ( end_index start_index -- )
 6 *     ?do 0 i myarray! loop ;
 7 *
 8 * ( A helper word to view a block array )
 9 * : array-view ( end_index start_index -- )
10 *     ( Print 10 values per line with 6 digit columns. )
11 *     ?do i 10 mod 0= if cr then i myarray @ 6 .r loop ;
12 *
13 *
14 *
15 *   ok
1 2 thru  ok
```

`enter-screen` is used to enter screens 1 and 2 with the code for initializing (`array-zero`), accessing (`myarray`, `myarray@`, and `myarray!`), and viewing (`array-view`) the binary data. Once the Forth code has been placed into blocks 1 and 2, a `thru` command is used to load the code.

The word `block-array:` is a defining word. You place the starting block number (in our case, 3) on the stack before using the `block-array:` and give a new name after it. Any time that new name (`myarray`, created on line 12 of screen 1 in this case) is used, it expects an index (into an array of cells) on the stack. It will load the correct block into a buffer and compute address in that buffer for the index given. Because cells are 2 bytes on Tali, the total number of cells is 4096/2=2048. The indices start at 0, so the index of the last valid cell is 2047. Please note that the code given above does not range check the index, so it is up to the user to not exceed this value or to add range checking.

The blocks 3-6 being used to store the array may be uninitialized or may have been initialized for text. We'll use the helper words to initialize all of the elements in the array, and then place some data into the array.

```
2048 0 array-zero  ok
50 0 array-view
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0 ok
12345 4 myarray!  ok
6789 10 myarray!  ok
4 myarray@ . 12345  ok
50 0 array-view
     0     0     0     0 12345     0     0     0     0     0
  6789     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0 ok
flush  ok
```

In the above session, all the values in the array are zeroed. Next, the first 50 values (indices 0-49) are viewed. Some numbers are stored at indices 4 and 10. The value at index 4 is fetched and printed, and the first 50 values are displayed again. Finally, all buffers are flushed to make sure any changes are permanent.

If the system is powered down and back up at a later time, the data can be accessed by first loading the helper words in blocks 1-2.

```
1 2 thru  ok
50 0 array-view
     0     0     0     0 12345     0     0     0     0     0
  6789     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0 ok
```

The methods shown in this example require the user to run `flush` or `save-buffers` before powering down the system. If the user wants the new values written to block storage immediately after being modified, the word `myarray!` could be modified to run `save-buffers` after storing the new value. As a side effect, however, an entire 1K block would be overwritten every time a single value was changed, making the routine much slower.

Tutorial: Wordlists and the Search Order

A wordlist is, quite simply, a list of words that the user can run directly or can compile into other word definitions. Wordlists are commonly used to separate words into different categories, often by function or application. One of the wordlists, called the "current" wordlist, is the list that new words will be added to when they are created. Out of the box, Tali comes with four wordlists: FORTH, EDITOR, ASSEMBLER, and ROOT.

Each wordlist has a unique wordlist identifier, or wid. To get the wid of the built-in wordlists, you can use the words `forth-wordlist`, `editor-wordlist`, `assembler-wordlist`, or `root-wordlist`. The wid is just a simple number that is used to reference its particular wordlist, and each of these words just places their unique number on the stack.

When Tali performs a cold start, the search order is set to just the FORTH wordlist and the current wordlist is also set to the FORTH wordlist. Any new words created by the the user at this stage will be added to the beginning of the FORTH wordlist.

The user is also allowed to create their own wordlist with the command `wordlist`. This word leaves the next available wid on the stack, but it is up to the user to remember this wid and to provide a name for this new wordlist. This is often done by turning the new wid into a constant, as shown in the example below.

It is often desirable to use multiple wordlists at the same time. The "search order" is used to determine which wordlists are in use at any given time, as well as determining the order they are searched in. When a word is used, each wordlist in the search order is searched for that word. In the case where a word appears in multiple wordlists, the first wordlist in the search order that contains a word of that name will be the version of the word that is used.

The data structures for the wordlists and the search order are not directly accessable to the user, but rather are manipulated with the following set of words:

order	(—) Display the current search order and current wordlist. The search order is printed with the first wordlist on the left and the last wordlist on the right. After the search order, the current (compilation) wordlist is printed.
get-order	(— widn … wid1 n) Get the current search order. This has the number of wordlists in the search order on the top of the stack, with the wids for the wordlists, in order, under that. Wid1 is the wordlist that will be searched first and widn is the wordlist that will be searched last.
set-order	(widn … wid1 n —) Set the current search order. This takes the wids and the number of wordlists in the search order on the stack.
>order	(wid —) Add the given wordlist to the beginning of the search order.
get-current	(— wid) Get the wid for the current wordlist. This is the wordlist that new words will be compiled to.

set-current	(wid —) Set the current wordlist. New words created after this point will go into the wordlist indicated here.
wordlist	(— wid) Create a new wordlist and return the wid for this new wordlist. Up to eight user-defined wordlists may be created this way.
search-wordlist	(addr u wid — 0 | xt 1 | xt -1) Search for a word in a specific wordlist. The return results are identical to those returned by `find`.

Using the built-in wordlists

To see the search order and the current wordlist, you can use the command `order`. This will print the names for the built-in wordlists and the wid number for all other wordlists. The search order is printed with the first wordlist on the left and the last wordlist on the right, and the current (compilation) wordlist is given at the far right.

```
order
Forth   Forth  ok
```

Here you can see that the FORTH wordlist is the only wordlist in the search order, and it's also set as the current wordlist (where new words will go). Typically, you will want to leave the FORTH wordlist in your search order. This contains all of the normal Forth words, as well as all of the words used to modify the search order. Most of the time you will simply want to add a wordlist to the search order and the word `>order` is very handy for doing this. To add the block editor words, you might say:

```
editor-wordlist >order
```

If you are working with assembly code in blocks, you may want both the block editor words and the assembler words available at the same time. In that event, you would say:

```
editor-wordlist >order assembler-wordlist >order
( or you could say... )
forth-wordlist editor-wordlist assembler-wordlist 3 set-order
```

Both of these lines have the same effect. They put the ASSEMBLER wordlist first, the EDITOR wordlist next, and the FORTH wordlist last.

To check the results from above, you might use the `order` command again:

```
order
Assembler Editor Forth   Forth  ok
```

Here you can see that the ASSEMBLER wordlist will be searched first, with the EDITOR wordlist searched next, and the FORTH wordlist searched last. You can also see that the FORTH wordlist is still the current (compilation) wordlist.

The wordlist that new words go into is controlled separately with `set-current`. It is possible, and sometimes even desirable, to set the compilation wordlist to one that is not in the search order. To add some words to the EDITOR wordlist, for example, one might say:

```
editor-wordlist set-current
```

Checking the results with `order` shows:

```
order
Assembler Editor Forth   Editor  ok
```

Any new words created after this point will be added to the EDITOR wordlist. To switch back to using the default FORTH wordlist for new words, you would say:

```
forth-wordlist set-current
```

Making New Wordlists

Using the `wordlist` command, a new empty wordlist can be created. This command leaves the wid on the stack, and it's the only time you will be given this wid, so it's a good idea to give it a name for later use. An example of that might look like:

```
\ Create a new wordlist for lighting up LEDs.
wordlist constant led-wordlist

\ Add the new wordlist to the search order.
led-wordlist >order

\ Set the new wordlist as the current wordlist.
led-wordlist set-current

\ Put a word in the new wordlist.
: led-on ( commands to turn LED on ) ;
```

In the example above, the new led-wordlist was added to the search order. The FORTH wordlist is still in the search order, so the user is allowed to use any existing Forth words as well as any of the new words placed into the led-wordlist, such as the `led-on` word above. If the above code is run from a cold start, which starts with just the FORTH wordlist in the search order and as the current wordlist, the results of running `order` afterwards will look like:

```
order
5 Forth   5  ok
```

Because Tali’s `order` command doesn’t know the name given to the new wordlist, it simply prints the wid number. In this case, the led-wordlist has the wid 5. You can also see that the new wordlist is the current wordlist, so all new words (such as `led-on` above) will be placed in that wordlist.

Wordlists can be used to hide a group of words when they are not needed (the EDITOR and ASSEMBLER wordlists do this). This has the benefits of keeping the list of words given by the `words` command down to a more reasonable level as well as making lookups of words faster. If the ASSEMBLER wordlist is not in the search order, for example, Tali will not spend any time searching though that list for a word being interpreted or compiled.

If a large number of helper words are needed to create an application, it might make sense to place all of the helper words in their own wordlist so that they can be hidden at a later point in time by removing that wordlist from the search order. Any words that were created using those helper words can still be run, as long as they are in a wordlist that is still in the search order.

In some applications, it might make sense to use the search order to hide all of the FORTH words. This may be useful if your program is going to use the Forth interpreter to process the input for your program. You can create your own wordlist, put all of the commands the user should be able to run into it, and then set that as the only wordlist in the search order. Please note that if you don’t provide a way to restore the FORTH wordlist back into the search order, you will need to reset the system to get back into Forth.

```
\ Create a wordlist for the application.
wordlist constant myapp-wordlist
myapp-wordlist set-current

\ Add some words for the user to run.
\ ...

\ Add a way to get back to Forth.
: exit forth-wordlist 1 set-order forth-wordlist set-current ;

\ Switch over to only the application commands.
myapp-wordlist 1 set-order
```

Older Vocabulatory Words

The ANS search-order set of words includes some older words that were originally used with "vocabularies", which the wordlists replace. Some of these words appear to have odd behavior at first glance, however they allow some older programs to run by manipulating the wordlists to provide the expected behavior. Tali supports the following words with a few caveats:

ALSO

(—) Duplicate the first wordlist at the beginning of the search order.

DEFINITIONS

(—) Set the current wordlist to be whatever wordlist is first in the search order.

FORTH

(—) Replace the first wordlist in the search order with the FORTH wordlist. This word is commonly used immediately after `only`.

ONLY

(—) Set the search order to the minimum wordlist, which is the ROOT wordlist on Tali. This word is commonly followed by the word `forth`, which replaced the ROOT wordlist with the FORTH wordlist.

PREVIOUS

(—) Remove the first wordlist from the search order.

The older vocabulary words were commonly used like so:

```
\ Use the FORTH and ASSEMBLER vocabularies.
\ Put new words in the ASSEMBLER vocabulary.
ONLY FORTH ALSO ASSEMBLER DEFINITIONS

\ Do some assembly stuff here.

\ Remove the ASSEMBLER and load the EDITOR vocabulary.
PREVIOUS ALSO EDITOR

\ Do some editing here.  If any new words are created,
\ they still go into the ASSEMBLER vocabulary.

\ Go back to just FORTH and put new words there.
PREVIOUS DEFINITIONS
```

Tali currently performs the desired "vocabulary" operations by manipulating the wordlists and search order. This works correctly for `ONLY FORTH` (which almost always appears with those two words used together and in that order), `DEFINITIONS`, and `PREVIOUS`. The `ALSO ASSEMBLER` and `ALSO EDITOR` portions will not work correctly as Tali does not have a word `ASSEMBLER` or a word `EDITOR`. If code contains these types of vocabulary words, you will need to replace them with something like `assembler-wordlist >order`. If you are trying to run older code that needs an editor or assembler, you will likely need to rewrite that code anyway in order to use Tali's editor commands and assembler syntax.

The only words from this list that are recommended for use are `ONLY FORTH` as a shortcut for `forth-wordlist 1 set-order`, `DEFINITIONS` as a shortcut after you've just used `>order` to add a wordlist to the search order and you want to set the current (compilations) wordlist to be that same wordlist, and finally `PREVIOUS`, which removes the first wordlist from the search order. Take care with `PREVIOUS` as it will happily leave you with no wordlists in the search order if you run it too many times.

The Line-Based Editor `ed`

> Ed makes no response to most commands – there is no prompting or typing of messages like "ready". (This silence is preferred by experienced users, but sometimes a hangup for beginners.) [BWK]
>
> — B. W. Kernighan, A Tutorial Introduction to the UNIX Text Editor

Tali Forth 2 currently ships with a clone of the `ed` line-based editor of Unix fame. It is envoked with `ed:`, though the formal name is `ed6502`.

`ed:` uses about 2 KB of ROM in the default setup. If you know for certain you are not going to be using it, you can reclaim that space by removing "ed" from the TALI_OPTIONAL_WORDS list in your platform file.

For those not familiar with UNIX `ed`, there is a tutorial included in this manual. This section is a brief overview of the currently available functions.

Supported Commands

`ed:` currently supports only a small number of the commands of the Unix version:

a	Add new lines below given line
d	Delete line
f	Show current target address for writes (`w`)
i	Add new lines above given line
p	Print lines
n	Print lines with line numbers
q	Quit if no unsaved work
Q	Unconditional quit, unsaved work is lost
w	Write text to given memory location (eg `7000w`)
=	Print value of given parameter (eg `$=` gives number of last line)

The following parameters are currently available:

.	Current line number
,	When alone: All lines, the same as `1,$` or `%`
;	Range from current line to end, same as `.,$`

$	Last line
%	All lines, the same as `1,$` or `,` alone

An empty line (pressing the ENTER key) will advance by one line and print it. A simple number will print that line without the line number and make that line the new current line.

Future planned commands

These are subject to available memory. There is also no time frame for these additions.

+	Advance by one line, print it and make it the new current line
-	Go back by one line, print it and make it the new current line
c	Change a line, possibly adding new lines
e	Edit lines given as `addr,u` in text buffer
j	Join two lines to a new line
m	Move block of text to new line
r	Append text from a block to end of text buffer
s	Substitute one string on line with another
!	Execute a shell command (Forth command in our case)
#	Comment, ignore rest of the line

Differences to Unix ed

Apart from missing about 90 percent of the features:

- The `w` (write) command takes its parameter before and not after the word. Where Unix ed uses the format `w <FILENAME>`, ed6502 takes the address to write the text to as `7000w`.

`ed:` currently only works with decimal numbers. It saves and restores BASE, but all numbers inside ed: will be decimal. This includes the address used with `w`.

Using `ed` for programming

`Ed:` can be used to write programs and then execute them with `evaluate`. For instance, a session to add a small string could look something like this:

```
        ed:
        a
        .( Shepard, is that ... You're alive?)
        .
        7000w ①
        22    ②
        q
```

① Address we save the command to

② Number of characters saved including final line feed

It is a common mistake to forget the `.` (dot) to end the input, and try to go immediately to saving the text. Then, we can run the program:

```
        evaluate
```

Note that `evaluate` will handle line feeds, carriage returns and other white space apart from simple spaces without problems.

Known Issues

Memory use

`Ed:` currently uses memory without releasing it when done. For small, quick edits, this probably is not a problem. However, if you known you are going to be using more memory, you probably will want to set a marker first.

```
        marker pre-edit ①
        ed:             ②
        pre-edit        ③
```

① Set marker at current value of `here`

② Edit normally

③ Call marker, releasing memory

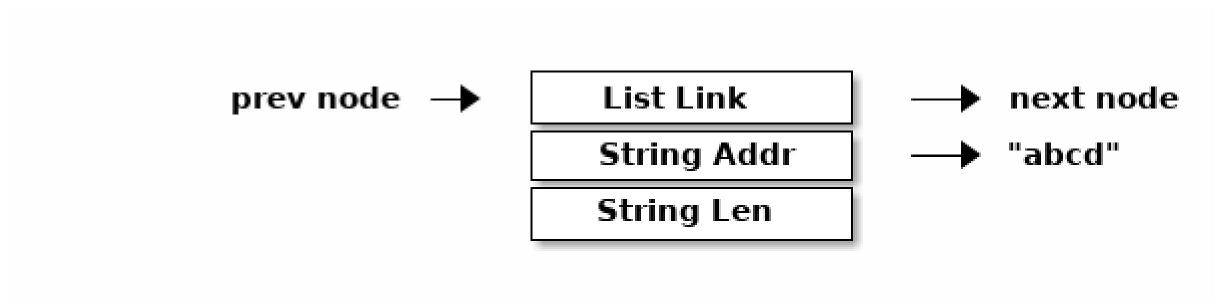
This issue might be taken care of in a future release.

Address of Saved Text

`Ed:` returns the address of the saved text on the stack as `(□—□addr  u  )`. If nothing is saved, the program would return a zero length as TOS.

Developer Information

The "buffer" of `ed:` is a simple single-linked list of nodes, consisting of a pointer to the next entry, a pointer to the string address, and the length of that string.



Each entry is two bytes, making six bytes in total for each node. A value of 0000 in the pointer to the next address signals the end of the list. The buffer starts at the point of the `cp` (accessed with the Forth word `here`) and is only saved to the given location when the `w` command is given.

Tutorial: The ed Line-Based Editor

> While TECO was known for its complex syntax, ed must have been the most user-hostile editor ever created.[PHS]
>
> — Peter H. Saulus, The Daemon, the Gnu and the Penguin

Tali Forth 2 comes with two editors, a traditional block-based editor of the type common with Forth, and the line-based editor `ed:`, formally known as `ed6502`. This second editor is included because I like line-based editors. More to the point, the saved text uses less space than the block editor, where every block, regardless of how much text is in it, uses 1024 bytes. In contrast, `ed:` uses one byte per character plus one end-of-line character per line.

The original `ed` was created by Ken Thompson and Dennis Ritchie along with the Unix operating system, sometime about 1971. It is terse, robust, and has a reputation for being completely unhelpful. Any error is just signaled with a question mark (`?`). There isn't even a prompt unless it is explicitly turned on.

Newer versions of Unix `ed` allow an option to display an explanation of the last error, but Tali doesn't have space for that. Error messages are for wimps. And who really needs a prompt anyway?

Commands in `ed:` are single-letter commands like `a` or `p`. They can be prefixed with a combination of letters and special characters to designate the line numbers the command is supposed to work on. For example, `1,4d` deletes lines one to four.

First steps with `ed:`

Like its big brother `vi` (or its newer incarnation `vim`), `ed:` has various modes, except that `ed:` is so small it only has two. We start out in the *command mode* in which we accept, well, commands. Using `a` or `i` switches to *input mode* where all of the characters are added to the buffer.

The first important thing is about how to get out of command mode: You type `.` (the period or dot) at the beginning of the line as the only character to return to command mode. A typical `ed:` session will look something like this:[1]

```
        ed:     ①
        a       ②
        After time adrift among open stars
        Along tides of light
        And through shoals of dust
        I will return to where I began.
        .       ③
                ④
```

① Start the editor from Tali Forth. It doesn't take anything on the stack.

② Switch to insert mode and type the text.

③ The dot alone on the line signals the end of the text. We return to command mode.

④ The cursor moves down to the next line, without printing any confirmation. This is where you continue typing.

When you first use `ed:`, you'll spend lots of time printing what you've written and trying to figure out what the line numbers are. The commands for this are `p` (print without line numbers) and `n` (print with line numbers). The first special character prefix we'll use for this is `%` (the percent symbol, alternatively a comma) works as well. This makes the command that follows it apply to the whole text.

```
%p      ①
After time adrift among open stars
Along tides of light
And through shoals of dust
I will return to where I began.
        ②
```

① This could also be `,p`

② Note again we return to an empty line.

The `%n` (or `,n`) command is usually more helpful because it gives you line numbers:

```
,n      ①
1       After time adrift among open stars
2       Along tides of light
3       And through shoals of dust
4       I will return to where I began.
```

① This could also be `%n`

Line numbers are indented automatically by one tab. Note we start counting with 1, not 0, because this is an editor for real humans, not computer science types.

Just entering the command directly without a line number will print the *current line*, which `ed` adjusts depending on what you are doing. After `a` it is the last line.

To find out which is the current line, type the `=` (equal sign) command.

This session could continue as such:

```
n
4       I will return to where I began.
```

The `d` (delete) command removes a line. Let's explicitly remove the second line:

```
        2d
```

Again, ed: provides absolutely no feedback on what just happened. We need to call %n (or ,n) again if we are unsure:

```
        %n
        1       After time adrift among open stars
        2       And through shoals of dust
        3       I will return to where I began.
```

Note that lines three and four have moved up — they are now lines two and three.

To avoid confusion, when you have to delete a large number of lines, start at the bottom and move upwards towards the beginning of the text.

We can also use comma-separated numbers to indicate a range of lines (say, 1,2d). As you probably will have guessed, or the , (or %) prefix can be used to delete the complete text. Be careful — in the real version of ed, you can undo changes with the u command. Tali doesn't support this option. If you delete something, it's gone.

Now, let's say we want to put back the second line. We can do this again with a, to add text *after* the first line. Note there is currently also no way to paste the line we have just deleted. If we can't remember it, we're in trouble.

```
        1a      ①
        I, uh, did something
        .       ②
                ③
```

① Add text *after* the first line.

② The dot takes us out again.

③ Still no feedback.

Displaying our whole text with %n again, we get:

```
        %n
        1       After time adrift among open stars
        2       I, uh, did something
        3       And through shoals of dust
        4       I will return to where I began.
```

Lines three and four are numbered again as they were.

Instead of using 1a, we could have used 2i to insert the new line *before* line number two. Most long-term users of ed (like, all three of them) develop a preference for a or i. This is easy because ed accepts `0a` as a way to add new lines *before* the first line. In most other circumstances, line `0` is illegal. There is also the `$` prefix for the last line.

The combination `$=` will print the number of the last line. Just `=` will print the current line.

Saving Your Text

The only way to currently save text with `ed:` on Tali is to write the buffer to a location in memory.

```
7000w    ①
128      ②
```

① The address in memory (always in decimal) comes immediately before the `w` command with no space.

② `ed` returns the number of characters written, including the end-of-line characters. Yes, this is actually feedback of sorts. But don't get cocky!

`ed:` currently only works with decimal numbers.

The `w` command was originally created for files. Tali doesn't have files, just addresses. This means that you can write anything anywhere, at the risk of completely destroying your system. Really, really don't write anything to 0000, which will overwrite the zero page of the 65c02.

Getting Out of `ed:`

We can leave `ed:` at any time with `Q` - note this is the capital letter "q". Any unsaved (unwritten, rather) text will be lost. The lowercase `q` will refuse to quit if there is still unwritten text. When it doubt, use `q`.

To access your text from the Forth command line, you can use standard Forth words like `type`. Since `ed:` leaves `( addr u )` on the stack when it quits, you can just use it directly.

```
cr type                    ①
After time adrift among open stars
I, uh, did something
And through the shoals of dust
I will return to where I began.
 ok                        ②
```

① Place the `cr` word before the `type` word to prevent the first line of the text being placed right after the Forth command.

② We're back to the helpful Forth interpreter.

You can also use `dump` to show how compact `ed:` stores the text:

```
dump
1B58  41 66 74 65 72 20 74 69  6D 65 20 61 64 72 69 66  After ti me adrif
1B68  74 20 61 6D 6F 6E 67 20  6F 70 65 6E 20 73 74 61  t among  open sta
1B78  72 73 0A 41 6E 64 20 74  68 65 6E 20 49 2C 20 75  rs.And t hen I, u ①
1B88  68 2C 20 64 69 64 20 73  6F 6D 65 74 68 69 6E 67  h, did s omething
1B98  0A 41 6E 64 20 74 68 72  6F 75 67 68 20 74 68 65  .And thr ough the
1BA8  20 73 68 6F 61 6C 73 20  6F 66 20 64 75 73 74 0A   shoals  of dust.
1BB8  49 20 77 69 6C 6C 20 72  65 74 75 72 6E 20 74 6F  I will r eturn to
1BC8  20 77 68 65 72 65 20 49  20 62 65 67 61 6E 2E 0A   where I  began..
1BD8   ok
```

① The dot in the text part of the hexdump at address $1B80 is not the period at the end of the line, but the way `dump` displays the non-printable $0A character. This control character marks the end of the line.

Note this text uses 128 bytes, in the block editor it would use one block of 1024 bytes.

Programming with `ed:`

You can use `ed:` to write and save programs. Fire it up as usual:

```
    ed:
    a
    : myloop ( -- )         ①
        101 1 do i . loop   ②
    ;
    myloop
    .
    7000w
    48
    q
```

① Type normally as you would with any other editor.

② Any indentation has to be provided by hand. There is no auto-indent.

Running `evaluate` will now print the numbers from 1 to 100.

Further Information

This tutorial will be expanded as new commands become available. In the meantime, there are other sources:

- https://en.wikipedia.org/wiki/Ed_(text_editor) Background and history
- https://www.gnu.org/software/ed/ed.html The official GNU ed page
- https://www.gnu.org/software/ed/manual/ed_manual.html The official GNU ed manual
- https://sanctum.geek.nz/arabesque/actually-using-ed/ Small tutorial of Unix ed

- http://www.psue.uni-hannover.de/wise2017_2018/material/ed.pdf A tutorial by B. W. Kernighan (yes, *that* Kernighan).

[1] All quotes in the `ed:` tutorial are taken from the *Mass Effect* games by BioWare/EA. As stated already, they hold the rights to all characters and whatnot.

The Assembler

Tali Forth is shipped with a built-in assembler that uses the Simpler Assembler Format (SAN). See the Appendix for an introduction to SAN.

The code was originally part of a stand-alone 65c02 assembler in Forth named tasm65c02. See https://github.com/scotws/tasm65c02 for details. Tasm65c02 is in the public domain.

Adding assembler code at the command line

Because Tali Forth is a Subroutine Threaded (STC) Forth, inserting assembler instructions is easy. In fact, the only real problem is accessing the assembler wordlist, which is normally not in the search tree because of its length. This, then, is one way to add assembler code:

```
        assembler-wordlist >order
        here             \ Remember where we are
        1 lda.#          \ LDA #1 in Simpler Assembler Notation (SAN)
        push-a           \ Pseudo-instruction, pushes A on the Forth data stack
        rts              \ End subroutine. Don't use BRK!
        execute          \ Run our code using value from HERE
        .s               \ Will show 1 as TOS
        previous
```

The first line is required to give the user access to the list of assembler mnemonics. They are not in the default wordlist path because of their sheer number:

```
        adc.# adc.x adc.y adc.z adc.zi adc.ziy adc.zx adc.zxi and. and.# and.x
        and.y and.z and.zi and.ziy and.zx and.zxi asl asl.a asl.x asl.z asl.zx
        bcc bcs beq bit bit.# bit.x bit.z bit.zx bmi bne bpl bra brk bvc bvs clc
        cld cli clv cmp cmp.# cmp.x cmp.y cmp.z cmp.zi cmp.ziy cmp.zx cmp.zxi
        cpx cpx.# cpx.z cpy cpy.# cpy.z dec dec.a dec.x dec.z dec.zx dex dey eor
        eor.# eor.x eor.y eor.z eor.zi eor.ziy eor.zx eor.zxi inc inc.a inc.x
        inc.z inc.zx inx iny jmp jmp.i jmp.xi jsr lda lda.# lda.x lda.y lda.z
        lda.zi lda.ziy lda.zx lda.zxi ldx ldx.# ldx.y ldx.z ldx.zy ldy ldy.#
        ldy.x ldy.z ldy.zx lsr lsr.a lsr.x lsr.z lsr.zx nop ora ora.# ora.x
        ora.y ora.z ora.zi ora.ziy ora.zx ora.zxi pha php phx phy pla plp plx
        ply rol rol.a rol.x rol.z rol.zx ror ror.a ror.x ror.z ror.zx rti rts
        sbc sbc.# sbc.x sbc.y sbc.z sbc.zi sbc.ziy sbc.zx sbc.zxi sec sed sei
        sta sta.x sta.y sta.z sta.zi sta.ziy sta.zx sta.zxi stx stx.z stx.zy sty
        sty.z sty.zx stz stz.x stz.z stz.zx tax tay trb trb.z tsb tsb.z tsx txa
        txs tya
```

The last line in our code, `previous`, removes the assembler wordlist again.

In the example above, it is important to use `rts` and not `brk` as the last instruction to return to the command line.

Seriously. Never use `brk` inside Tali Forth assembler code!

Note you can freely mix Forth high-level words and assembler instructions. For example, this will work:

```
hex
10 lda.#        \ LDA #$10
decimal
10 ldx.#        \ LDA #10
```

Running the disassembler gives us (actual addresses may vary):

```
12BF    10 lda.#
12C1     A ldx.#
```

This also allows the use various different formatting tricks like putting more than one assembler instruction in a line or including in-line comments:

```
dec.a dec.a     \ DEC twice
nop ( just chilling ) nop ( still don't want to work )
nop ( not going to happen ) nop ( just go away already! )
```

Adding assembler code to new words

The assembler words are immediate, that is, they are executed even during compilation. Simply adding them to a word doesn't work. For example, if we want a word that pushes 1 on the Forth data stack and prints it, we might be tempted to do this (assuming `assembler-wordlist >order` first):

```
: print-a-one  compiled
1 lda.#                 \ fails with "Stack underflow"
```

The problem is that the number `1` is compiled, and then the immediate word `lda.#` is executed, but it can't find its operand on the stack. To avoid this problem, we can use the `[` and `]` words:

```
: print-a-one  compiled
[ 1 lda.# ]  compiled
[ push-a ]  compiled
u. ;  ok
```

We do not need to add an explicit `rts` instruction when compiling new words with assembler because the `;` does it automatically. This is because Tali Forth uses

Subroutine Threaded Code (STC).

Running print-a-one prints the number 1. We can use a slightly simpler variant:

```
: print-a-one  compiled
[ 1 lda.#  ok
push-a ]  compiled
u. ;  ok
```

This time, we've only used one left square bracket to start the assembler code and one right bracket to end it. Because of this, we get ok instead of compiled because we are technically not in compile-mode anymore. 1 lda.# can write the machine code right away.

Looking at our new word with see gives us (addresses may vary):

```
nt: A2A  xt: A3C
flags (CO AN IM NN HC ST): 0 0 0 1 1 0
size (decimal): 19

0A3C  A9 01 CA CA 95 00 74 01  20 3D D6 20 89 D6 A9 20  ......t.  =. ...
0A4C  20 30 8E   0.

A3C      1 lda.#   ①
A3E        dex     ②
A3F        dex
A40      0 sta.zx
A42      1 stz.zx
A44   D63D jsr     ③
A47   D689 jsr
A4A     20 lda.#
A4C   8E30 jsr
```

① The 1 lda.# as a single line;

② Four lines of code for push-a;

③ Four lines from u.

Some Forths add the words code and end-code to mark the beginning and end of an assembler blocks. In our case, these would just be simple synonyms for [and], so we don't bother.

Accessing Forth words from assembler

To execute Forth words when then assembler code is run, we need to store a subroutine jump to the word's execution token (xt). This we can get with ' ("tick"). For instance, to print the byte in the accumulator:

```
here
10 lda.#
```

```
        push-a          ①
        ' u. jsr        ②
        rts
        execute
```

① Push the value from A to TOS

② Code a subroutine jump to `u.`

This will print `10`.

Labels, jumps, and branches

The support for labels is currently very limited. An anonymous label can be marked with `-->` (the "arrow") as a target for a backwards jump with `<j` (the "back jump". A primitive example (that produces an endless loop):

```
        : .nums
        [ 0 lda.#
        -->                     ; anonymous label
        inc.a push-a pha ]      ; PHA required because u. will overwrite A
        u.
        [ pla <j jmp ]          ; endless loop
        ;
```

Executing the word `.nums` will print numbers starting with 1 till 255 and then wrap.

The directive `<j` is actually a dummy, or to put a bit more politely, syntactic sugar: The `jmp` instruction itself takes the value from the stack. `-->` itself is nothing more than an immediate version of `here` and in fact shares the same assembler code.

Disassembling `.nums` shows how this code works (addresses may vary):

```
        99D      0 lda.#
        99F        inc.a   ①
        9A0        dex
        9A1        dex
        9A2      0 sta.zx
        9A4      1 stz.zx
        9A6        pha
        9A7   D676 jsr
        9AA   D6C2 jsr
        9AD     20 lda.#
        9AF   8E18 jsr
        9B2        pla
        9B3    99F jmp     ②
```

① Address specified by label `->` is `$099F`

② Address was picked up by `jmp` instruction

Branches work similar. Instead of `<j` as a "back jump", we use `<b` as a "back branch". For example, this word takes a number of "a" to print (in slightly different notation):

```
        : .na ( n -- )
        [
              0 lda.zx  ①
                tay
        -->
             97 lda.#
                push-a
                phy
        ]
        emit
        [
                ply
                dey
             <b bne
                inx  ②
                inx
        ]
        ;
```

① `LDA 0,X` in traditional notation

② Assembler version of `drop`

Looking at the assembler code with `see`, we can see that the branch instruction takes $F2 as an operand.

Currently, there is no mechanism that checks to see if the operand is in the correct range for a branch. It is assumed that the assembler will be used only for small code snippets where this will not be a problem.

Pseudo-instructions and macros

push-a takes the byte in the Accumulator A and pushes it to the top of the Forth Data Stack. This is a convenience macro for

```
        dex
        dex
        sta.zx 0        ; STA 0,X
        stz.zx 1        ; STZ 1,X
```

Under the hood

The assembler instructions are in fact just normal, very simple Forth words that send the opcode and the length of the instruction in bytes to common routines for processing.

The assembler instructions will trigger an underflow error if there is no operand on the stack when required.

```
        lda.#   \ requires operand first on the stack -> triggers error
```

Gotchas and known issues

Working with assembler requires an intimate knowledge of Tali Forth’s internals. Some of the things that range from just very dangerous to downright suicidal are:

Using the X register. Tali Forth uses X to hold the Data Stack pointer. Manipulating it risks crashing the whole system beyond any hope of recovery. If for some reason you feel you must use X, be careful to save and restore the original value, such as:

```
        phx
        ( do something with X )
        plx
```

There are currently no forward branches. The words `b>` and `j>` will be used once they are added. Forward branches are more complex because they require backtracking to fill in the address that is not known when the jump or branch instruction is coded.

The assembler instruction `and` receives a dot for absolute addressing to avoid conflict with the Forth word of the same name: `1000 and.` is the correct form.

`brk` is a two-byte instruction because the assembler enforces the signature byte. You shouldn’t use `brk` anyway.

Other ways to insert assembler code

Sometimes the assembler can be overkill, or we are given a dump of hex values from a different assembler to store. Probably the very simplest way is to add the opcodes and operands directly with the `c,` instruction to store the machine code byte by byte. Our very first example of pushing the number 1 to the Data Stack in assembler becomes:

```
        hex  here a9 c, 01 c, ca c, ca c, 95 c, 00 c, 74 c, 01 c, 60 c,
```

This leaves the address of this routine on the stack through the `here`. We run this fragment with `execute` and find the number 1 on the stack.

This, however, is error-prone to type. Tali Forth provides a special word called `hexstore ( addr u addr1 – u )` for those occasions. It stores the string provided by `( addr u )` at the location `addr1` and returns the number of bytes stored.

```
hex
s" a9 01 ca ca 95 00 74 01 60" 6000 hexstore
drop     ①
6000 execute
```

① Get rid of return value bytes stored

This word can be tricky to use with `here` because the string storage command `s"` uses memory. The current address must be chosen *before* the string is stored:

```
hex
here dup  s" a9 01 ca ca 95 00 74 01 60" rot hexstore
drop execute
```

Instead of `drop execute` in the last line, a `dump` will show that the correct bytes were stored (address may vary):

```
0990  A9 01 CA CA 95 00 74 01  60  ......t. `
```

Disassembly gives us the fragment we were expecting:

```
9AD      1 lda.#
9AF        dex
9B0        dex
9B1      0 sta.zx
9B3      1 stz.zx
9B5        rts
```

Note here again the `rts` as last instruction.

We can also use the line-editor `ed` to add hex values for `hexstore`, which makes it easier to correct typing errors. Adding our code:

```
ed
a
a9 01 ca ca 95 00 74 01 60
.
5000w  ①
27     ②
q
```

① Save string at address 5000

② Shows us length of number string saved

Unless we ran `hex` before adding the word, the string is now stored at the decimal addresss 5000.

However, we’ve added the words as hexadecimal code. To call `hexstore`, we must switch at the right time:

```
        5000 27 6000 hex hexstore  ok
        drop
        decimal
        6000 execute
```

You can get around this by either using all-hex numbers or enter the number string in decimal.

The Disassembler

Tali Forth is currently shipped with a very primitive disassembler, which is started with `disasm ( addr u — )`.

Format

The output format is in Simpler Assembler Notation (SAN). Briefly, the instruction's mode is added to the mnemonic, leaving the operand a pure number. For use in a postfix environment like Tali Forth, the operand is listed *before* the mnemonic. This way, traditional assembly code such as

```
LDA #1
DEC
STA $1000
STA $80
NOP
LDA ($80)
```

becomes (assuming `hex` for hexadecimal numbers):

```
        1 lda.#
          dec.a
     1000 sta
       80 sta.z
          nop
       80 lda.zi
```

See the Appendix for a more detailed discussion of the format.

Output

The disassembler prints the address of the instruction, followed by any operand and the mnemonic. To get the code of `drop`, for instance, we can use `' drop 6 disasm`:

```
36142  55337 jsr     STACK DEPTH CHECK
36145        inx
36146        inx
36147        rts
```

The Forth word `see` calls the disassembler while using a hexadecimal number base. So `see drop` produces:

```
nt: BC3E  xt: 8D2E
flags (CO AN IM NN HC ST): 0 0 0 0 0 0
```

```
size (decimal): 5

8D2E  20 29 D8 E8 E8   )...

8D2E   D829 jsr     STACK DEPTH CHECK
8D31        inx
8D32        inx
```

Note that `see` does not print the final `rts` instruction.

Determining address labels

When disassembling, using either `disasm` or `see`, the dictionary is searched anytime a `jsr` is encountered and the name of the word will be printed if a word with that address is found. Some interal routines in Tali are not in the Forth dictionary and so no name will be printed. Here is an example when running `see order`

```
nt: C9FF  xt: 9845
flags (CO AN IM NN HC ST): 0 0 0 0 0 0
size (decimal): 42

9845  20 63 89 20 34 91 B5 00  F0 1E A8 E8 E8 B5 00 5A   c. 4... .......Z
9855  20 70 98 7A 88 D0 F4 20  1E A1 20 1E A1 20 29 91   p.z...  .. .. ).
9865  B5 00 20 70 98 20 63 89  E8 E8  .. p. c. ..

9845   8963 jsr     cr
9848   9134 jsr     get-order
984B      0 lda.zx
984D     1E beq
984F        tay
9850        inx
9851        inx
9852      0 lda.zx
9854        phy
9855   9870 jsr
9858        ply
9859        dey
985A     F4 bne
985C   A11E jsr     space
985F   A11E jsr     space
9862   9129 jsr     get-current
9865      0 lda.zx
9867   9870 jsr
986A   8963 jsr     cr
986D        inx
986E        inx
```

This word is a mixture of assembly and other forth words. Note that the second to last jsr shows a destination address of 9870 (in hex). To trace this further, consult the labelmap for your platform in the /docs folder. In this case, searching for 9870 in the labelmap finds the following label and the assembly files can be searched to locate this routine if you need to see its source.

```
order_print_wid_string= $9870
```

Literals and Strings

Tali compiles literals into words by saving a jsr to a helper routine followed immediately by the data for the literal. During disassembly, the literal value will be printed and the disassembler will resume disassembling from just after the literal value. Doubles are saved in memory as two single cell literal values.

Strings are similar, however they are saved in memory as a jmp over the string data, then the string data, then a jsr to the string handling routine, and finally the address and length of the string (similar to how literals are handled). When the disassembler encounters a string, it will print SLITERAL followed by the address and length of the string.

```
: example s" This is a string" ;  ok
see example
nt: 800  xt: 80F
flags (CO AN IM NN HC ST): 0 0 0 1 1 0
size (decimal): 26

080F  4C 22 08 54 68 69 73 20  69 73 20 61 20 73 74 72  L".This  is a str
081F  69 6E 67 20 A9 A0 12 08  10 00  ing .... ..

80F    822 jmp
822   A0A9 jsr     SLITERAL 812 10
 ok
```

To see the value of the string, you can either look at the memory dump above the disassembly or you can `type` the string yourself (note that `see` will always give the values in hex while `disasm` will use the current `base`):

```
hex 812 10 type
```

Gotchas and known issues

Tali Forth enforces the **signature byte** of the `brk` assembler instruction. That is, it is treated like a two-byte instruction. Since you probably shouldn't be using `brk` anyway, this behavior is usually only interesting when examing the code, where a block of zeros will produce something like the following with the disassembler:

```
124B      0 brk
```

```
124D      0 brk
124F      0 brk
1251      0 brk
```

Because of the stack structure of Forth, the disassembler will not catch assembler instructions that were **assigned an operand by mistake**. Take this (broken) code:

```
nop
10 dex  ①
nop
rts
```

① Error: DEX does not take an operand!

The disassembler will output this code (addresses might vary):

```
4661        nop
4662        dex  ①
4663        nop
4664        rts
```

① Incorrect operand for DEX was silently ignored

The 10 we had passed as an operand are still on the stack, as `.s` will show. A `dump` of the code will show that the number was ignored, leading to code that will actually run correctly (again, addresses will vary):

```
1235  EA CA EA 60
```

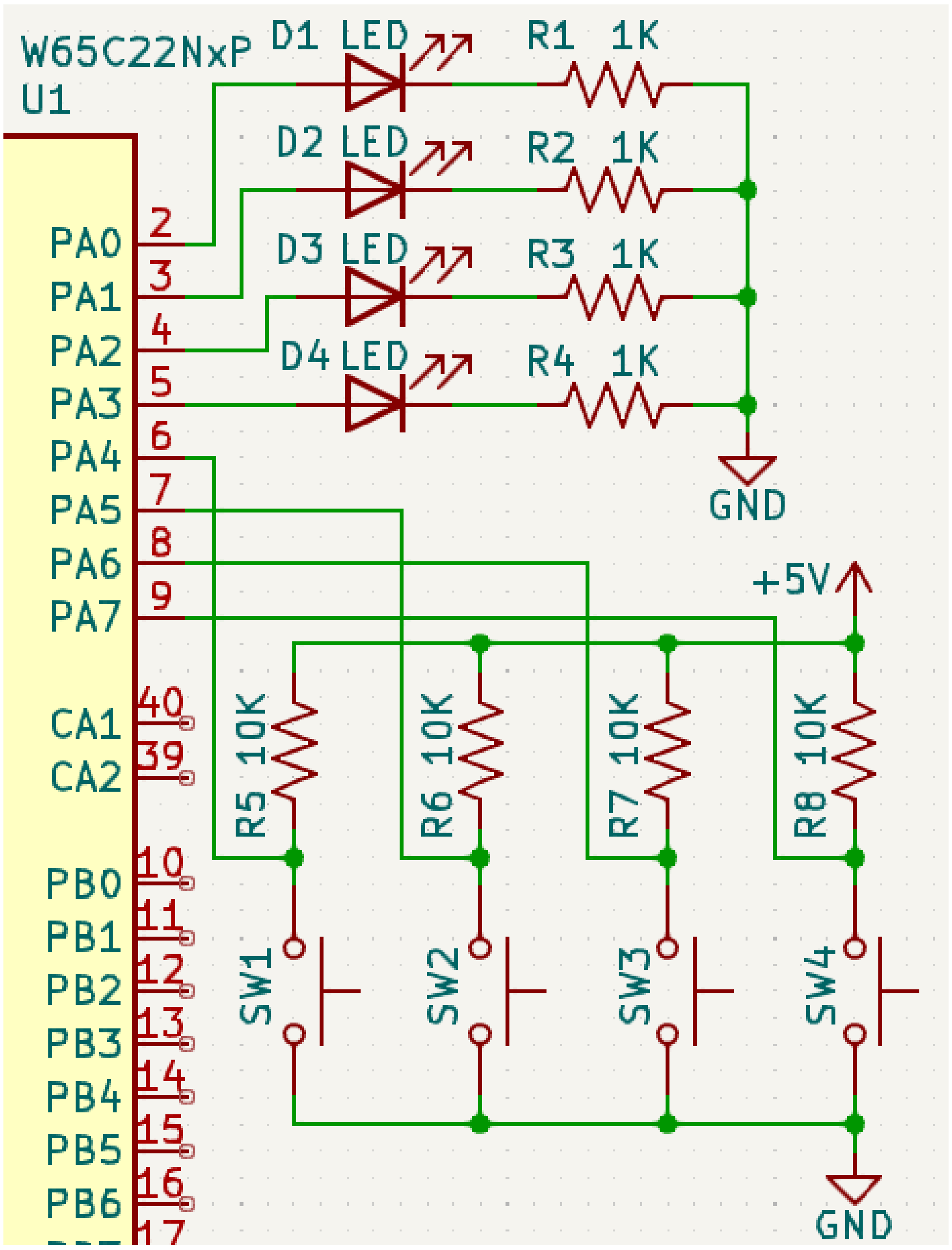
These mistakes can surface further downstream when the incorrect value on the Data Stack causes problems.

Tutorial: Interfacing with Hardware

Tali Forth is an excellent platform for playing directly with hardware. Tali lets you poke and prod hardware interactively. Once you figure out how to use the hardware directly, you can write new words to access the hardware. These words can be tested interactively and then be used to write an application that uses the hardware.

This tutorial shows how to interface some LEDs and pushbutton switches on a Ben Eater style 65C02 computer with a serial port (recommended for Tali) and the switches and LEDs wires to PORTA of a 65C22 Versatile Interface Adapter (VIA). For this example, the VIA will be memory mapped starting at address $6000 and the LEDs and pushbutton switches will be wired as shown here. If your hardware is different, you can adjust the Forth source code accordingly.

The Hardware



The LEDs are connected to Port A bits 0-3 and the pushbutton switches are connected to Port A bits

4-7. The LEDs are wired such that a "1" in a bit will light up that LED, while a "0" will turn off that LED. The switches are wired in an "active low" configuration, such that pressing a switch will result in a "0" on that bit, and releasing the switch will result in a "1" on that bit. Although that may seem backwards, this is a standard method for wiring up pushbuttons. Our software will need to account for the fact that the switches are active low.

The Software

The first step is to initialize Port A of the VIA so that bits 0-3 are outputs (to the LEDs) and bits 4-7 are inputs (from the switches). The datasheet for the W65C22 will be our reference material (available directly from WDC at https://www.westerndesigncenter.com/wdc/documentation/w65c22.pdf).

Referencing Table 2-1 and reading section 2.1 in the W65C22 VIA datasheet shows that we will need to access the Data Direction Register A (register 3) to set the direction of the pins as well as Input Register A and Output Register A (both at register 1 - we’ll just name this PA for "Port A" and use that for both input and output). To get started, we will make names for these two registers in the VIA.

```
\ Name the starting address for the VIA.
\ The registers are memory mapped, so register 3 will be
\ 3 higher than the base address.  Change this address if
\ your VIA is in a different location.
$6000 constant via_base_address

\ Name the two registers we will use.
\ Calculate their addresses based on the base address.
via_base_address 1 +  constant PA    \ Port A data
via_base_address 3 +  constant DDRA  \ Port A data direction
```

Now we can make bits 0-3 outputs by writing a value to DDRA (Data Direction Register A) that has 1s where we want output pins. We’ll use binary values in this code (starts with % for binary and bit #0 is on the right side) to make it easy to see the individual bits, but the values can be given in any base that Forth supports. We’ll also turn on every other LED so it will be easy to see if our code is working. Because these registers are 8-bits wide, we will use C! (Character Store), which stores a single byte at the given address (both given on the stack).

```
\ Make bits 0-3 on Port A outputs.
%00001111 DDRA C!
\ Turn on every other LED.
%00001010 PA C!
```

That’s it! We are now able to directly control the LEDs from Forth just by writing a new value to the PA memory location in Forth. Let’s make some helper words to make working with the LEDs a bit easier.

```
: LED_Init ( -- )  \ Initialize the LED pins as outputs.
   %00001111 DDRA C! ;
: LED! ( c -- )  \ Send byte to LEDs (only bits 0-3 used).
   PA C! ;
```

When the hardware is first powered up, we will need to run LED_Init once (it won't hurt if it is run again, but it should be run at least once). After that, we can just use LED! to send a new pattern to the LEDs.

```
: mydelay ( -- ) \ A simple delay - adjust first number to adjust speed.
   10000 0 do loop ;
: LED_Dance ( -- ) \ Make the LEDs dance
   LED_Init
   10 0 do         \ Loop 10 times
      %1100 LED! mydelay
      %0110 LED! mydelay
      %0011 LED! mydelay
      %1001 LED! mydelay
   loop ;

\ Try it out.
LED_Dance
```

Now that we have control of the LEDs, lets move on to the switches. These are wired in an "active low" configuration, so they give a "0" when pressed and a "1" when not pressed. We'll start with SW1, which is wired to PA4 so it will be in bit 4 when we read from Port A. We will use the C@ (Character Fetch) word to read an 8-bit value from PA. Let's use C@ directly first, and then we will make some helper words for determining if each switch is pressed or not.

```
\ Read the value on Port A and print it out.
PA C@ .
```

`PA` puts the address of Port A on the stack. `C@` reads the value at that address and leaves that on the stack. Finally, `.` prints the value on the stack. This will print out the byte value from Port A, however it will contain both the values of the switches as well as the bits for the LEDs. By pressing different switches while running this code, you can see that the value changes. (Hint: You can press CTRL-P to bring up the previous line of Forth code if you want to run it again - Tali remembers the last 8 lines.)

We will want to "mask" the bits that we are not interested in - in this case by forcing them all to be zeroes. We will use the AND instruction to do that, and it needs a bitmask (a special value to indicate which bits we want) that has a 1 in the bit location we are interested in and zeroes in all other bits. For SW1, on bit 4, that might look like this:

```
PA C@ %00010000 AND .
```

This code is only interested in the switch on bit 4 (SW1). When that switch is pressed, bit 4 will be read as a zero (because the switches are active low). This code zeroes out all of the other bits, so the result of this code will be zero when the switch is pressed. Do note that you don't get "1" as the result when the switch is not pressed, but rather 16 (assuming Tali is in decimal mode). That's because bit 4 has the decimal value of 16. The value for any bit can be determined by raising 2 to the bit number.

To check a different switch, just change the bitmask.

```
\ Check SW2 on bit 5.
PA C@  %00100000 AND  .
```

This code will print the current status of switch SW2 on bit 5. It also prints 0 when the switch is pressed, but this prints 64 when the switch is released because bit 5's value is twice that of bit 4.

What we want are some helper words for each button to tell if they are pressed or not. We can then use whether they are pressed or not as a true/false value to control loops and IF statements. Words that test for something and return a true or false value usually end with a question mark in the name.

```
: SW1?  ( -- f ) \ Return TRUE if SW1 is pressed.
   PA C@  %00010000 AND  0= ;
```

Note that we are not printing the result here, but we are checking to see if it is zero or not and leaving the true or false result from `0=` on the stack for other code to use. Our stack comment indicates that this word leaves a flag on the stack after it is run. Other words could be created for the other buttons by changing the bitmask.

Finally, let's put this all together and have the LEDs dance until the SW1 switch is pressed. Note that you may need to hold the button down for a bit, as it's only checked at one point during the LED dance.

```
: LED_Dance2 ( -- ) \ Dance the LEDs until SW1 pressed.
   LED_Init
   BEGIN
      %1100 LED! mydelay
      %0110 LED! mydelay
      %0011 LED! mydelay
      %1001 LED! mydelay
   SW1? UNTIL ;

\ Try it out.
LED_Dance2
```

LCD Example

With the above under our belt, we're ready to tackle something a bit more advanced. We'll replace the LEDs and buttons with a character LCD screen.

This section shows how to interface with an LCD on a Ben Eater style 65C02 computer with a serial port (recommended for Tali) and LCD wired to PORTA and PORTB of a 65C22 as shown here: https://eater.net/schematics/6502.png

TODO: Redraw schematic to show LCD wiring

The important details are that the 65C22 Versatile Interface Adapter (called the VIA from here on) is memory mapped starting at address $6000, the LCD DB0-7 (Data Bus) pins are connected to VIA pins PB0-7 (Port B), LCD RS (register select) is connected to VIA PA5, LCD R/W* (read/write*) is connected to VIA PA6, and LCD E (enable) is connected to VIA PA7. The remaining Port A pins can be used for other purposes, and we will be careful not to disturb those pins as we adjust RS, R/W*, and E.

The reference materials to consult will be the W65C22 datasheet for the VIA and the Hitachi HD44780U datasheet (your character LCD likely either has this chipset or a clone of it - search for "ADE-207-272(Z)" to locate the exact version used here).

Because the LCD is connected to the VIA, we will need to initialize the VIA first, and then the LCD. We need bits all 8 bits of Port B on the VIA, as well as bits 5-7 on Port A to be outputs. Reading in the W65C22 VIA datasheet shows that we will need to access Data Direction Register A (register 3) and Data Direction Register B (register 2) to set the direction of the pins. Then can use Output Register A (register 1) and Output Register B (register 0) to send the data and commands to the LCD. To get started, we will make names for these registers in the VIA.

```
\ Name the starting address for the VIA.
\ The registers are memory mapped, so register 2 will be
\ 2 higher than the base address.  Change this address if
\ your VIA is in a different location.
$6000 constant via_base_address

\ Name the two registers we will use.
\ Calculate their addresses based on the base address.
via_base_address     constant PB    \ Port B data
via_base_address 1 + constant PA    \ Port A data
via_base_address 2 + constant DDRB  \ Port B data direction
via_base_address 3 + constant DDRA  \ Port A data direction
```

Now we can initialize the LCD. This will be more involved than just making the correct pins on the VIA outputs. We'll do that first, but then we will need to talk to the HD44780U IC on the LCD screen. The HD44780U datasheet, in the "Interfacing the HD44790U" section, shows how to talk to this IC. You place the data you want to send to the LCD (either an instruction or a character to display) on the data lines (which will be Port B), use RS to select if this is a command (RS=0) or a character to display (RS=1), use R/W* to select if you a reading (1) or writing (0), and finally you strobe the E line by bringing it high and then back low. It’s this action that actually transfers the data or command into the LCD.

Because we’re going to need to twiddle the control lines, it makes sense to create words for doing that. These words need to adjust just a single bit, such as RS, without changing any of the other bits. Accidentally bringing E high, for example, might strobe in a command when we weren’t ready for that yet. To accomplish this, we will read in the current value on Port A, use a bitmask to turn on or off an individual bit, and then write the new value back to Port A, thus updating just a single bit. This is commonly called the "read-modify-write" technique.

```
: LCD_RS_HIGH ( -- )  \ Make the LCD RS line high.
   PA C@        \ Get the current value of Port A.
   %00100000 OR \ Make the RS bit high.
   PA C!        \ Write it back to Port A.
;

: LCD_RS_LOW ( -- ) \ Make the LCD RS line low.
   PA C@         \ Get the current value of Port A.
   %11011111 AND \ Make the RS bit low.
   PA C!         \ Write it back to Port A.
;
```

Here you can see we use the OR instruction combined with a bitmask that has a "1" in the desired location to turn on a particular bit, and we use the AND instruction combined with a bitmask that has a "0" in the desired location to turn off a particular bit. We’ll do the same for the R/W* line (note that Forth allows symbols like / and * in the name of a word).

```
: LCD_R/W*_HIGH ( -- )  \ Make the LCD R/W* line high.
   PA C@        \ Get the current value of Port A.
   %01000000 OR \ Make the R/W* bit high.
   PA C!        \ Write it back to Port A.
;

: LCD_R/W*_LOW ( -- ) \ Make the LCD R/W* line low.
   PA C@         \ Get the current value of Port A.
   %10111111 AND \ Make the R/W* bit low.
   PA C!         \ Write it back to Port A.
;
```

We are only going to strobe E, so we won’t bother with separate words for high and low for this line, and will just create a word for strobing data to the LCD.

```
: LCD_Strobe ( -- )  \ Bring E high and then low
   PA C@           \ Get Port A value.
   DUP             \ Make a copy.
   %10000000 OR    \ Make E high.
   PA C!           \ Send it out.
   %01111111 AND  \ Make it low.
   PA C!          \ Send it out.
;
```

We don't need to do any bitmasking for the data, as we're using the entire 8-bit Port B for the data and we will read or write it all at once. We will make some helper words to send commands and to send data, and then we can fully initialize the LCD. We are also going to take a shortcut here and not bother to check the "busy" flag of the LCD, as this would require changing the direction of the data lines. The penalty for this shortcut is that we will need to delay after each command or character to give the LCD time to process it, and we will have to use the maximum delay (4.1ms) even though most command are processed in microseconds.

```
: LCD_Delay ( -- ) \ A simple software delay.
  400 0 do loop ; \ About 5ms at 1MHz operation, scale value for higher clocks.

: LCD_Command ( u - ) \ Send the given command to the LCD.
   PB C!        \ Put the command on the data lines.
   LCD_RS_LOW   \ RS low to select command mode
   LCD_R/W*_LOW \ R/W* low to select writing to LCD
   LCD_Strobe   \ Hand it over to the LCD.
   LCD_Delay
;

: LCD_PutChar ( u - ) \ Send the given character to the LCD.
   PB C!        \ Put the character on the data lines.
   LCD_RS_HIGH  \ RS high to select character mode
   LCD_R/W*_LOW \ R/W* low to select writing to LCD
   LCD_Strobe   \ Hand it over to the LCD.
   LCD_Delay
;

: LCD_Init ( -- )
   \ Make the correct pins outputs on the VIA.
   %11111111 DDRB C!  \ Data lines all outputs
   \ Make only bits 5-7 outputs on Port A without affecting
   \ the other bits (they may be used for something else).
   DDRA C@  %1110000 OR  DDRA C!
   \ Start sending commands to initialize the LCD.
   %00111000 LCD_Command \ This needs to be sent three times
   %00111000 LCD_Command \ for reliable software reset of
   %00111000 LCD_Command \ the LCD.
   %00001110 LCD_Command \ Turn on display and cursor.
   %00000110 LCD_Command \ Move cursor after each char.
   %00000001 LCD_Command \ Clear the screen.
;
```

The three main words that will be used in applications are LCD_Init to initialize the LCD into 4-bit mode, LCD_Command to send commands to the LCD (see pages 24-25 of the HD44780U datasheet for available commands), and LCD_PutChar to send text for the LCD to display. Lets test these by printing a * on the screen.

```
LCD_Init
42 LCD_PutChar \ 42 is the ASCII value for *
```

If all is well, the LCD screen should have just a * on it, with a cursor in the next location. If anything isn’t working, we can run the guts of a word interactively and check the hardware pins to see where it goes wrong. Once this is working, we can print "Hi" next.

```
char H LCD_PutChar
char i LCD_PutChar
```

This is fine for very short messages, but it would be nice to be able to print longer messages. Next we will make a word that prints an entire string to the LCD screen.

```
: LCD_type ( addr u -- ) \ Print a string to the LCD
 0 ?do \ Loop through all the characters
   dup i + c@  LCD_PutChar \ Print the current letter
 loop
 ;
```

Now we can print strings so the LCD. Do note that S" needs a space before the first letter of the string.

```
s" Hi there" LCD_type
```

We’re making a bit of a mess on our LCD, so lets clear the screen. That’s command 1 (%00000001) in the datasheet.

```
1 LCD_command
```

That seems handy enough we should make it into a word.

```
\ Clear the LCD screen.
: LCD_clear ( -- )   1 LCD_command ;
```

Developer Guide

Overview of Tali Forth

Design Considerations

When creating a new Forth, there are a bunch of design decisions to be made.

Probably the best introduction to these questions is found in "Design Decisions in the Forth Kernel" at http://www.bradrodriguez.com/papers/moving1.htm by Brad Rodriguez.

Spoiler alert: Tali Forth is a subroutine-threaded (STC) variant with a 16-bit cell size and a dictionary that keeps headers and code separate. If you don't care and just want to use the program, skip ahead.

Characteristics of the 65c02

Since this is a bare-metal Forth, the most important consideration is the target processor. The 65c02 only has one full register, the accumulator A, as well as two secondary registers X and Y. All are 8-bit wide. There are 256 bytes that are more easily addressable on the Zero Page. A single hardware stack is used for subroutine jumps. The address bus is 16 bits wide for a maximum of 64 KiB of RAM and ROM.

For the default setup, we assume 32 KiB of each, but allow this to be changed so people can adapt Tali to their own hardware.

Cell Size

The 16-bit address bus suggests the cell size should be 16 bits as well. This is still easy enough to realize on a 8-bit MPU.

Threading Technique

A "thread" in Forth is simply a list of addresses of words to be executed. There are four basic threading techniques: [GK]

Indirect threading (ITC)
: The oldest, original variant, used by FIG Forth. All other versions are modifications of this model.

Direct threading (DTC)
: Includes more assembler code to speed things up, but slightly larger than ITC.

Token threading (TTC)
: The reverse of DTC in that it is slower, but uses less space than the other Forths. Words are created as a table of tokens.

Subroutine threading (STC)

Converts the words to a simple series of `jsr` combinations. Easy to understand and less complex than the other variants, but uses more space and is slower.

Our lack of registers and the goal of creating a simple and easy to understand Forth makes subroutine threading the most attractive solution, so Tali 2 is an STC Forth. We try to mitigate the pain caused by the 12 cycle cost of each and every `jsr`-`rts` combination by including a relatively high number of native words.

Register Use

The lack of registers — and any registers larger than 8 bit at that — becomes apparent when you realize that Forth classically uses at least four virtual registers:

Table 1. The classic Forth registers

Register	Name
W	Working Register
IP	Interpreter Pointer
DSP	Data Stack Pointer
RSP	Return Stack Pointer

On a modern processor like a RISC-V RV32I with 32 registers of 32 bit each, none of this would be a problem (in fact, we'd probably run out of ways to use the registers). On the 65c02, at least we get the RSP for free with the built-in stack pointer. This still leaves three registers. We cut that number down by one through subroutine threading, which gets rid of the IP. For the DSP, we use the 65c02's Zero Page indirect addressing mode with the X register. This leaves W, which we put on the Zero Page as well.

Data Stack Design

We'll go into greater detail on how the Data Stack works in a later chapter when we look at the internals. Briefly, the stack is realized on the Zero Page for speed. For stability, we provide underflow checks in the relevant words, but give the user the option of stripping it out for native compilation. There are no checks for overflow because those cases tend to be rare.

Dictionary Structure

Each Forth word consists of the actual code and the header that holds the meta-data. The headers are arranged as a simple single-linked list.

In contrast to Tali Forth 1, which kept the header and body of the words together, Tali Forth 2 keeps them separate. This lets us play various tricks with the code to make it more effective.

Deeper down the rabbit hole

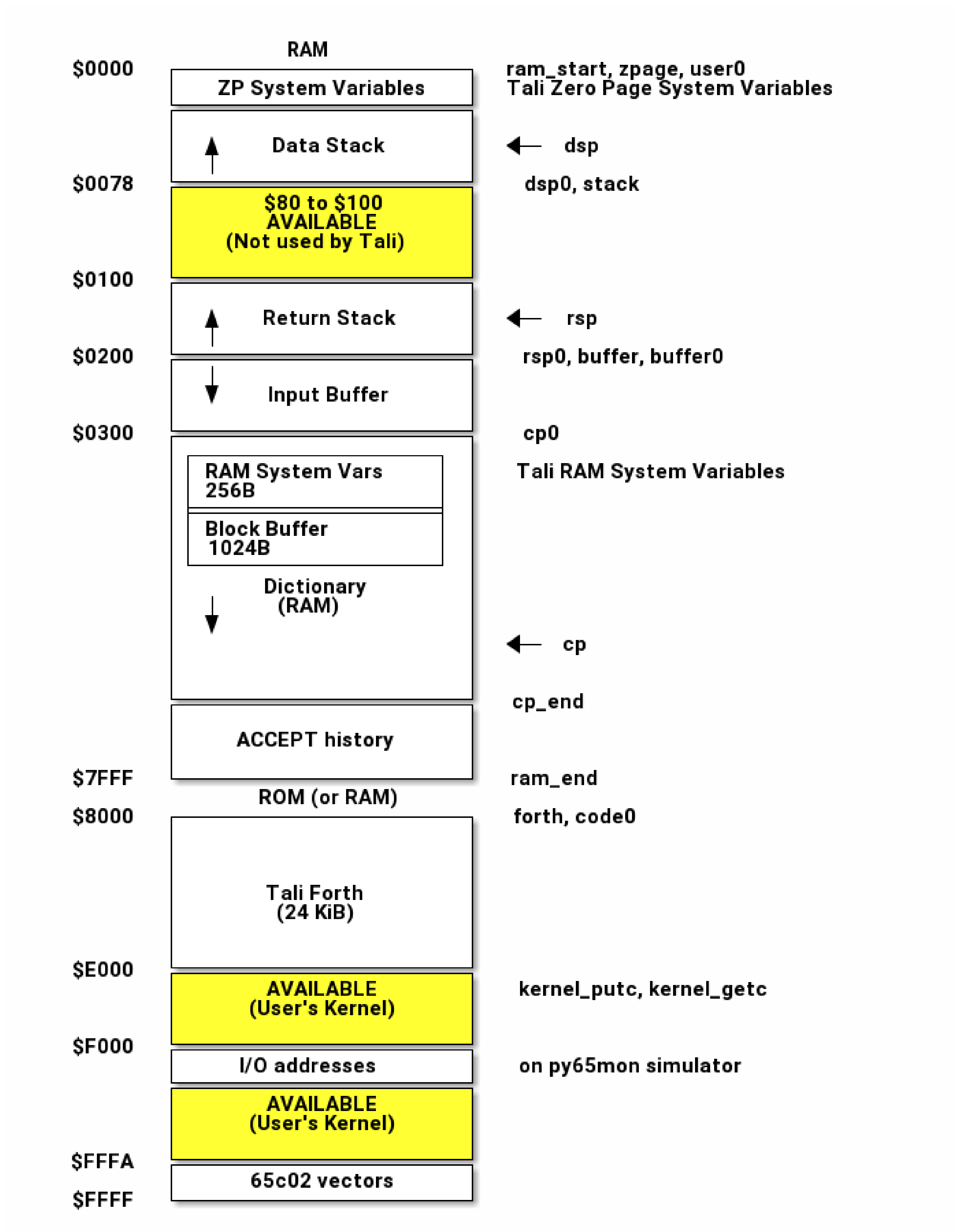
This concludes our overview of the basic Tali Forth 2 structure. For those interested, a later chapter will provide far more detail.

How Tali Forth Works

> Our intent was to create a pleasant computing environment for ourselves, and our hope was that others liked it. [DMR]
>
> — Dennis M. Ritchie, Reflections on Software Research

Memory Map

Tali Forth can be configured to work with various memory layouts and amounts of RAM and ROM. Out of the box, the version that runs with the py65 emulator looks like this:



Note that some of these values are hard-coded into the test suite; see the file `definitions.asm` for details.

The Data Stack

Tali Forth uses half of Zero Page for the system variables and Data Stack (DS). In the default py65mon platform, this is the address range $00-$7F (it can be adjusted by changing `zpage` and `zpage_end` in the platform file). This leaves the other half of the Zero Page for any kernel stuff the user might require. The DS grows from the end of Tali's space down towards the initial system variables. See the file `definitions.asm` for details. Because of the danger of underflow, it is recommended that the user kernel's variables are kept closer to $0100 than to $007F.

The X register is used as the Data Stack Pointer (DSP). It points to the least significant byte of the current top element of the stack ("Top of the Stack", TOS).

In the first versions of Tali Forth 1, the DSP pointed to the next *free* element of the stack. The new system makes detecting underflow easier and follows the convention in Liara Forth.

Initially, the DSP points to $78, not $7F as might be expected. This provides a few bytes as a "floodplain" for underflow. The initial value of the DSP is defined as `dsp0` in the code.

Single Cell Values

Since the cell size is 16 bits, each stack entry consists of two bytes. They are stored little endian (least significant byte first). Therefore, the DSP points to the LSB of the current TOS. [1]

Because the DSP points to the current top of the stack, the byte it points to after boot — `dsp0` — will never be accessed: The DSP is decremented first with two `dex` instructions, and then the new value is placed on the stack. This means that the initial byte is garbage and can be considered part of the floodplain.

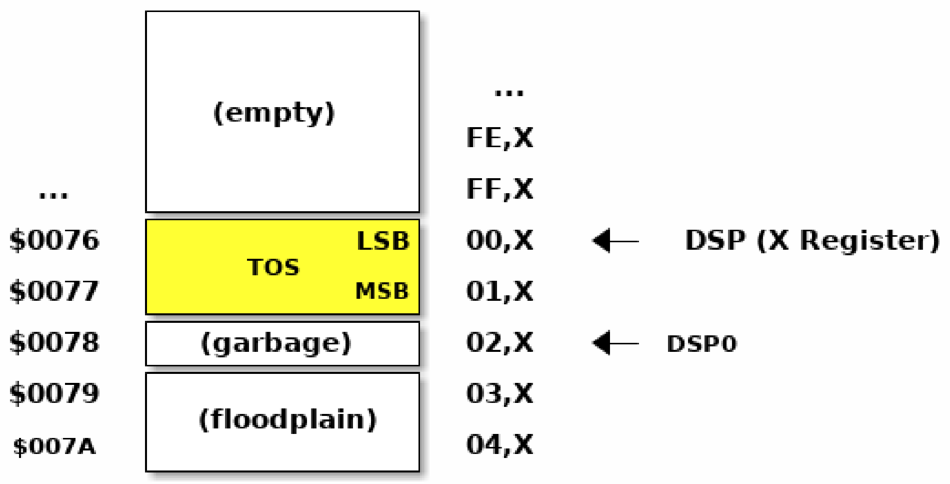


Figure 3. Snapshot of the Data Stack with one entry as TOS. The DSP has been increased by one and the value written.

Note that the 65c02 system stack — used as the Return Stack (RS) by Tali — pushes the MSB on first and then the LSB (preserving little endian), so the basic structure is the same for both stacks.

Because of this stack design, the second entry ("next on stack", NOS) starts at `02,X` and the third entry ("third on stack", 3OS) at `04,X`.

Underflow Detection

Most native words come with built-in underflow detection. This is realized with a subroutine jump to specialized routines for the number of cells (not: bytes) that are expected on the Data Stack. For example, a word such as `drop` starts with the test:

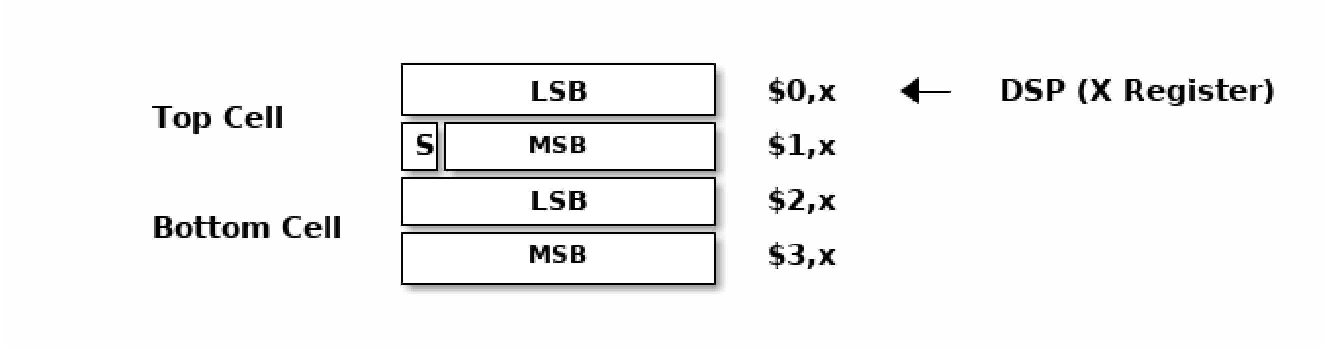
```
                jsr underflow_1
```

Underflow detection adds three bytes and 16 cycles to the words that have it. However, it increases the stability of the program. There is an option for stripping it out when compiling user-defined words (see below).

Tali Forth does not check for overflow, which in normal operation is too rare to justify the computing expense.

Double Cell Values

The double cell is stored on top of the single cell.



If we run in the `c65` debugger we can see the double value `$12345678.` is stored in NUXI order:

```
hex  ok
12345678.  ok
.s <2> 5678 1234  ok
<ctrl-c>
PC f02e  nv-bdIzc  A 03 X 72 Y 00 SP f9 > m x+2.78
       0  1  2  3  4  5  6  7   8  9  a  b  c  d  e  f   0123456789abcdef
0070              34 12 78 56                           |    4.xV        |
```

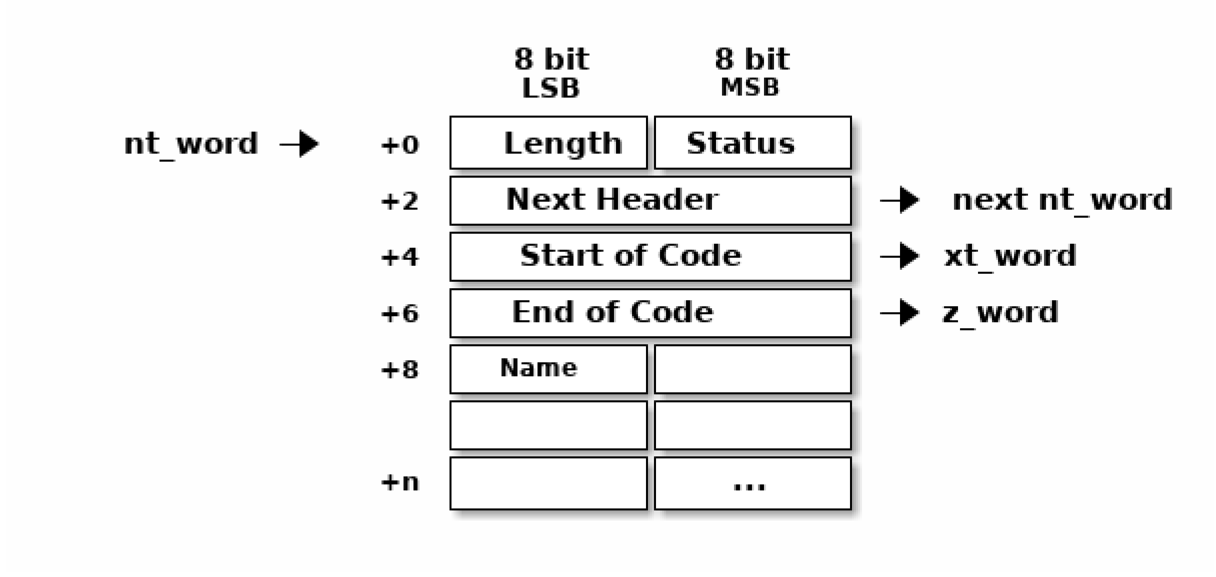
Note this places the sign bit of the double cell number (**S**) at the beginning of the byte below the DSP.

Dictionary

Tali Forth follows the traditional model of a Forth dictionary — a linked list of words terminated with a zero pointer. The headers and code are kept separate to allow various tricks in the code.

Elements of the Header

Each header is at least eight bytes long:



Each word has a `name token` (nt, `nt_word` in the code) that points to the first byte of the header. This is the length of the word's name string, which is limited to 255 characters.

The second byte in the header (index 1) contains the status flags. It is created by the flags defined in the file `definitions.asm`:

CO	**Compile Only.** This word may only be used inside definitions of new words.
IM	**Immediate.** This Word is executed immediately during definitions of new words.
NN	**Never Native.** This Word is never inlined. This is usually because the word needs the caller's return address for processing, or because the word contains some non-relocatable data or code like the absolute `jmp` generated by flow control words. TaliForth automatically flags user words as **NN** when it detects `jmp` instructions.
AN	**Always Native.** This Word must always be inlined, usually because it depends on the return stack state. Setting both **NN** and **AN** together indicates a Word which can be either inlined or not with a specific return stack prologue that is removed when inlined. This is limited to the words `R>`, `R@`, `>R`, `2R>`, `2R@`, and `2>R`.
HC	**Has CFA.** The Word's first three bytes are considered the Code Field Area (CFA). The CFA is a `jsr` to either a known handler like `dovar` or indirectly to `dodefer` and is followed by the Parameter Field Area (PFA) with any data used by the CFA. This is used by words defined with `create` so that `>body` returns the correct value.

The **NN** and **AN** flags are intrepreted together like this:

NN	AN	Interpretation
0	0	Normal word called by JSR (non-native) or inlined (native). No flag.
1	0	Word can only be called by JSR (never native; NN).
0	1	Word can only be inlined (always native; AN).
1	1	Normal word with return stack juggling removed when inlining (ST).

Note there are currently three bits unused.

The status byte is followed by the **pointer to the next header** in the linked list, which makes it the name token of the next word. A 0000 in this position signals the end of the linked list, which by convention is the word `bye` for the native code words.

This is followed by the current word's **execution token** (xt, `xt_word`) that points to the start of the actual code. Some words that have the same functionality point to the same code block.

Because Tali uses a subroutine threaded model (STC), the classic Forth distinction between the Code Field Area (CFA) and the Parameter Field Area (PFA, also Data Field Area) is meaningless — it's all "payload".

The next pointer is for the **end of the code** (`z_word`) to enable native compilation of the word (if allowed and requested).

The **name string** starts at the eighth byte. The string is *not* zero-terminated. Tali Forth lowercases names as they are copied into the dictionary and also lowercases during lookup, so `quarian` is the same word as `QUARIAN`. If the name in the dictionary is directly modified, it is important to ensure that only lowercase letters are used, or else Tali will not be able to find that word.

Structure of the Header List

Tali Forth distinguishes between three different word sources: The **native words** that are hard-coded in the `words/*.asm` files, the **Forth words** from `forth_words.asm` which are defined as high-level words and then generated at run-time when Tali Forth starts up, and **user words** in the file `user_words.asm`.

Tali has an unusually high number of native words in an attempt to make the Forth as fast as possible on the 65c02 and compensate for the disadvantages of the subroutine threading model (STC). The first word on that list — the one that is checked first — is always `drop`, the last one — the one checked for last — is always `bye`. The words which are (or are assumed to be) used more than others come first. Since humans are slow, words that are used more interactively like `words` always come later.

The list of Forth words ends with the intro strings. This functions as a primitive form of a self-test: If you see the welcome message, compilation of the Forth words worked.

Input

Tali Forth follows the ANS Forth input model with `refill` instead of older forms. There are four possible input sources:

- The keyboard ("user input device", can be redirected)
- A character string in memory
- A block
- A text file

To check which one is being used, we first check `blk` which gives us the number of a mass storage block being used, or 0 for the one of the other input sources. In the second case, we use `source-id` to find out where input is coming from:

Table 2. Non-block input sources

Value	Source
0	keyboard (can be redirected)
-1	string in memory
`n`	file-id

The input can be redirected by storing the address of your routine in the memory location given by the word `input`. Tali expects this routine to wait until a character is available and to return the character in A, rather than on the stack.

The output can similarly be redirected by storing the address of your routine in the memory location given by the word `output`. Tali expects this routine to accept the character to output in A, rather than on the stack.

Both the input routine and output routine may use the tmp1, tmp2, and tmp3 memory locations (defined in assembly.asm), but they need to push/pop them so they can restore the original values before returning. The X and Y registers also need to be preserved. If the input or output routines are written in Forth, extra care needs to be taken because many of the Forth words use these tmp variables and it's not immediately obvious without checking the assembly for each word.

Booting

The initial commands after reboot flow into each other: `cold` to `abort` to `quit`. This is the same as with pre-ANS Forths. However, `quit` now calls `refill` to get the input. `refill` does different things based on which of the four input sources (see above) is active:

Keyboard entry	This is the default. Get line of input via `accept` and return `true` even if the input string was empty.
`evaluate` **string**	Return a `false` flag
Input from a block	Blocks are evaluated as a 1024 byte string.
Input from a file	*Not implemented at this time*

The Command Line Interface (CLI)

Tali Forth accepts input lines of up to 256 characters. The address of the current input buffer is stored in `cib`. The length of the current buffer is stored in `ciblen` — this is the address that `>in` returns. `source` by default returns `cib` and `ciblen` as the address and length of the input buffer.

The Word `evaluate`

The word `evaluate`is used to execute commands that are in a string. A simple example:

```
s" 1 2 + ." evaluate
```

Tali Forth uses `evaluate` to load high-level Forth words from the file `forth_words.fs` and, if present, any extra, user-defined words from `user_words.fs`. The code in these files has all comments removed and all whitespace replaced with a single splace between words. This minimized version is assembled directly into the ROM image as a string that will be evaluated at startup.

The Words `create` and `does>`

The tandem of words `create` and `does>` is the most complex, but also most powerful part of Forth. Understanding how it works in Tali Forth is important if you want to be able to modify the code. In this text, we walk through the generation process for a subroutine threaded code (STC) such as Tali Forth.

For a more general explanation, see Brad Rodriguez' series of articles at http://www.bradrodriguez.com/papers/moving3.htm There is a discussion of this walkthrough at http://forum.6502.org/viewtopic.php?f=9&t=3153

We start with the following standard example, a high-level Forth version of the word `constant`.

```
: constant  ( "name" -- )  create , does> @ ;
```

We examine this in three phases or "sequences", following Rodriguez (based on [DB]).

Sequence 1: Compiling the Word `constant`

`constant` is a defining word, one that makes new words. In pseudocode, ignoring any compilation to native 65c02 assembler, the above compiles to:

```
        jsr CREATE
        jsr COMMA
        jsr (DOES>)         ; from DOES>
   a:   jsr DODOES          ; from DOES>
   b:   jsr FETCH
        rts
```

To make things easier to explain later, we've added the labels a and b in the listing.

This example uses the traditional word (does>), which in Tali Forth 2 is actually an internal routine that does not appear as a separate word. This version is easier to explain.

does> is an immediate word that adds not one, but two subroutine jumps, one to (does>) and one to dodoes, which is a pre-defined system routine like dovar. We'll discuss those later.

In Tali Forth, a number of words such as defer are "hand-compiled", that is, instead of using forth such as

```
: defer create ['] abort , does> @ execute ;
```

we write an optimized assembler version ourselves (see the actual defer code). In these cases, we need to use (does>) and dodoes instead of does> as well.

Sequence 2: Executing the Word constant

Now when we execute

```
42 constant life
```

This pushes the rts of the calling routine — call it "main" — to the 65c02's stack (the Return Stack, as Forth calls it), which now looks like this:

```
        (1) rts                 ; to main routine
```

Without going into detail, the first two subroutine jumps of constant give us this word:

```
        (Header "LIFE")
        jsr DOVAR               ; in CFA, from LIFE's CREATE
        4200                    ; in PFA (little-endian)
```

Next, we jsr to (does>). The address that this pushes on the Return Stack is the instruction of constant we had labeled a.

```
        (2) rts to CONSTANT ("a")
        (1) rts to main routine
```

Now the tricks start. (does>) takes this address off the stack and uses it to replace the dovar jsr target in the CFA of our freshly created life word. We now have this:

```
        (Header "LIFE")
        jsr a                   ; in CFA, modified by (DOES>)
    c:  4200                    ; in PFA (little-endian)
```

Note we added a label `c`. Now, when `(does>)` reaches its own `rts`, it finds the `rts` to the main routine on its stack. This is a Good Thing™, because it aborts the execution of the rest of `constant`, and we don't want to do `dodoes` or `fetch` now. We're back at the main routine.

Sequence 3: Executing `life`

Now we execute the word `life` from our "main" program. In a STC Forth such as Tali Forth, this executes a subroutine jump.

```
        jsr LIFE
```

The first thing this call does is push the return address to the main routine on the 65c02's stack:

```
        (1) rts to main
```

The CFA of `life` executes a subroutine jump to label `a` in `constant`. This pushes the `rts` of `life` on the 65c02's stack:

```
        (2) rts to LIFE ("c")
        (1) rts to main
```

This `jsr` to a lands us at the subroutine jump to `dodoes`, so the return address to `constant` gets pushed on the stack as well. We had given this instruction the label `b`. After all of this, we have three addresses on the 65c02's stack:

```
        (3) RTS to CONSTANT ("b")
        (2) RTS to LIFE ("c")
        (1) RTS to main
```

`dodoes` pops address `b` off the 65c02's stack and puts it in a nice safe place on Zero Page, which we'll call `z`. More on that in a moment. First, `dodoes` pops the `rts` to `life`. This is `c`, the address of the PFA or `life`, where we stored the payload of this constant. Basically, `dodoes` performs a `dovar` here, and pushes `c` on the Data Stack. Now all we have left on the 65c02's stack is the `rts` to the main routine.

```
        [1] RTS to main
```

This is where `z` comes in, the location in Zero Page where we stored address `b` of `constant`. Remember, this is where the PFA of `constant` begins, the `fetch` command we had originally codes after `does>` in the very first definition. The really clever part: We perform an indirect `jmp` — not a `jsr`! — to this address.

```
        jmp (z)
```

Now the little payload program of `constant` is executed, the subroutine jump to `fetch`. Since we just put the PFA (`c`) on the Data Stack, `fetch` replaces this by 42, which is what we were aiming for all along. And since `constant` ends with a `rts`, we pull the last remaining address off the 65c02's stack, which is the return address to the main routine where we started. And that's all.

Put together, this is what we have to code:

`does>`
: Compiles a subroutine jump to `(does>)`, then compiles a subroutine jump to `dodoes`.

`(does>)`
: Pops the stack (address of subroutine jump to `dodoes` in `constant`, increase this by one, replace the original `dovar` jump target in `life`.

`dodoes`
: Pop stack (PFA of `constant`), increase address by one, store on Zero Page; pop stack (PFA of `life`), increase by one, store on Data Stack; `jmp` to address we stored in Zero Page.

Remember we have to increase the addresses by one because of the way `jsr` stores the return address for `rts` on the stack on the 65c02: It points to the third byte of the `jsr` instruction itself, not the actual return address. This can be annoying, because it requires a sequence like:

```
        inc z
        bne +
        inc z+1
*
        (...)
```

Note that with most words in Tali Forth, as any STC Forth, the distinction between PFA and CFA is meaningless or at least blurred, because we go native anyway. It is only with words generated by `create` and `does>` where this really makes sense.

Control Flow

Branches

For `if` and `then`, we need to compile something called a "conditional forward branch", traditionally called `0branch`. In Tali Forth, this is not visible to the user as an actual, separate word anymore, but we can explain things better if we assume it is still around.

At run-time, if the value on the Data Stack is false (flag is zero), the branch is taken ("branch on zero", therefore the name). Except that we don't have the target of that branch yet — it will later be added by `then`. For this to work, we remember the address after the `0branch` instruction during the compilation of `if`. This is put on the Data Stack, so that `then` knows where to compile it's address in the second step. Until then, a dummy value is compiled after 0branch to reserve the space we need.

> This section and the next one are based on a discussion at http://forum.6502.org/viewtopic.php?f=9\&t=3176 see there for more details. Another take on this subject that handles things a bit differently is at http://blogs.msdn.com/b/ashleyf/archive/2011/02/06/loopty-do-i-loop.aspx

In Forth, this can be realized by

```
: if  postpone 0branch here 0 , ; immediate
```

and

```
: then  here swap ! ; immediate
```

Note then doesn't actually compile anything at the location in memory where it is at. It's job is simply to help if out of the mess it has created. If we have an else, we have to add an unconditional branch and manipulate the address that if left on the Data Stack. The Forth for this is:

```
: else  postpone branch here 0 , here rot ! ; immediate
```

Note that then has no idea what has just happened, and just like before compiles its address where the value on the top of the Data Stack told it to — except that this value now comes from else, not if.

Loops

Loops are more complicated, because we have do, ?do, loop, +loop, unloop, and leave to think about. These can involve up to three branches: One for the normal looping action (loop and +loop), one to skip over the loop at the beginning (?do) and one to skip out of the loop (leave).

Like many other forth implementations, Tali Forth 2 originally used the return stack to manage loop control, including the loop exit address and the loop step and limit values. However this required extensive stack juggling which slowed loop performance. After investigating several alternatives we switched to a separate loop control stack. Each loop uses a four byte (double word) loop control block (LCB) to store the current loop limits. All branch addresses including the loop exit are now directly compiled into code rather than stored on the stack.

> In order to simplify the loop completion check after each iteration, we don't store the actual loop index and limit values in the LCB. Instead we calculate a fudge factor (sometimes referred to as 'fufa' in the code) that makes every loop appear to finish at exactly $8000, and use this to adjust the loop index. This lets us use a simple 16 bit overflow test to see if we're done. One side effect is that the i and j words get a little more complicated. For more details see http://forum.6502.org/viewtopic.php?f=9&t=2026 and the do_runtime implementation.

Remembering state across nested loops means a stack of LCBs. Whereas the return stack grows downward from $1ff, our current loop control stack grows upward from $100. The zero-page `loopctrl` byte forms our loop stack pointer, limiting us to at most 64 nested loops if the return stack is empty. We also cache the least significant byte of the active loop index in the zero-page `loopidx0` which often lets us avoid indexed access to the LCB.

The key to staying sane while designing these constructs is to make a list of what we should happen at compile time and what at run time. Let's start with a high-level view of what happens at run time to manage a `do` loop:

- `do` adds four to the loop control stack pointer in `loopctrl` to assign a new LCB. It writes the initial loop index and offset to the LCB and updates the cached `loopidx0`. `?do` is very similar.
- most of the time `loop` just increments the cached `loopidx0`. It only touches the LCB when the low byte overflows.
- `+loop` updates `loopidx0` and (if needed) the high byte in the LCB. It only touches the LCB when we have a step size larger than 255 or an overflow on the low index byte.
- `unloop` subtracts four from `loopctrl` to drop the current LCB. It caches the low byte of the now current loop index in `loopidx0` so that any enclosing loop sees the correct value.
- the `i` and `j` words use 16-bit math to calculate the actual loop index from the LCB offset and fudge factor values. Although it's certainly not portable forth, our LCB approach means that `i` and `j` can be safely referenced by words called within a loop. (This isn't the case in Forths that use the return stack for loop control.)
- `leave` simply jumps out of the loop to an address hard-coded at compile time.

And what about compile time?

- `do` emits the runtime code to set up the loop from the limit values. The `?do` variant includes a conditional jump that skips the loop entirely, dropping the limits. Since we won't know the exit address until we're finished compiling the loop body, we emit placeholder bytes and save the placeholder's address on the stack so `loop` can update it later. We also stash the current `loopleave` variable so that we can handle `leave` in nested loops (see below).
- `loop` and `+loop` generate the runtime code that increment the loop offset with an efficient check for whether we've crossed the completion limit. Now that we've finished compiling the loop contents we can also patch up the exit addresses needed for `?do` and `leave`.
- `unloop`, `i`, and `j` don't have any compile-time behavior.
- `leave` also needs to jump to the end of the loop but we don't yet know where that is. Because `leave` can appear multiple times in a loop, we need some trickery to keep a list of all `leave` placeholders to update. The address of the first `leave` placholder is stored in a variable called `loopleave`. Then the next `leave` placeholder address is stored **as** the placeholde value of the previous `leave`! This can be repeated indefinitely and forms a linked list. Once we've finished compiling `loop` can walk the list and write the exit address into each placeholder. (To safely handle nested loops we also need to push and pop `loopleave` whenever we start or finish compiling a new loop.)

It's clear that all the complicated stuff happens at compile-time. This is good, because we only have to do that once for each loop. In Tali Forth all of loop control is coded in assembler. You can see all of the gory details of the loop word implementations in `words/core.asm`.

Native Compiling

In a pure subroutine threaded code, higher-level words are merely a series of subroutine jumps. For instance, the Forth word `[char]`, formally defined in high-level Forth as

```
: [char] char postpone literal ; immediate
```

in assembler is simply

```
                jsr xt_char
                jsr xt_literal
```

as an immediate, compile-only word. There are two problems with this method: First, it is slow, because each `jsr`-`rts` pair consumes four bytes and 12 cycles as overhead. Second, for smaller words, the jumps use far more bytes than the actual code. Take for instance `drop`, which in its naive form is simply

```
                inx
                inx
```

for two bytes and four cycles. If we jump to this word as is assumed with pure subroutine threaded Forth, we add four bytes and 12 cycles — double the space and three times the time required by the actual working code.

(In practice, it's even worse, because `drop` checks for underflow. The actual assembler code is

```
                jsr underflow_1

                inx
                inx
```

for five bytes and 20 cycles. We'll discuss the underflow checks further below.)

To get rid of this problem, Tali Forth supports **native compiling** (also known as inlining). The system variable `nc-limit` sets the threshold up to which a word will be included not as a subroutine jump, but in machine language. Let's start with an example where `nc-limit` is set to zero, that is, all words are compiled as subroutine jumps. Take a simple word such as

```
: aaa 0 drop ;
```

when compiled with an `nc-limit` of 0 and check the actual code with `see`

```
see aaa
nt: 800  xt: 80B
flags (CO AN IM NN HC ST): 0 0 0 1 1 0
size (decimal): 6

080B  20 A2 A7 20 2E 8D   .. ..

80B   A7A2 jsr     0
80E   8D2E jsr     drop
```

(The actual addresses might vary). Our word `aaa` consists of two subroutine jumps, one to zero and one to `drop`. Now, if we increase the threshold to 20 and define a new word with the same instructions with

```
20 nc-limit !
: bbb 0 drop ;
```

we get different code:

```
see bbb
nt: 812  xt: 81D
flags (CO AN IM NN HC ST): 0 0 0 1 1 0
size (decimal): 11

081D  CA CA 74 00 74 01 20 29  D8 E8 E8  ..t.t. ) ...

81D        dex
81E        dex
81F      0 stz.zx
821      1 stz.zx
823   D829 jsr     STACK DEPTH CHECK
826        inx
827        inx
```

Even though the definition of `bbb` is the same as `aaa`, we have totally different code: The number 0000 is pushed to the Data Stack (the first six bytes), then we check for underflow (the next three), and finally we `drop` by moving X register, the Data Stack Pointer. Our word is definitely longer, but have just saved 12 cycles.

To experiment with various parameters for native compiling, the Forth word `words&sizes` is included in `user_words.fs` (but commented out by default). The Forth is:

```
: words&sizes ( -- )
        latestnt
        begin
                dup
        0<> while
                dup name>string type space
                dup wordsize u. cr
                2 + @
        repeat
        drop ;
```

An alternative is `see` which also displays the length of a word. One way or another, changing `nc-limit` should show differences in the Forth words.

While a new word may have built-in words natively compiled into it, all new words are flagged Never-Native by default because a word needs to meet some special criteria to be safe to native compile. In particular, the word cannot have any control structures (if, loop, begin, again, etc) and, if written in assembly, cannot have any JMP instructions in it (except for error handling, such as underflow detection).

If you are certain your new word meets these criteria, then you can enable native compilation of this word into other words by invoking the word `allow-native` or the word `always-native` immediately after the definition of your new word. The `allow-native` will use the `nc-limit` value to determine when to natively compiled just like it does for the built-in words, and `always-native` will always natively compile regardless of the setting of `nc-limit`.

Return Stack Special Cases

There are a few words that cause problems with subroutine threaded code (STC): Those that access the Return Stack such as `r>`, `>r`, `r@`, `2r>`, and `2>r`. We first have to remove the return address on the top of the stack, only to replace it again before we return to the caller. This mechanism would normally prevent the word from being natively compiled at all, because we'd try to remove a return address that doesn't exit.

This becomes clearer when we examine the code for `>r` (comments removed):

```
xt_r_from:
                pla
                sta tmptos
                ply

                ; --- CUT FOR NATIVE CODING ---

                dex
                dex
                pla
                sta 0,x
                pla
                sta 1,x

                ; --- CUT FOR NATIVE CODING ---

                phy
                lda tmptos
                pha

z_r_from:       rts
```

The first three and last three instructions are purely for housekeeping with subroutine threaded code. To enable this routine to be included as native code, they are removed when native compiling is enabled by the word `compile,` This leaves us with just the six actual instructions in the center of the routine to be compiled into the new word.

Underflow Stripping

As described above, every underflow check adds three bytes to the word being coded. Stripping this check by setting the `strip-underflow` system variable (named `uf-strip` in the source code) to `true` simply removes these three bytes from new natively compiled words.

It is possible, of course, to have lice and fleas at the same time. For instance, this is the code for `>r`:

```
xt_to_r:
                pla
                sta tmptos
                ply

                ; --- CUT HERE FOR NATIVE CODING ---

                jsr underflow_1

                lda 1,x
                pha
                lda 0,x
                pha

                inx
                inx

                ; --- CUT HERE FOR NATIVE CODING ---

                phy
                lda tmptos
                pha

z_to_r:         rts
```

This word has *both* native compile stripping and underflow detection. However, both can be removed from newly native code words, leaving only the eight byte core of the word to be compiled.

Enabling Native Compiling on New Words

By default, user-defined words are flagged with the Never-Native (NN) flag. While the words used in the definition of the new word might have been natively compiled into the new word, this new word will always be compiled with a JSR when used in future new words. To override this behavior and allow a user-defined word to be natively compiled, the user can use `allow-native` word to remove the NN flag and allow native compiling if the word is smaller than `nc-limit`. Alternatively, the `always-native` word will set the Always-Native (AN) flag and force native compilation, regardless of `nc-limit`. These modifiers go just after the definition has been completed (with a semicolon). An example of doing this might be:

```
: double dup + ; always-native
```

Please note that adding the always-native flag to a word overrides the never-native flag.

⚠ Do not apply `allow-native` or `always-native` to a word that has any kind of control structures in it, such as `if`, `case` or any kind of loop. If these words ever get native compiled, the JMP instructions used in the control structures are copied verbatim, causing them to jump back into the original words.

⚠ When adding your own words in assembly, if a word has a `jmp` instruction in it, it should have the NN (Never Native) flag set in the headers.asm file and should never have the AN (Always Native) flag set.

`cmove`, `cmove>` and `move`

The three moving words `cmove`, `cmove>` and `move` show subtle differences that can trip up new users and are reflected by different code under the hood. `cmove` and `cmove>` are the traditional Forth words that work on characters (which in the case of Tali Forth are bytes), whereas `move` is a more modern word that works on address units (which in our case is also bytes).

If the source and destination regions show no overlap, all three words work the same. However, if there is overlap, `cmove` and `cmove>` demonstrate a behavior called "propagation" or "clobbering" : Some of the characters are overwritten. `move` does not show this behavior. This example shows the difference:

```
create testbuf  char a c,  char b c,  char c c,  char d c,  ( ok )
testbuf 4 type  ( abcd ok )
testbuf dup char+ 3  cmove  ( ok )
testbuf 4 type ( aaaa ok )
```

Note the propagation in the result. `move`, however, doesn't propagate. The last two lines would be:

```
testbuf dup char+ 3  move  ( ok )
testbuf 4 type  ( aabc ok )
```

In practice, `move` is usually what you want to use.

[1] Try reading that last sentence to a friend who isn’t into computers. Aren’t abbreviations fun?

Developing

> After spending an entire weekend wrestling with blocks files, stacks, and the like, I was horrified and convinced that I had made a mistake. Who in their right mind would want to program in this godforsaken language! [DH]
>
> — Doug Hoffman, Some notes on Forth from a novice user

Required Tools

To run Tali Forth 2 in a simulator, you will need `python3` and `py65` installed to be able to run `py65mon`, or you will need `make` and `gcc` installed to compile the the `c65` simulator that comes with Tali (preferred).

To assemble Tali Forth 2, you will need `64tass` (version 1.56.2625 or later) and `make`.

To recompile the documentation for Tali Forth 2, you will need the following tools:

`Ditaa` is used to generate the diagrams from text file descriptions and is available at https://ditaa.sourceforge.net/ Ditaa is not required if you are not going to change any of the diagrams.

Ditaa is a java program, so I made a helper script (named just `ditaa`) to help run it. You'll need to replace the path to the jar file for your system.

```
#!/bin/sh
java -jar /path/to/jarfile/ditaa0_9.jar $@
```

`asciidoctor` and `asciidoctor-pdf` are used to generate the html and PDF versions of this manual. These are rubygems are are installed by first installing ruby and then running the following commands:

```
sudo gem install asciidoctor
sudo gem install asciidoctor-pdf
```

These tools have an annoying "feature" of having their version number in the executable name. To work around this, I created symbolic links in my personal bin folder (eg. a folder in my path) as shown below. You will need to adjust with the name of these utilities on your system.

```
ln -s /usr/bin/asciidoctor.ruby3.2 asciidoctor
ln -s /usr/bin/asciidoctor-pdf.ruby3.2 asciidoctor-pdf
```

Optional Tools

Generating the MarkDown and PDF versions of the manual is optional. You will need `pandoc` (package was named `pandoc-cli` on my system) and `texlive` installed. These versions of the manual are not compiled by default (only the HTML version is compiled by default). If you would like the manual in these formats, you can use the following commands:

```
make docsmd
make docspdf
```

Adding New Words

The simplest way to add new words to Tali Forth is to include them in the file `forth_code/user_words.fs`. This is the suggested place to put them for personal use.

To add words to the permanent set, it is best to start a pull request on the GitHub page of Tali Forth. How to setup and use `git` and GitHub is beyond the scope of this document — we'll just point out that they are not as complicated as they look, and they make experimenting a lot easier.

During development, Tali Forth tends to follow a sequence of steps for new words:

- If it is an ANS Forth word, first review the standard online. In some cases, there is a reference implementation that can be used.
- Otherwise, check other sources for a high-level realization of the word, for instance Jonesforth or Gforth. A direct copy is usually not possible (or legally allowed, given different licenses), but studying the code provides hints for a Tali Forth version.
- Write the word in Forth in the interpreter. After it has been tested interactively, add a high-level version to the file `forth_code/forth_words.fs`.
- Add automatic tests for the new word to the test suite. Ideally, there will be test code included in the ANS Forth specification. If not, document what the test does.
- In a further step, if appropriate, convert the word to assembler. This requires adding an entry to `words/headers.asm` and the code itself to one of the files in `words/*.asm`. In this first step, it will usually be a simple 1:1 sequence of `jsr` subroutine jumps to the existing native Forth words. Some special consideration is needed for immediate words, postponed words and the word `does>` (see the section on Converting Forth to Assembly for help with these situations).
- If appropriate, rewrite all or some of the subroutine jumps in direct assembler. Because we have the automatic tests in place, we can be confident that the assembly version is correct as well.

However, if you are contributing code, feel free to happily ignore this sequence and just submit whatever you have.

Deeper Changes

Tali Forth was not only placed in the public domain to honor the tradition of giving the code away freely. It is also to let people play around with it and adapt it to their own machines. This is also the reason it is (perversely) over-commented.

To work on the internals of Tali Forth, you will need the 64tass assembler.

The 64tass Assembler

While Tali Forth 2 was originally developed with the Ophis assember, it was ported to the 64tass assembler because this assembler allows conditional compilation.

For Linux users, your operating system may have a pre-built 64tass package you can install. For everyone else, you can head over to: https://sourceforge.net/projects/tass64/ Windows users will probably want to just grab a binary (just put the executable in a convenient folder and make sure that folder is in the path). Users of other OSes will probably need to compile from source (which is super easy as the code has almost no dependancies).

Once you have 64tass installed, switch to the folder where the Tali code lives and run the Makefile with a simple `make` command (assumes you have GNU make installed). This also updates the file listings in the `docs` folder.

General Notes

- The X register is used as the Data Stack Pointer (DSP) and should only be used if there is no other alternative.
- The Y register, however, is free to be changed by subroutines. This also means it should not be expected to survive subroutines unchanged.
- Natively coded words generally should have exactly one point of entry — the `xt_word` link — and exactly one point of exit at `z_word`. In may cases, this requires a branch to an internal label `_done` right before `z_word`.
- Because of the way native compiling works, the trick of combining `jsr`-`rts` pairs to a single `jmp` instruction (usually) doesn’t work.
- In broad terms Tali Forth 2 should be easy to understand and use. When adding new code you should prefer simplicity over complexity, particularly for compile-time words. Speed is a virtue for core run-time words and reducing code size is always a virtue.

Coding Style

Until there is a tool for 64tass assembly code that formats the source file the way gofmt does for Go (golang), the following format is suggested.

- Tabs are **eight characters long** and converted to spaces.
- Opcodes are indented by **two tabs**.
- Function-like routines are followed by a one-tab indented "function doc string" based on the Python 3 format: Three quotation marks at the start, three at the end in their own line, unless it is a one-liner. This should make it easier to automatically extract the docs for them at some point.

- The native words have a special comment format with lines that start with `##` that allows the automatic generation of word lists by a tool in the tools folder, see there for details.
- Assembler mnemonics are lower case. I get enough uppercase insanity writing German, thank you very much.
- Hex numbers are, however, upper case, such as `$FFFE`.
- Numbers in mnemonics are a stripped-down as possible to reduce visual clutter: use `lda 0,x` instead of `lda $00,x`.
- Comments are included like popcorn to help readers who are new both to Forth and 6502 assembler.

Converting Forth to Assembly

When converting a Forth word to assembly, you will need to take the Forth definition and process it word by word, in order, into assembly. All of the words used in the definition need to already be in assembly.

The processing is different for regular, immediate, and postponed words, with special handling required for the word `does>`. These are all covered below, with examples. Take each word in the definition, determine which type of word it is, and then follow the steps outlined below for that word type.

Once the word has been converted, a dictionary header needs to be added for it in words/headers.asm. This process is covered in detail at the end of this section.

Processing Regular (Non-Immediate) Words

If the definition word you are processing is not immediate (you can check this with `see`, eg. `see dup` and make sure the IM flag is 0) then it just translates into a JSR to the native code implementing the xt (execution token) of that word. Most words have an external entrypoint which begins with `xt_` followed by the name (spelled out, in the case of numbers and symbols) of the word. Once your word is properly tested you can opt to use the internal entrypoint which replaces `xt_` with `w_` (for "word") and skips data stack underflow checks.

As an example, let’s turn the following definition into assembly:

```
: getstate state @ ;
```

Translates into:

```
; ## GETSTATE ( -- n ) "Get the current state"
; ## "getstate" coded Custom
xt_getstate:
w_getstate:     ; no underflow check so w_ entrypoint is the same as xt_
                jsr w_state
                jsr w_fetch ; @ is pronounced "fetch" in Forth.
z_getstate:
```

```
                rts
```

The above code could be added to words/wordlist.asm, probably right after get-order. Each file in words/*.asm groups related words, and each is roughly in alphabetical order by word name with a few exceptions for words that need to be close to each other.

The header above the code is in a special format used to track where words come from and their current status. It is parsed by a tool that helps to track information about the words, so the format (including the ##s) is important. The first line has the name (which is uppercase, but needs to match whatever comes after the xt_, w_ and z_ in the labels below it), the input and output stack parameters in standard Forth format, and a string that has a short description of what the word does. The second line has a string showing the name as it would be typed in Forth (useful for words with symbols in them), the current testing status (coded, tested, auto), and where the word comes from (ANS, Gforth, etc.) See the top of words/headers.asm for more information on the status field, but "coded" is likely to be the right choice until you've thoroughly tested your new word.

Local labels begin with an underscore "_" and are only visible within the same scope (between two regular labels). This allows multiple words to all have a `_done:` label, for example, and each word will only branch to its own local version of `_done:` found within its scope. Any branching within the word (eg. for ifs and loops) should be done with local labels. Labels without an underscore at the beginning are globally available.

The labels xt_xxxx and z_xxxx need to be the entry and exit point, respectively, of your word. The xxxx portion should be your word spelled out (eg. numbers and symbols spelled out with underscores between them). Although allowed in the Forth word, the dash "-" symbol is not allowed in the label (the assembler will try to do subtraction), so it is replaced with an underscore anywhere it is used. The one and only RTS should be right after the z_xxxx label. If you need to return early in your word, put a `_done:` label just before the z_xxxx label and branch to that. The w_xxxx label should be immediately after the `jsr underflow_n` check if your word has one, otherwise it should coincide with the xt_xxxx label.

You can see that the body is just a sequence of JSRs calling each existing word in turn. If you aren't sure of the w_xxxx name of a forth word, you can search words/*.asm for the Forth word (in lowercase) in double quotes and you will find it in the header for that word. `w_fetch`, above, could be found by searching for "@" (including the quotes) if you didn't know its name.

Processing Immediate Words

To determine if a word is immediate, use the word `see` on it (eg. `see [char]` for the example below). Processing an immediate word takes a little more detective work. You'll need to determine what these words do to the word being compiled and then do it yourself in assembly, so that only what is actually compiled into the word (in forth) shows up in your assembly. Some immediate words, such as `.(` don't have any affect on the word being compiled and will not have any assembly generated.

Let's start with the simple example:

```
: star [char] * emit ;
```

The fact that [char] is a square-bracketed word is a strong hint that it's an immediate word, but you can verify this by looking at the IM flag using `see [char]`. This word takes the next character (after a single space) and compiles instructions to put it on the stack. It also uses up the * in the input. It will need to be replaced with the final result, which is code to put a * on the stack. Checking emit shows that it's a normal (non-immediate) word and will be translated into assembly as a JSR.

When we go to add our word, we discover that the name xt_star is already in use (for the multiplication word `*` in words/core.asm), so this will show how to deal with that complication as well.

```
; ## STAR_WORD ( -- ) "Print a * on the screen"
; ## "star" coded Custom
xt_star_word:
w_star_word
                ; Put a * character on the stack.
                dex             ; Make room on the data stack.
                dex
                lda #42         ; * is ASCII character 42.
                sta 0,x         ; Store in low byte of stack cell.
                stz 1,x         ; high byte is zeroed for characters.
                jsr w_emit      ; Print the character to the screen.
z_star_word:
                rts
```

We chose the labels xt_star_word and z_star_word for this word, but it will be named "star" in the dictionary and Tali won't confuse it with `*` for multiplication. The `[char] *` portion of the definition has the behavior of compiling the instructions to put the character "*" on the stack. We translate that into the assembly that does that directly. The word `emit` is a normal word, and is just translated into a JSR.

Processing Postponed Words

Postponed words in a definition are very easy to spot because they will have the word `POSTPONE` in front of them. You will still need to determine if the word being postponed is immediate or not, as that will affect how you translate it into assembly.

If the word being postponed is an immediate word, then it is very simple and translates to just a JSR to the word being postponed. In this case, the word POSTPONE is being used to instruct Forth to compile the next word rather than running it (immediately) when it is seen in the forth definition. Because your assembly is the "compiled" version, you just have to include a call to the word being postponed.

If the word being postponed is a regular word, then you need to include assembly to cause that word to be compiled when your word is run. There is a helper function `cmpl_subroutine` that takes the high byte of the address in Y and the low byte in A to help you out with this.

We'll take a look at the Forth word `IS` (used with deferred words) because it has a mix of regular, postponed immediate, and postponed regular words without being too long. The definition in Forth looks like:

```
: is state @ if postpone ['] postpone defer! else ' defer! then ; immediate
```

This has an IF in it, which we will need to translate into branches and will be a good demonstration of using local labels. This word has stateful behavior (eg. it acts differently in INTERPRET mode than it does in COMPILE mode). While we could translate the "state @" portion at the beginning into JSRs to xt_state and xt_fetch, it will be much faster to look in the state variable directly in assembly. You can find all of the names of internal Tali variables in definitions.asm.

The assembly version of this (which you can find in words/core.asm as this is the actual assembly definition of this word) is:

```
; ## IS ( xt "name" -- ) "Set named word to execute xt"
; ## "is"  auto  ANS core ext
        ; """http://forth-standard.org/standard/core/IS"""
xt_is:
w_is:
                ; This is a state aware word with different behavior
                ; when used while compiling vs interpreting.
                ; Check STATE
                lda state
                ora state+1
                beq _interpreting
_compiling:
                ; Run ['] to compile the xt of the next word
                ; as a literal.
                jsr w_bracket_tick

                ; Postpone DEFER! by compiling a JSR to it.
                ldy #>w_defer_store
                lda #<w_defer_store
                jsr cmpl_subroutine
                bra _done
_interpreting:
                jsr w_tick
                jsr w_defer_store
_done:
z_is:           rts
```

In the header, you can see this word is part of the ANS standard in the extended core word set. The "auto" means that there are automated tests (in the tests subdirectory) that automatically test this word. There is also a link in the comments (not technically part of the header) to the ANS standard for this word.

The STATE @ IF portion of the definition is replaced by checking the state directly. The state variable is 0 for interpreting and -1 ($FFFF) for compiling. This assembly looks directly in the state variable (it's a 16-bit variable, so both halves are used to check for 0). In order to keep the assembly in the same order as the Forth code, we branch on zero (the if would have been compiled into the runtime code for this branch) to the else section of the code.

The true section of the if has two postponed words. Conveniently (for demonstration purposes), the first one is an immediate word and the second is not. You can see that the first postponed word is translated into a JSR and the second is translated into a call to cmpl_subroutine with Y and A filled in with the address of the word being postponed. Because the true section should not run the code for the else section, we use a BRA to a _done label.

The else section of the if just has two regular words, so they are just translated into JSRs.

The immediate on the end is handled in the header in headers.asm by adding IM to the status flags. See the top of headers.asm for a description of all of the header fields.

Processing DOES>

The word does> is an immediate word. It is commonly used, along with create (which is not immediate and can be processed normally), in defining words. Defining words in Forth are words that can be used to declare new words. Because it is likely to be seen in Forth code, its particular assembly behavior is covered here.

To see how does> is translated, we will consider the word 2CONSTANT:

```
: 2constant ( d -- ) create swap , , does> dup @ swap cell+ @ ;
```

This word is from the ANS double set of words and it creates a new named constant that puts its value on the stack when it is run. It's commonly used like this:

```
12345678. 2constant bignum
bignum d.
```

The . at the end of the number makes it a double-cell (32-bit on Tali) number.

The assembly code for 2CONSTANT (taken from words/double.asm) looks like:

```
; ## TWO_CONSTANT (C: d "name" -- ) ( -- d) "Create a constant for a double word"
; ## "2constant"  auto  ANS double
        ; """https://forth-standard.org/standard/double/TwoCONSTANT
        ; Based on the Forth code
        ; : 2CONSTANT ( D -- )  CREATE SWAP , , DOES> DUP @ SWAP CELL+ @ ;
        ; """
xt_two_constant:
                jsr underflow_2
w_two_constant:
                jsr w_create
                jsr w_swap
                jsr w_comma
                jsr w_comma

                jsr does_runtime    ; does> turns into these two routines.
                jsr dodoes
                jsr w_dup
                jsr w_fetch
                jsr w_swap
                jsr w_cell_plus
                jsr w_fetch

z_two_constant: rts
```

This word takes an argument, so underflow checking is added right at the top. Underflow checking is optional, but recommended for words that take arguments on the stack. To add underflow checking to your word, just call the appropriate underflow checking helper (underflow_1 to underflow_4) based on how many cells you are expecting (minimum) on the stack. If there aren't that many cells on the stack when the word is run, an error message will be printed and the rest of the word will not be run.

This word takes a double-cell value on the stack, so underflow_2 was used. The underflow check must be the first line in your word. Note the internal w_two_constant entrypoint is placed after the underflow check. This speeds up other native words that use 2constant.

All of the other words other than `does>` in this definition are regular words, so they just turn into JSRs. The word `does>` turns into a `jsr does_runtime` followed by a `jsr dodoes`.

Adding the Header in headers.asm

Once your word has been entered into one of the words/*.asm files with the appropriate comment block over it and the xt_xxxx, w_xxxx and z_xxxx labels for the entry and exit points, it is time to add the dictionary header for your word to link it into one of the existing wordlists. The words here are not in alphabetical order and are loosely grouped by function. If you aren't sure where to put your word, then put it near the top of the file just under the header for `drop`.

Each header is simply a declaration of bytes and words that provides some basic information that Tali needs to use the word, as well as the addresses of the beginning and ending (not including the rts at the end) of your word. That's why you need the xt_xxxx and z_xxxx labels in your word (where xxxx is the spelled-out version of your word's name).

Before we dicuss adding a word, let's go over the form a dictionary header. The fields we will be filling in are described right at the top of headers.asm for reference. We'll look at an easy to locate word, `drop`, which is used to remove the top item on the stack. It's right near the top of the list. We'll also show the word `dup`, which is the next word is the dictionary. The headers for these two words currently look like:

```
nt_drop:
        .byte 4, 0
        .word nt_dup, xt_drop, z_drop
        .text "drop"

nt_dup:
        .byte 3, 0
        .word nt_swap, xt_dup, z_dup
        .text "dup"
```

The first component of a dictionary header is the label, which comes in the form nt_xxxx where xxxx is the spelled out version of your word's name. The xxxx should match whatever you used in your xt_xxxx and z_xxxx labels.

The next two fields are byte fields, so we create them with the 64tass assembler `.byte` directive. The first field is the length of the name, in characters, as it will be typed in Tali. The second field is the status of the word, where each bit has a special meaning. If there is nothing special about your word, you will just put 0 here. If your word needs some of the status flags, you add them together (with +) here to form the status byte. The table below gives the constants you will use and a brief description of when to use them.

CO	Compile Only. Add this if your word should only be allowed when compiling other words. Tali will print an error message if the user tries to run this word in interpreted mode.
IM	Immediate Word. Add this when a word should always be run rather than compiled (even when in compiling mode).
NN	Never Native Compile (must always be called by JSR when compiled). Add this when your word contains a JMP instruction, or if it plays with the return address it is called from.
AN	Always Native Compile (will be native compiled when compiled). The opcodes for this word will be copied (native compiling) into a new word when this word is used in the definition. For short simple words that are just a sequence of JSRs, you can safely set this bit. This bit should not be set if the assembly has a JMP instruction in it (see NN above). Note: If neither NN or AN is set, then the word might be native compiled based on its size and the value in the Forth variable `nc-limit`.
HC	Has CFA (words created by CREATE and DOES> only). You will probably never need this bit for words that you write in assembly.
ST	Manipulates the return stack differently for native vs non-native compilation. This is used for words like R>, R@ and >R but you're unlikely to need this for your own words in assembly.

If you created a short word made out of just JSRs, and you wanted it to be an immediate, compile-only word, you might put `IM+CO` for this field.

The next line contains three addresses, so the 64tass `.word` directive is used here. The first address is the nt_xxxx of the next word in the word list (with 0 used for the very last word in the word list). The words are listed in dictionary order, so this will normally be the nt_xxxx of the word just below (there may be some anonymous labels used if the next word is conditionally assembled). The second address is the xt (execution token), or entry point, of your new word. This will be your xt_xxxx label for your word. The third address is the end of your routine, just before the RTS instruction. You will use your z_xxxx label here. The xt_xxxx and z_xxxx are used as the bounds of your word if it ends up being natively compiled.

In the sample headers above, you can see that `drop` links to `dup` as the next word, and `dup` links to `swap` (not shown) as the next word. When you go to add your own word, you will need to adjust these linkages.

The last line is the actual name of the word, as it will be typed in forth, in lowercase. It uses the 64tass `.text` directive and 64tass allows literal strings, so you can just put the name of your word in double-quotes. If your word has a double-quote in it, look up `nt_s_quote` in the headers to see how this is handled.

Although Tali is not case-sensitive, all words in the dictionary headers **must be in lowercase** or Tali will not be able to find them. The length of this string also needs to match the length given as the first byte, or Tali will not be able to find this word.

As an example, we'll add the words `star` and `is` from the previous examples. Technically, `is` is already in the dictionary, but this example will show you how to create the header for a regular word (`star`) and for one that requires one of the status flags (`is`).

```
nt_drop:
        .byte 4, 0
        .word nt_star_word, xt_drop, z_drop
        .text "drop"

nt_star_word:
        .byte 4, 0
        .word nt_is, xt_star_word, z_star_word
        .text "star"

nt_is:
        .byte 2, IM
        .word nt_dup, xt_is, z_is
        .text "is"
nt_dup:
        .byte 3, 0
        .word nt_swap, xt_dup, z_dup
        .text "dup"
```

The first thing to note is the updated linked list of words. In order to put the new words between `drop` and `dup`, we make `drop` link to `star`, which then links to `is`, and that links back to `dup`. If you use the `words` command, you will find the new words near the beginning of the list.

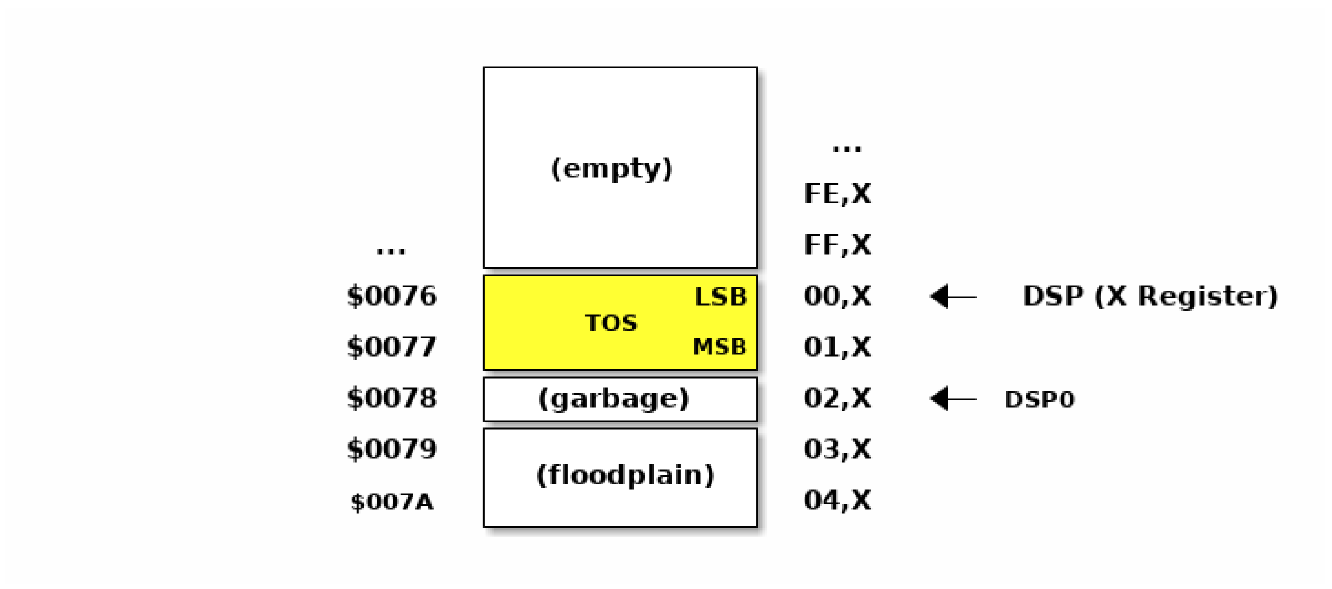
The second thing to note is the status byte of each word. If the word doesn't need any special status, then just use 0. Neither of our added words contain the JMP instruction (branches are OK, but JMP is not), so neither is required to carry the NN (Never Native) flag. The word `is`, in it's original Forth form, was marked as an immediate word, and we do that by putting the IM flag on it here in the dictionary header.

Code Cheat Sheets

> Programming computers can be crazy-making. [LB2]
>
> — Leo Brodie, Thinking Forth

The Stack Drawing

This is your friend and should probably go on your wall or something.



Coding Idioms

> The first modern FORTH was coded in FORTRAN. Shortly thereafter it was recoded in assembler. Much later it was coded in FORTH. [CHM2]
>
> — Charles Moore, The Evolution of FORTH

While coding a Forth, there are certain assembler fragments that get repeated over and over again. These could be included as macros, but that can make the code harder to read for somebody only familiar with basic assembly.

Some of these fragments could be written in other variants, such as the "push value" version, which could increment the DSP twice before storing a value. We try to keep these in the same sequence (a "dialect" or "code mannerism" if you will) so we have the option of adding code analysis tools later.

- `drop` cell of top of the Data Stack

```
                inx
                inx
```

- `push` a value to the Data Stack. Remember the Data Stack Pointer (DSP, the X register of the 65c02) points to the LSB of the TOS value.

```
                dex
                dex
                lda <LSB>      ; or pla, jsr key_a, etc.
                sta 0,x
                lda <MSB>      ; or pla, jsr key_a, etc.
                sta 1,x
```

- pop a value off the Data Stack

```
                lda 0,x
                sta <LSB>      ; or pha, jsr emit_a, etc
                lda 1,x
                sta <MSB>      ; or pha, jsr emit_a, etc
                inx
                inx
```

vim Shortcuts

One option for these is to add abbreviations to your favorite editor, which should of course be vim, because vim is cool. There are examples farther down. They all assume that auto-indent is on and we are two tabs into the code, and use `#` at the end of the abbreviation to keep them separate from the normal words. My `~/.vimrc` file contains the following lines for work on `.asm` files:

```
ab drop# inx<tab><tab>; drop<cr>inx<cr><left>
ab push# dex<tab><tab>; push<cr>dex<cr>lda $<LSB><cr>sta $00,x<cr>lda $<MSB><cr>sta
$01,x<cr><up><up><u>
ab pop# lda $00,x<tab><tab>; pop<cr>sta $<LSB><cr>lda $01,x<cr>sta
$<MSB><cr>inx<cr>inx<cr><up><up><up>>
```

Future and Long-Term plans

Scot has moved on to bigger things (eg. processors with more bits). Sam continues to provide support and bugfixes and maintains the current repository. Help is also generally available at the 6502.org Users Forum in the Forth category. http://forum.6502.org/viewforum.php?f=9

See the GitHub page for further details. https://github.com/SamCoVT/TaliForth2

Appendix

Glossary

Error determining name on line: ; ## KEY? (— char) "Return true if a character is available"

`!`	*ANS core* (n addr —) "Store TOS in memory" https://forth-standard.org/standard/core/Store
`#`	*ANS core* (ud — ud) "Add character to pictured output string" https://forth-standard.org/standard/core/num Add one char to the beginning of the pictured output string.
`#>`	*ANS core* (d — addr u) "Finish pictured number conversion" https://forth-standard.org/standard/core/num-end Finish conversion of pictured number string, putting address and length on the Data Stack.
`#s`	*ANS core* (d — addr u) "Completely convert pictured output" https://forth-standard.org/standard/core/numS Completely convert number for pictured numerical output.
`'`	*ANS core* ("name" — xt) "Return a word's execution token (xt)" https://forth-standard.org/standard/core/Tick
`(`	*ANS core* (—) "Discard input up to close paren (comment)" http://forth-standard.org/standard/core/p
`*`	*ANS core* (n n — n) "16*16 -→ 16 " https://forth-standard.org/standard/core/Times Multiply two signed 16 bit numbers, returning a 16 bit result.
`*/`	*ANS core* (n1 n2 n3 — n4) "n1 * n2 / n3 -→ n" https://forth-standard.org/standard/core/TimesDiv Multiply n1 by n2 and divide by n3, returning the result without a remainder. This is */MOD without the mod.
`*/mod`	*ANS core* (n1 n2 n3 — n4 n5) "n1 * n2 / n3 -→ n-mod n" https://forth-standard.org/standard/core/TimesDivMOD Multiply n1 by n2 producing the intermediate double-cell result d. Divide d by n3 producing the single-cell remainder n4 and the single-cell quotient n5.
`+`	*ANS core* (n n — n) "Add TOS and NOS" https://forth-standard.org/standard/core/Plus
`+!`	*ANS core* (n addr —) "Add number to value at given address" https://forth-standard.org/standard/core/PlusStore
`+loop`	*ANS core* (—) "Finish loop construct" https://forth-standard.org/standard/core/PlusLOOP

`,`	*ANS core* (n —) "Allot and store one cell in memory" https://forth-standard.org/standard/core/Comma Store TOS at current place in memory.
`-`	*ANS core* (n n — n) "Subtract TOS from NOS" https://forth-standard.org/standard/core/Minus
`-leading`	*Tali String* (addr1 u1 — addr2 u2) "Remove leading spaces" Remove leading whitespace. This is the reverse of -TRAILING
`-rot`	*Gforth* (a b c — c a b) "Rotate upwards" http://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Data-stack.html
`-trailing`	*ANS string* (addr u1 — addr u2) "Remove trailing spaces" https://forth-standard.org/standard/string/MinusTRAILING Remove trailing spaces
`.`	*ANS core* (u —) "Print TOS" https://forth-standard.org/standard/core/d
`."`	*ANS core ext* ("string" —) "Print string from compiled word" https://forth-standard.org/standard/core/Dotq Compile string that is printed during run time. ANS Forth wants this to be compile-only, even though everybody and their friend uses it for everything. We follow the book here, and recommend `.(` for general printing.
`.(`	*ANS core* (—) "Print input up to close paren .(comment)" http://forth-standard.org/standard/core/Dotp
`.r`	*ANS core ext* (n u —) "Print NOS as unsigned number with TOS with" https://forth-standard.org/standard/core/DotR
`.s`	*ANS tools* (—) "Print content of Data Stack" https://forth-standard.org/standard/tools/DotS Print content of Data Stack non-distructively. We follow the format of Gforth and print the number of elements first in brackets, followed by the Data Stack content (if any).
`/`	*ANS core* (n1 n2 — n) "Divide NOS by TOS" https://forth-standard.org/standard/core/Div
`/mod`	*ANS core* (n1 n2 — n3 n4) "Divide NOS by TOS with a remainder" https://forth-standard.org/standard/core/DivMOD
`/string`	*ANS string* (addr u n — addr u) "Shorten string by n" https://forth-standard.org/standard/string/DivSTRING
`0`	*Tali Forth* (— 0) "Push 0 to Data Stack" The disassembler assumes that this routine does not use Y. Note that CASE, FALSE, and FORTH-WORDLIST use the same routine to place a 0 on the data stack.

`0<`	*ANS core* (n — f) "Return a TRUE flag if TOS negative" https://forth-standard.org/standard/core/Zeroless
`0<>`	*ANS core ext* (m — f) "Return TRUE flag if not zero" https://forth-standard.org/standard/core/Zerone
`0=`	*ANS core* (n — f) "Check if TOS is zero" https://forth-standard.org/standard/core/ZeroEqual
`0>`	*ANS core ext* (n — f) "Return a TRUE flag if TOS is positive" https://forth-standard.org/standard/core/Zeromore
`1`	*Tali Forth* (— n) "Push the number 1 to the Data Stack" This is also the code for EDITOR-WORDLIST
`1+`	*ANS core* (u — u+1) "Increase TOS by one" https://forth-standard.org/standard/core/OnePlus
`1-`	*ANS core* (u — u-1) "Decrease TOS by one" https://forth-standard.org/standard/core/OneMinus
`2`	*Tali Forth* (— u) "Push the number 2 to stack"
`2!`	*ANS core* (n1 n2 addr —) "Store two numbers at given address" https://forth-standard.org/standard/core/TwoStore Stores so n2 goes to addr and n1 to the next consecutive cell. Is equivalent to `SWAP OVER ! CELL+ !`
`2*`	*ANS core* (n — n) "Multiply TOS by two" https://forth-standard.org/standard/core/TwoTimes
`2/`	*ANS core* (n — n) "Divide TOS by two" https://forth-standard.org/standard/core/TwoDiv
`2>r`	*ANS core ext* (n1 n2 —)(R: — n1 n2 "Push top two entries to Return Stack" https://forth-standard.org/standard/core/TwotoR Push top two entries to Return Stack.
`2@`	*ANS core* (addr — n1 n2) "Fetch the cell pair n1 n2 stored at addr" https://forth-standard.org/standard/core/TwoFetch Note n2 stored at addr and n1 in the next cell — in our case, the next two bytes. This is equvalent to `DUP CELL+ @ SWAP @`
`2constant`	*ANS double* (C: d "name" —) (— d) "Create a constant for a double word" https://forth-standard.org/standard/double/TwoCONSTANT
`2drop`	*ANS core* (n n —) "Drop TOS and NOS" https://forth-standard.org/standard/core/TwoDROP
`2dup`	*ANS core* (a b — a b a b) "Duplicate first two stack elements" https://forth-standard.org/standard/core/TwoDUP

`2literal`	*ANS double* (C: d —) (— d) "Compile a literal double word" https://forth-standard.org/standard/double/TwoLITERAL Shares code with xt_sliteral for compiling a double word
`2over`	*ANS core* (d1 d2 — d1 d2 d1) "Copy double word NOS to TOS" https://forth-standard.org/standard/core/TwoOVER
`2r>`	*ANS core ext* (— n1 n2) (R: n1 n2 —) "Pull two cells from Return Stack" https://forth-standard.org/standard/core/TwoRfrom Pull top two entries from Return Stack.
`2r@`	*ANS core ext* (— n n) "Copy top two entries from Return Stack" https://forth-standard.org/standard/core/TwoRFetch
`2swap`	*ANS core* (n1 n2 n3 n4 — n3 n4 n1 n1) "Exchange two double words" https://forth-standard.org/standard/core/TwoSWAP
`2variable`	*ANS double* ("name" —) "Create a variable for a double word" https://forth-standard.org/standard/double/TwoVARIABLE The variable is not initialized to zero.
`:`	*ANS core* ("name" —) "Start compilation of a new word" https://forth-standard.org/standard/core/Colon
`:NONAME`	*ANS core* (—) "Start compilation of a new word"" https://forth-standard.org/standard/core/ColonNONAME Compile a word with no nt. ";" will put its xt on the stack.
`;`	*ANS core* (—) "End compilation of new word" https://forth-standard.org/standard/core/Semi End the compilation of a new word into the Dictionary.
`<`	*ANS core* (n m — f) "Return true if NOS < TOS" https://forth-standard.org/standard/core/less
`<#`	*ANS core* (—) "Start number conversion" https://forth-standard.org/standard/core/num-start Start the process to create pictured numeric output.
`<>`	*ANS core ext* (n m — f) "Return a true flag if TOS != NOS" https://forth-standard.org/standard/core/ne
`=`	*ANS core* (n n — f) "See if TOS and NOS are equal" https://forth-standard.org/standard/core/Equal
`>`	*ANS core* (n n — f) "See if NOS is greater than TOS" https://forth-standard.org/standard/core/more

`>body`	*ANS core* (xt — addr) "Return a word's Code Field Area (CFA)" https://forth-standard.org/standard/core/toBODY Given a word's execution token (xt), return the address of the start of that word's parameter field (PFA). This is defined as the address that HERE would return right after CREATE.
`>in`	*ANS core* (— addr) "Return address of the input pointer"
`>number`	*ANS core* (ud addr u — ud addr u) "Convert a number" https://forth-standard.org/standard/core/toNUMBER Convert a string to a double number. Logic here is based on the routine by Phil Burk of the same name in pForth, see https://github.com/philburk/pforth/blob/master/fth/numberio.fth for the original Forth code. We arrive here from NUMBER which has made sure that we don't have to deal with a sign and we don't have to deal with a dot as a last character that signalizes double - this should be a pure number string.
`>order`	*Gforth search* (wid —) "Add wordlist at beginning of search order" https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Word-Lists.html
`>r`	*ANS core* (n —)(R: — n) "Push TOS to the Return Stack" https://forth-standard.org/standard/core/toR This word is handled differently for native and for subroutine coding, see `COMPILE,`. This is a complile-only word.
`?`	*ANS tools* (addr —) "Print content of a variable" https://forth-standard.org/standard/tools/q
`?do`	*ANS core ext* (C: —) (limit start —) "Conditional loop start" https://forth-standard.org/standard/core/qDO
`?dup`	*ANS core* (n — 0 | n n) "Duplicate TOS non-zero" https://forth-standard.org/standard/core/qDUP
`@`	*ANS core* (addr — n) "Push cell content from memory to stack" https://forth-standard.org/standard/core/Fetch
`[`	*ANS core* (—) "Enter interpretation state" https://forth-standard.org/standard/core/Bracket This is an immediate and compile-only word
`[']`	*ANS core* (—) "Store xt of following word during compilation" https://forth-standard.org/standard/core/BracketTick
`[char]`	*ANS core* ("c" —) "Compile character" https://forth-standard.org/standard/core/BracketCHAR Compile the ASCII value of a character as a literal. This is an immediate, compile-only word.
`\`	*ANS block ext* (—) "Ignore rest of line" https://forth-standard.org/standard/block/bs

`]`	*ANS core* (—) "Enter the compile state" https://forth-standard.org/standard/right-bracket This is an immediate word.
`abort`	*ANS core* (—) "Reset the Data Stack and restart the CLI" https://forth-standard.org/standard/core/ABORT Clear Data Stack and continue into QUIT. We can jump here via subroutine if we want to because we are going to reset the 65c02's stack pointer (the Return Stack) anyway during QUIT. Note we don't actually delete the stuff on the Data Stack.
`abort"`	*ANS core* ("string" —) "If flag TOS is true, ABORT with message" https://forth-standard.org/standard/core/ABORTq Abort and print a string.
`abs`	*ANS core* (n — u) "Return absolute value of a number" https://forth-standard.org/standard/core/ABS Return the absolute value of a number.
`accept`	*ANS core* (addr n — n) "Receive a string of characters from the keyboard" https://forth-standard.org/standard/core/ACCEPT Receive a string of at most n1 characters, placing them at addr. Return the actual number of characters as n2. Characters are echoed as they are received. ACCEPT is called by REFILL in modern Forths.
`action-of`	*ANS core ext* ("name" — xt) "Get named deferred word's xt" http://forth-standard.org/standard/core/ACTION-OF
`again`	*ANS core ext* (addr —) "Code backwards branch to address left by BEGIN" https://forth-standard.org/standard/core/AGAIN
`align`	*ANS core* (—) "Make sure CP is aligned on word size" https://forth-standard.org/standard/core/ALIGN On a 8-bit machine, this does nothing. ALIGNED uses this routine as well, and also does nothing
`aligned`	*ANS core* (addr — addr) "Return the first aligned address" https://forth-standard.org/standard/core/ALIGNED
`allot`	*ANS core* (n —) "Reserve or release memory" https://forth-standard.org/standard/core/ALLOT Reserve a certain number of bytes (not cells) or release them. If n = 0, do nothing. If n is negative, release n bytes, but only to the beginning of the Dictionary. If n is positive (the most common case), reserve n bytes, but not past the end of the Dictionary. See http://forth-standard.org/standard/core/ALLOT
`allow-native`	*Tali Forth* (—) "Flag last word to allow native compiling"
`also`	*ANS search ext* (—) "Make room in the search order for another wordlist" http://forth-standard.org/standard/search/ALSO
`always-native`	*Tali Forth* (—) "Flag last word as always natively compiled"

`and`	*ANS core* (n n — n) "Logically AND TOS and NOS" https://forth-standard.org/standard/core/AND
`assembler-wordlist`	*Tali Assembler* (— u) "WID for the Assembler wordlist" Commonly used like `assembler-wordlist >order` to add the assembler words to the search order so they can be used. See the tutorial on Wordlists and the Search Order for more information.
`at-xy`	*ANS facility* (n m —) "Move cursor to position given" https://forth-standard.org/standard/facility/AT-XY On an ANSI compatible terminal, place cursor at row n colum m. ANSI code is ESC[<n>;<m>H
`base`	*ANS core* (— addr) "Push address of radix base to stack" https://forth-standard.org/standard/core/BASE The ANS Forth standard sees the base up to 36, so we can cheat and ingore the MSB
`begin`	*ANS core* (— addr) "Mark entry point for loop" https://forth-standard.org/standard/core/BEGIN
`bell`	*Tali Forth* (—) "Emit ASCII BELL"
`bl`	*ANS core* (— c) "Push ASCII value of SPACE to stack" https://forth-standard.org/standard/core/BL
`blank`	*ANS string* (addr u —) "Fill memory region with spaces" https://forth-standard.org/standard/string/BLANK
`blkbuffer`	*Tali block* (— addr) "Push address of block buffer"
`block`	*ANS block* (u — a-addr) "Fetch a block into a buffer" https://forth-standard.org/standard/block/BLK https://forth-standard.org/standard/block/BLOCK
`block-c65-init`	*Tali block* (— f) "Initialize c65 simulator block storage" Set up block IO to read/write to/from c65 block file. Run simulator with a writable block file option e.g. `touch blocks.dat; c65/c65 -b blocks.dat -r taliforth-py65mon.bin` Returns true if c65 block storage is available and false otherwise.
`block-ramdrive-init`	*Tali block* (u —) "Create a ramdrive for blocks" Create a RAM drive, with the given number of blocks, in the dictionary along with setting up the block words to use it. The read/write routines do not provide bounds checking. Expected use: `4 block-ramdrive-init` (to create blocks 0-3)
`block-read`	*Tali block* (addr u —) "Read a block from storage (deferred word)" BLOCK-READ is a vectored word that the user needs to override with their own version to read a block from storage. The stack parameters are (buffer_address block# —).

`block-read-vector`	*Tali block* (— addr) "Address of the block-read vector" BLOCK-READ is a vectored word that the user needs to override with their own version to read a block from storage. This word gives the address of the vector so it can be replaced.
`block-write`	*Tali block* (addr u —) "Write a block to storage (deferred word)" BLOCK-WRITE is a vectored word that the user needs to override with their own version to write a block to storage. The stack parameters are (buffer_address block# —).
`block-write-vector`	*Tali block* (— addr) "Address of the block-write vector" BLOCK-WRITE is a vectored word that the user needs to override with their own version to write a block to storage. This word gives the address of the vector so it can be replaced.
`bounds`	*Gforth* (addr u — addr+u addr) "Prepare address for looping" http://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Memory-Blocks.html Given a string, return the correct Data Stack parameters for a DO/LOOP loop over its characters. This is realized as OVER + SWAP in Forth, but we do it a lot faster in assembler
`buffblocknum`	*Tali block* (— addr) "Push address of variable holding block in buffer"
`buffer`	*ANS block* (u — a-addr) "Get a buffer for a block" https://forth-standard.org/standard/block/BUFFER
`buffer:`	*ANS core ext* (u "<name>" — ; — addr) "Create an uninitialized buffer" https://forth-standard.org/standard/core/BUFFERColon Create a buffer of size u that puts its address on the stack when its name is used.
`buffstatus`	*Tali block* (— addr) "Push address of variable holding buffer status"
`bye`	*ANS tools ext* (—) "Break" https://forth-standard.org/standard/tools/BYE
`c!`	*ANS core* (c addr —) "Store character at address given" https://forth-standard.org/standard/core/CStore
`c,`	*ANS core* (c —) "Store one byte/char in the Dictionary" https://forth-standard.org/standard/core/CComma
`c@`	*ANS core* (addr — c) "Get a character/byte from given address" https://forth-standard.org/standard/core/CFetch
`case`	*ANS core ext* (C: — 0) (—) "Conditional flow control" http://forth-standard.org/standard/core/CASE
`cell+`	*ANS core* (u — u) "Add cell size in bytes" https://forth-standard.org/standard/core/CELLPlus Add the number of bytes ("address units") that one cell needs. Since this is an 8 bit machine with 16 bit cells, we add two bytes.

`cells`	*ANS core* (u — u) "Convert cells to size in bytes" https://forth-standard.org/standard/core/CELLS
`char`	*ANS core* ("c" — u) "Convert character to ASCII value" https://forth-standard.org/standard/core/CHAR
`char+`	*ANS core* (addr — addr+1) "Add the size of a character unit to address" https://forth-standard.org/standard/core/CHARPlus
`chars`	*ANS core* (n — n) "Number of bytes that n chars need" https://forth-standard.org/standard/core/CHARS Return how many address units n chars are. Since this is an 8 bit machine, this does absolutely nothing and is included for compatibility with other Forth versions
`cleave`	*Tali Forth* (addr u — addr2 u2 addr1 u1) "Split off word from string"
`cmove`	*ANS string* (addr1 addr2 u —) "Copy bytes going from low to high" https://forth-standard.org/standard/string/CMOVE Copy u bytes from addr1 to addr2, going low to high (addr2 is larger than addr1). Based on code in Leventhal, Lance A. 6502 Assembly Language Routines", p. 201, where it is called move left".
`cmove>`	*ANS string* (add1 add2 u —) "Copy bytes from high to low" https://forth-standard.org/standard/string/CMOVEtop Based on code in Leventhal, Lance A. "6502 Assembly Language Routines", p. 201, where it is called "move right".
`cold`	*Tali Forth* (—) "Reset the Forth system" Reset the Forth system. Does not restart the kernel, use the 65c02 reset for that. Flows into ABORT.
`compare`	*ANS string* (addr1 u1 addr2 u2 — -1 | 0 | 1) "Compare two strings" https://forth-standard.org/standard/string/COMPARE Compare string1 (denoted by addr1 u1) to string2 (denoted by addr2 u2). Return -1 if string1 < string2, 0 if string1 = string2 and 1 if string1 > string2 (ASCIIbetical comparison). A string that entirely matches the beginning of the other string, but is shorter, is considered less than the longer string.
`compile,`	*ANS core ext* (xt —) "Compile xt" https://forth-standard.org/standard/core/COMPILEComma Compile the given xt in the current word definition. It is an error if we are not in the compile state. Because we are using subroutine threading, we can't use , (COMMA) to compile new words the traditional way. By default, native compiled is allowed, unless there is a NN (Never Native) flag associated. If not, we use the value NC_LIMIT (from definitions.asm) to decide if the code is too large to be natively coded: If the size is larger than NC_LIMIT, we silently use subroutine coding. If the AN (Always Native) flag is set, the word is always natively compiled.

`compile-only`	*Tali Forth* (—) "Mark most recent word as COMPILE-ONLY" Set the Compile Only flag (CO) of the most recently defined word.
`constant`	*ANS core* (n "name" —) "Define a constant" https://forth-standard.org/standard/core/CONSTANT
`count`	*ANS core* (c-addr — addr u) "Convert character string to normal format" https://forth-standard.org/standard/core/COUNT Convert old-style character string to address-length pair. Note that the length of the string c-addr is stored in character length (8 bit), not cell length (16 bit). This is rarely used these days, though COUNT can also be used to step through a string character by character.
`cr`	*ANS core* (—) "Print a line feed" https://forth-standard.org/standard/core/CR
`create`	*ANS core* ("name" —) "Create Dictionary entry for 'name'" https://forth-standard.org/standard/core/CREATE
`d+`	*ANS double* (d d — d) "Add two double-celled numbers" https://forth-standard.org/standard/double/DPlus
`d-`	*ANS double* (d d — d) "Subtract two double-celled numbers" https://forth-standard.org/standard/double/DMinus
`d.`	*ANS double* (d —) "Print double" http://forth-standard.org/standard/double/Dd
`d.r`	*ANS double* (d u —) "Print double right-justified u wide" http://forth-standard.org/standard/double/DDotR Based on the Forth code : D.R >R TUCK DABS <# #S ROT SIGN #> R> OVER - SPACES TYPE
`d>s`	*ANS double* (d — n) "Convert a double number to single" https://forth-standard.org/standard/double/DtoS Though this is basically just DROP, we keep it separate so we can test for underflow
`dabs`	*ANS double* (d — d) "Return the absolute value of a double" https://forth-standard.org/standard/double/DABS
`decimal`	*ANS core* (—) "Change radix base to decimal" https://forth-standard.org/standard/core/DECIMAL
`defer`	*ANS core ext* ("name" —) "Create a placeholder for words by name" https://forth-standard.org/standard/core/DEFER Reserve an name that can be linked to various xt by IS.
`defer!`	*ANS core ext* (xt2 x1 —) "Set xt1 to execute xt2" http://forth-standard.org/standard/core/DEFERStore

`defer@`	*ANS core ext* (xt1 — xt2) "Get the current XT for a deferred word" http://forth-standard.org/standard/core/DEFERFetch
`definitions`	*ANS search* (—) "Make first wordlist in search order the current wordlist"
`depth`	*ANS core* (— u) "Get number of cells (not bytes) used by stack" https://forth-standard.org/standard/core/DEPTH
`digit?`	*Tali Forth* (char — u f | char f) "Convert ASCII char to number" Inspired by the pForth instruction DIGIT, see https://github.com/philburk/pforth/blob/master/fth/numberio.fth Rewritten from DIGIT>NUMBER in Tali Forth. Note in contrast to pForth, we get the base (radix) ourselves instead of having the user provide it. There is no standard name for this routine, which itself is not ANS; we use DIGIT? following pForth and Gforth.
`disasm`	*Tali Forth* (addr u —) "Disassemble a block of memory" Convert a segment of memory to assembler output. This word is vectored so people can add their own disassembler. Natively, this produces Simpler Assembly Notation (SAN) code, see the section on The Disassembler in the manual and the file disassembler.asm for more details.
`dnegate`	*ANS double* (d — d) "Negate double cell number" https://forth-standard.org/standard/double/DNEGATE
`do`	*ANS core* (C: —) (limit start —) "Start a loop" https://forth-standard.org/standard/core/DO
`does>`	*ANS core* (—) "Add payload when defining new words" https://forth-standard.org/standard/core/DOES Create the payload for defining new defining words. See http://www.bradrodriguez.com/papers/moving3.htm and the Developer Guide in the manual for a discussion of DOES>'s internal workings. This uses tmp1 and tmp2.
`drop`	*ANS core* (u —) "Pop top entry on Data Stack" https://forth-standard.org/standard/core/DROP
`dump`	*ANS tools* (addr u —) "Display a memory region" https://forth-standard.org/standard/tools/DUMP
`dup`	*ANS core* (u — u u) "Duplicate TOS" https://forth-standard.org/standard/core/DUP
`ed:`	*Tali Forth* (— u) "Line-based editor" Start the line-based editor ed6502. See separate file ed.asm or the manual for details.

`editor-wordlist`	*Tali Editor* (— u) "WID for the Editor wordlist" Commonly used like `editor-wordlist >order` to add the editor words to the search order so they can be used. This will need to be done before any of the words marked "Tali Editor" can be used. See the tutorial on Wordlists and the Search Order for more information.
`el`	*Tali Editor* (line# —) "Erase the given line number"
`else`	*ANS core* (C: orig — orig') (—) "Conditional flow control" http://forth-standard.org/standard/core/ELSE
`emit`	*ANS core* (char —) "Print character to current output" https://forth-standard.org/standard/core/EMIT Run-time default for EMIT. The user can revector this by changing the value of the OUTPUT variable. We ignore the MSB completely, and do not check to see if we have been given a valid ASCII character. Don't make this native compile.
`empty-buffers`	*ANS block ext* (—) "Empty all buffers without saving" https://forth-standard.org/standard/block/EMPTY-BUFFERS
`endcase`	*ANS core ext* (C: case-sys —) (x —) "Conditional flow control" http://forth-standard.org/standard/core/ENDCASE
`endof`	*ANS core ext* (C: case-sys1 of-sys1-- case-sys2) (—) "Conditional flow control" http://forth-standard.org/standard/core/ENDOF This is a dummy entry, the code is shared with ELSE
`enter-screen`	*Tali Editor* (scr# —) "Enter all lines for given screen"
`environment?`	*ANS core* (addr u — 0 | i*x true) "Return system information" https://forth-standard.org/standard/core/ENVIRONMENTq
`erase`	*ANS core ext* (addr u —) "Fill memory region with zeros" https://forth-standard.org/standard/core/ERASE Note that ERASE works with "address" units (bytes), not cells.
`erase-screen`	*Tali Editor* (scr# —) "Erase all lines for given screen"
`evaluate`	*ANS core* (addr u —) "Execute a string" https://forth-standard.org/standard/core/EVALUATE Set SOURCE-ID to -1, make addr u the input source, set >IN to zero. After processing the line, revert to old input source. We use this to compile high-level Forth words and user-defined words during start up and cold boot. In contrast to ACCEPT, we need to, uh, accept more than 255 characters here, even though it's a pain in the 8-bit.
`execute`	*ANS core* (xt —) "Jump to word based on execution token" https://forth-standard.org/standard/core/EXECUTE

`execute-parsing`	*Gforth* (addr u xt —) "Pass a string to a parsing word" https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/The-Input-Stream.html Execute the parsing word defined by the execution token (xt) on the string as if it were passed on the command line. See the file tests/tali.fs for examples.
`exit`	*ANS core* (—) "Return control to the calling word immediately" https://forth-standard.org/standard/core/EXIT If we're in a loop, user should UNLOOP first to clean up any loop control. This should be natively compiled.
`false`	*ANS core ext* (— f) "Push flag FALSE to Data Stack" https://forth-standard.org/standard/core/FALSE
`fill`	*ANS core* (addr u char —) "Fill a memory region with a character" https://forth-standard.org/standard/core/FILL Fill u bytes of memory with char starting at addr. Note that this works on bytes, not on cells. On an 8-bit machine such as the 65c02, this is a serious pain in the rear. It is not defined what happens when we reach the end of the address space
`find`	*ANS core* (caddr — addr 0 | xt 1 | xt -1) "Find word in Dictionary" https://forth-standard.org/standard/core/FIND Included for backwards compatibility only, because it still can be found in so may examples. It should, however, be replaced by FIND-NAME. Counted string either returns address with a FALSE flag if not found in the Dictionary, or the xt with a flag to indicate if this is immediate or not. FIND is a wrapper around FIND-NAME, we get this all over with as quickly as possible. See https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Word-Lists.html https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Name-token.html
`find-name`	*Gforth* (addr u — nt|0) "Get the name token of input word"
`flush`	*ANS block* (—) "Save dirty buffers and empty buffers" https://forth-standard.org/standard/block/FLUSH
`fm/mod`	*ANS core* (d n1 — rem n2) "Floored signed division" https://forth-standard.org/standard/core/FMDivMOD Note that by default, Tali Forth uses SM/REM for most things.
`forth`	*ANS search ext* (—) "Replace first WID in search order with Forth-Wordlist" https://forth-standard.org/standard/search/FORTH
`forth-wordlist`	*ANS search* (— u) "WID for the Forth Wordlist" https://forth-standard.org/standard/search/FORTH-WORDLIST This is a dummy entry, the actual code is shared with ZERO.

`get-current`	*ANS search* (— wid) "Get the id of the compilation wordlist" https://forth-standard.org/standard/search/GET-CURRENT
`get-order`	*ANS search* (— wid_n .. wid_1 n) "Get the current search order" https://forth-standard.org/standard/search/GET-ORDER
`havekey`	*Tali Forth* (— addr) "Return address of key? vector"
`here`	*ANS core* (— addr) "Put Compiler Pointer on Data Stack" https://forth-standard.org/standard/core/HERE This code is also used by the assembler directive ARROW ("→") though as immediate and by HERE as an immediate compile word
`hex`	*ANS core ext* (—) "Change base radix to hexadecimal" https://forth-standard.org/standard/core/HEX
`hexstore`	*Tali* (addr1 u1 addr2 — u2) "Store a list of numbers" Given a string addr1 u1 with numbers in the current base seperated by spaces, store the numbers at the address addr2, returning the number of elements. Non-number elements are skipped, an zero-length string produces a zero output.
`hold`	*ANS core* (char —) "Insert character at current output" https://forth-standard.org/standard/core/HOLD Insert a character at the current position of a pictured numeric output string on https://github.com/philburk/pforth/blob/master/fth/numberio.fth
`i`	*ANS core* (— n) "Copy loop counter to stack" https://forth-standard.org/standard/core/I See definitions.asm and the Control Flow section of the manual.
`if`	*ANS core* (C: — orig) (flag —) "Conditional flow control" http://forth-standard.org/standard/core/IF
`immediate`	*ANS core* (—) "Mark most recent word as IMMEDIATE" https://forth-standard.org/standard/core/IMMEDIATE Make sure the most recently defined word is immediate. Will only affect the last word in the dictionary. Note that if the word is defined in ROM, this will have no affect, but will not produce an error message.
`input`	*Tali Forth* (— addr) "Return address of input vector"
`input>r`	*Tali Forth* (—) (R: — n n n n) "Save input state to the Return Stack" Save the current input state as defined by insrc, cib, ciblen, and toin to the Return Stack. Used by EVALUTE.
`int>name`	*Tali Forth* (xt — nt) "Get name token from execution token" www.complang.tuwien.ac.at/forth/gforth/Docs-html/Name-token.html This is called >NAME in Gforth, but we change it to INT>NAME to match NAME>INT

`invert`	*ANS core* (n — n) "Complement of TOS" https://forth-standard.org/standard/core/INVERT
`is`	*ANS core ext* (xt "name" —) or (C: "name") "Set named word to execute xt" http://forth-standard.org/standard/core/IS
`j`	*ANS core* (— n) "Copy second loop counter to stack" https://forth-standard.org/standard/core/J Copy second loop counter from Return Stack to stack. Note we use a fudge factor for loop control; see the Control Flow section of the manual for more details.
`key`	*ANS core* (— char) "Get one character from the input"
`l`	*Tali Editor* (—) "List the current screen" note "l" is used by LIST in the block words
`latestnt`	*Tali Forth* (— nt) "Push most recent nt to the stack" www.complang.tuwien.ac.at/forth/gforth/Docs-html/Name-token.html The Gforth version of this word is called LATEST
`latestxt`	*Gforth* (— xt) "Push most recent xt to the stack" http://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Anonymous-Definitions.html
`leave`	*ANS core* (—) "Leave DO/LOOP construct" https://forth-standard.org/standard/core/LEAVE Note that this does not work with anything but a DO/LOOP in contrast to other versions such as discussed at http://blogs.msdn.com/b/ashleyf/archive/2011/02/06/loopty-do-i-loop.aspx
`line`	*Tali Editor* (line# — c-addr) "Turn a line number into address in current screen"
`list`	*ANS block ext* (scr# —) "List the given screen" https://forth-standard.org/standard/block/LIST
`literal`	*ANS core* (n —) "Store TOS to be push on stack during runtime" https://forth-standard.org/standard/core/LITERAL Compile-only word to store TOS so that it is pushed on stack during runtime. This is a immediate, compile-only word. At runtime, it works by calling literal_runtime by compling JSR LITERAL_RT.
`load`	*ANS block* (scr# —) "Load the Forth code in a screen/block" https://forth-standard.org/standard/block/LOAD
`loop`	*ANS core* (—) "Finish loop construct" https://forth-standard.org/standard/core/LOOP Compile-time part of LOOP. This is specialized to increment by one.

`lshift`	*ANS core* (x u — u) "Shift TOS left" https://forth-standard.org/standard/core/LSHIFT
`m*`	*ANS core* (n n — d) "16 * 16 --> 32" https://forth-standard.org/standard/core/MTimes Multiply two 16 bit numbers, producing a 32 bit result. All values are signed. Adapted from FIG Forth for Tali Forth.
`m*/`	*ANS double* (d1 n1 n2 — d2) "Multiply d1 by n1 and divide by n2. Note n2 may be negative." https://forth-standard.org/standard/double/MTimesDiv From All About FORTH, MVP-Forth, public domain, from this forth code which is modified slightly for Tali2: DDUP XOR SWAP ABS >R SWAP ABS >R OVER XOR ROT ROT DABS SWAP R@ UM* ROT R> UM* ROT 0 D+ R@ UM/MOD ROT ROT R> UM/MOD SWAP DROP SWAP ROT 0< if dnegate then
`marker`	*ANS core ext* ("name" —) "Create a deletion boundary" https://forth-standard.org/standard/core/MARKER This word replaces FORGET in earlier Forths. Old entries are not actually deleted, but merely overwritten by restoring CP and DP. Run the named word at a later time to restore all of the wordlists to their state when the word was created with marker. Any words created after the marker (including the marker) will be forgotten.
`max`	*ANS core* (n n — n) "Keep larger of two numbers" https://forth-standard.org/standard/core/MAX Compare TOS and NOS and keep which one is larger. Adapted from Lance A. Leventhal "6502 Assembly Language Subroutines". Negative Flag indicates which number is larger. See also http://6502.org/tutorials/compare_instructions.html and http://www.righto.com/2012/12/the-6502-overflow-flag-explained.html
`min`	*ANS core* (n n — n) "Keep smaller of two numbers" https://forth-standard.org/standard/core/MIN Adapted from Lance A. Leventhal "6502 Assembly Language Subroutines." Negative Flag indicateds which number is larger. See http://www.righto.com/2012/12/the-6502-overflow-flag-explained.html
`mod`	*ANS core* (n1 n2 — n) "Divide NOS by TOS and return the remainder" https://forth-standard.org/standard/core/MOD
`move`	*ANS core* (addr1 addr2 u —) "Copy bytes" https://forth-standard.org/standard/core/MOVE Copy u "address units" from addr1 to addr2. Since our address units are bytes, this is just a front-end for CMOVE and CMOVE>. This is actually the only one of these three words that is in the CORE set.
`name>int`	*Gforth* (nt — xt) "Convert Name Token to Execute Token" See https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Name-token.html

`name>string`	*Gforth* (nt — addr u) "Given a name token, return string of word" http://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Name-token.html
`nc-limit`	*Tali Forth* (— addr) "Return address where NC-LIMIT value is kept"
`negate`	*ANS core* (n — n) "Two’s complement" https://forth-standard.org/standard/core/NEGATE
`never-native`	*Tali Forth* (—) "Flag last word as never natively compiled"
`nip`	*ANS core ext* (b a — a) "Delete NOS" https://forth-standard.org/standard/core/NIP
`number`	*Tali Forth* (addr u — u | d) "Convert a number string" Convert a number string to a double or single cell number. This is a wrapper for >NUMBER and follows the convention set out in the Forth Programmer’s Handbook" (Conklin & Rather) 3rd edition p. 87. Based in part on the "Starting Forth" code https://www.forth.com/starting-forth/10-input-output-operators/ Gforth uses S>NUMBER? and S>UNUMBER? which return numbers and a flag https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/Number-Conversion.html Another difference to Gforth is that we follow ANS Forth that the dot to signal a double cell number is required to be the last character of the string.
`o`	*Tali Editor* (line# —) "Overwrite the given line"
`of`	*ANS core ext* (C: — of-sys) (x1 x2 — |x1) "Conditional flow control" http://forth-standard.org/standard/core/OF
`only`	*ANS search ext* (—) "Set earch order to minimum wordlist" https://forth-standard.org/standard/search/ONLY
`or`	*ANS core* (m n — n) "Logically OR TOS and NOS" https://forth-standard.org/standard/core/OR
`order`	*ANS core* (—) "Print current word order list and current WID" https://forth-standard.org/standard/search/ORDER Note the search order is displayed from first search to last searched and is therefore exactly the reverse of the order in which Forth stacks are displayed.
`output`	*Tali Forth* (— addr) "Return the address of the EMIT vector address"
`over`	*ANS core* (b a — b a b) "Copy NOS to TOS" https://forth-standard.org/standard/core/OVER

pad	*ANS core ext* (— addr) "Return address of user scratchpad" https://forth-standard.org/standard/core/PAD Return address to a temporary area in free memory for user. Must be at least 84 bytes in size (says ANS). It is located relative to the compile area pointer (CP) and therefore varies in position. This area is reserved for the user and not used by the system
page	*ANS facility* (—) "Clear the screen" https://forth-standard.org/standard/facility/PAGE Clears a page if supported by ANS terminal codes. This is Clear Screen ("ESC[2J") plus moving the cursor to the top left of the screen
parse	*ANS core ext* ("name" c — addr u) "Parse input with delimiter character" https://forth-standard.org/standard/core/PARSE Find word in input string delimited by character given. Do not skip leading delimiters — this is the main difference to PARSE-NAME. PARSE and PARSE-NAME replace WORD in modern systems. ANS discussion http://www.forth200x.org/documents/html3/rationale.html#rat:core:PARSE
parse-name	*ANS core ext* ("name" — addr u) "Parse the input" https://forth-standard.org/standard/core/PARSE-NAME Find next word in input string, skipping leading whitespace. This is a special form of PARSE and drops through to that word. See PARSE for more detail. We use this word internally for the interpreter because it is a lot easier to use. Reference implementations at http://forth-standard.org/standard/core/PARSE-NAME and http://www.forth200x.org/reference-implementations/parse-name.fs Roughly, the word is comparable to BL WORD COUNT. — Note that though the ANS standard talks about skipping "spaces", whitespace is actually perfectly legal (see for example http://forth-standard.org/standard/usage#subsubsection.3.4.1.1). Otherwise, PARSE-NAME chokes on tabs.
pick	*ANS core ext* (n n u — n n n) "Move element u of the stack to TOS" https://forth-standard.org/standard/core/PICK Take the u-th element out of the stack and put it on TOS, overwriting the original TOS. 0 PICK is equivalent to DUP, 1 PICK to OVER. Note that using PICK is considered poor coding form. Also note that FIG Forth has a different behavior for PICK than ANS Forth.
postpone	*ANS core* (—) "Change IMMEDIATE status (it's complicated)" https://forth-standard.org/standard/core/POSTPONE Add the compilation behavior of a word to a new word at compile time. If the word that follows it is immediate, include it so that it will be compiled when the word being defined is itself used for a new word. Tricky, but very useful.

`previous`	*ANS search ext* (—) "Remove the first wordlist in the search order" http://forth-standard.org/standard/search/PREVIOUS
`quit`	*ANS core* (—) "Reset the input and get new input" https://forth-standard.org/standard/core/QUIT Rest the input and start command loop
`r>`	*ANS core* (— n)(R: n --) "Move top of Return Stack to TOS" https://forth-standard.org/standard/core/Rfrom Move Top of Return Stack to Top of Data Stack.
`r>input`	*Tali Forth* (—) (R: n n n n —) "Restore input state from Return Stack" Restore the current input state as defined by insrc, cib, ciblen, and toin from the Return Stack.
`r@`	*ANS core* (— n) "Get copy of top of Return Stack" https://forth-standard.org/standard/core/RFetch This word is Compile Only in Tali Forth, though Gforth has it work normally as well
`recurse`	*ANS core* (—) "Copy recursive call to word being defined" https://forth-standard.org/standard/core/RECURSE
`refill`	*ANS core ext* (— f) "Refill the input buffer" https://forth-standard.org/standard/core/REFILL Attempt to fill the input buffer from the input source, returning a true flag if successful. When the input source is the user input device, attempt to receive input into the terminal input buffer. If successful, make the result the input buffer, set >IN to zero, and return true. Receipt of a line containing no characters is considered successful. If there is no input available from the current input source, return false. When the input source is a string from EVALUATE, return false and perform no other action." See https://www.complang.tuwien.ac.at/forth/gforth/Docs-html/The-Input-Stream.html and Conklin & Rather p. 156. Note we don't have to care about blocks because REFILL is never used on blocks - Tali is able to evaluate the entire block as a 1024 byte string.
`repeat`	*ANS core* (C: orig dest —) (—) "Loop flow control" http://forth-standard.org/standard/core/REPEAT
`root-wordlist`	*Tali Editor* (— u) "WID for the Root (minimal) wordlist"
`rot`	*ANS core* (a b c — b c a) "Rotate first three stack entries downwards" https://forth-standard.org/standard/core/ROT Remember "R for 'Revolution'" - the bottom entry comes out on top!
`rshift`	*ANS core* (x u — x) "Shift TOS to the right" https://forth-standard.org/standard/core/RSHIFT

`s"`	*ANS core* ("string"—)(—addr u) "Store string in memory" https://forth-standard.org/standard/core/Sq Store address and length of string given, returning (addr u). ANS core claims this is compile-only, but the file set expands it to be interpreted, so it is a state-sensitive word, which in theory are evil. We follow general usage.
`s>d`	*ANS core* (u—d) "Convert single cell number to double cell" https://forth-standard.org/standard/core/StoD
`s\"`	*ANS core* ("string"—)(—addr u) "Store string in memory" https://forth-standard.org/standard/core/Seq Store address and length of string given, returning (addr u). ANS core claims this is compile-only, but the file set expands it to be interpreted, so it is a state-sensitive word, which in theory are evil. We follow general usage. This is just like S" except that it allows for some special escaped characters.
`save-buffers`	*ANS block* (—) "Save all dirty buffers to storage" https://forth-standard.org/standard/block/SAVE-BUFFERS
`scr`	*ANS block ext* (—addr) "Push address of variable holding last screen listed" https://forth-standard.org/standard/block/SCR
`search`	*ANS string* (addr1 u1 addr2 u2—addr3 u3 flag) "Search for a substring" https://forth-standard.org/standard/string/SEARCH Search for string2 (denoted by addr2 u2) in string1 (denoted by addr1 u1). If a match is found the flag will be true and addr3 will have the address of the start of the match and u3 will have the number of characters remaining from the match point to the end of the original string1. If a match is not found, the flag will be false and addr3 and u3 will be the original string1's addr1 and u1.
`search-wordlist`	*ANS search* (caddr u wid—0 | xt 1 | xt -1) "Search for a word in a wordlist" https://forth-standard.org/standard/search/SEARCH_WORDLIST
`see`	*ANS tools* ("name"—) "Print information about a Forth word" https://forth-standard.org/standard/tools/SEE SEE takes the name of a word and prints its name token (nt), execution token (xt), size in bytes, flags used, and then dumps the code and disassembles it.
`set-current`	*ANS search* (wid—) "Set the compilation wordlist" https://forth-standard.org/standard/search/SET-CURRENT
`set-order`	*ANS search* (wid_n .. wid_1 n—) "Set the current search order" https://forth-standard.org/standard/search/SET-ORDER
`sign`	*ANS core* (n—) "Add minus to pictured output" https://forth-standard.org/standard/core/SIGN

`sliteral`	*ANS string* (addr u —)(— addr u) "Compile a string for runtime" https://forth-standard.org/standard/string/SLITERAL Add the runtime for an existing string.
`sm/rem`	*ANS core* (d n1 — n2 n3) "Symmetric signed division" https://forth-standard.org/standard/core/SMDivREM Symmetric signed division. Compare FM/MOD. Based on F-PC 3.6 by Ulrich Hoffmann. See http://www.xlerb.de/uho/ansi.seq
`source`	*ANS core* (— addr u) "Return location and size of input buffer"" https://forth-standard.org/standard/core/SOURCE
`source-id`	*ANS core ext* (— n) "Return source identifier" https://forth-standard.org/standard/core/SOURCE-ID Identify the input source unless it is a block (s. Conklin & Rather p. 156). This will give the input source: 0 is keyboard, -1 ($FFFF) is character string, and a text file gives the fileid.
`space`	*ANS core* (—) "Print a single space" https://forth-standard.org/standard/core/SPACE
`spaces`	*ANS core* (u —) "Print a number of spaces" https://forth-standard.org/standard/core/SPACES
`state`	*ANS core* (— addr) "Return the address of compilation state flag" https://forth-standard.org/standard/core/STATE STATE is true when in compilation state, false otherwise. Note we do not return the state itself, but only the address where it lives. The state should not be changed directly by the user; see http://forth.sourceforge.net/standard/dpans/dpans6.htm#6.1.2250
`strip-underflow`	*Tali Forth* (— addr) "Return address where underflow flag is kept" `STRIP-UNDERFLOW` is a flag variable that determines if underflow checking should be removed during the compilation of new words. Default is false.
`swap`	*ANS core* (b a — a b) "Exchange TOS and NOS" https://forth-standard.org/standard/core/SWAP
`then`	*ANS core* (C: orig —) (—) "Conditional flow control" http://forth-standard.org/standard/core/THEN This is a dummy entry, the code is shared with xt_else
`thru`	*ANS block ext* (scr# scr# —) "Load screens in the given range" https://forth-standard.org/standard/block/THRU
`to`	*ANS core ext* (n "name" —) or ("name") "Change a value" https://forth-standard.org/standard/core/TO Gives a new value to a, uh, VALUE.

`true`	*ANS core ext* (— f) "Push TRUE flag to Data Stack" https://forth-standard.org/standard/core/TRUE
`tuck`	*ANS core ext* (b a — a b a) "Copy TOS below NOS" https://forth-standard.org/standard/core/TUCK
`type`	*ANS core* (addr u —) "Print string" https://forth-standard.org/standard/core/TYPE Works through EMIT to allow OUTPUT revectoring.
`u.`	*ANS core* (u —) "Print TOS as unsigned number" https://forth-standard.org/standard/core/Ud
`u.r`	*ANS core ext* (u u —) "Print NOS as unsigned number right-justified with TOS width" https://forth-standard.org/standard/core/UDotR
`u<`	*ANS core* (n m — f) "Return true if NOS < TOS (unsigned)" https://forth-standard.org/standard/core/Uless
`u>`	*ANS core ext* (n m — f) "Return true if NOS > TOS (unsigned)" https://forth-standard.org/standard/core/Umore
`ud.`	*Tali double* (d —) "Print double as unsigned"
`ud.r`	*Tali double* (d u —) "Print unsigned double right-justified u wide"
`um*`	*ANS core* (u u — ud) "Multiply 16 x 16 → 32" https://forth-standard.org/standard/core/UMTimes Multiply two unsigned 16 bit numbers, producing a 32 bit result. Old Forth versions such as FIG Forth call this U*
`um/mod`	*ANS core* (ud u — ur u) "32/16 → 16 division" https://forth-standard.org/standard/core/UMDivMOD Divide double cell number by single cell number, returning the quotient as TOS and any remainder as NOS. All numbers are unsigned. This is the basic division operation all others use. Based on FIG Forth code, modified by Garth Wilson, see http://6502.org/source/integers/ummodfix/ummodfix.htm
`unloop`	*ANS core* (—) "Drop current loop control block" https://forth-standard.org/standard/core/UNLOOP
`until`	*ANS core* (C: dest —) (—) "Loop flow control" http://forth-standard.org/standard/core/UNTIL
`unused`	*ANS core ext* (— u) "Return size of space available to Dictionary" https://forth-standard.org/standard/core/UNUSED UNUSED does not include the ACCEPT history buffers. Total RAM should be HERE + UNUSED + <history buffer size>, the last of which defaults to $400
`update`	*ANS block* (—) "Mark current block as dirty" https://forth-standard.org/standard/block/UPDATE

`useraddr`	*Tali Forth* (— addr) "Push address of base address of user variables"
`value`	*ANS core* (n "name" —) "Define a value" https://forth-standard.org/standard/core/VALUE
`variable`	*ANS core* ("name" —) "Define a variable" https://forth-standard.org/standard/core/VARIABLE There are various Forth definitions for this word, such as `CREATE 1 CELLS ALLOT` or `CREATE 0 ,` We use a variant of the second one so the variable is initialized to zero
`while`	*ANS core* (C: dest — orig dest) (x —) "Loop flow control" http://forth-standard.org/standard/core/WHILE
`within`	*ANS core ext* (n1 n2 n3 —) "Test n1 within range [n2, n3) or outwith [n3, n2)" https://forth-standard.org/standard/core/WITHIN
`word`	*ANS core* (char "name " — caddr) "Parse input stream" https://forth-standard.org/standard/core/WORD Obsolete parsing word included for backwards compatibility only. Do not use this, use `PARSE` or `PARSE-NAME`. Skips leading delimiters and copies word to storage area for a maximum size of 255 bytes. Returns the result as a counted string (requires COUNT to convert to modern format), and inserts a space after the string. See "Forth Programmer's Handbook" 3rd edition p. 159 and http://www.forth200x.org/documents/html/rationale.html#rat:core:PARSE for discussions of why you shouldn't be using WORD anymore.
`wordlist`	*ANS search* (— wid) "Create new wordlist (from pool of 8)" https://forth-standard.org/standard/search/WORDLIST See the tutorial on Wordlists and the Search Order for more information.
`words`	*ANS tools* (—) "Print known words from Dictionary" https://forth-standard.org/standard/tools/WORDS This is pretty much only used at the command line so we can be slow and try to save space.
`wordsize`	*Tali Forth* (nt — u) "Get size of word in bytes" Given an word's name token (nt), return the size of the word's payload size in bytes (CFA plus PFA) in bytes. Does not count the final RTS.
`xor`	*ANS core* (n n — n) "Logically XOR TOS and NOS" https://forth-standard.org/standard/core/XOR

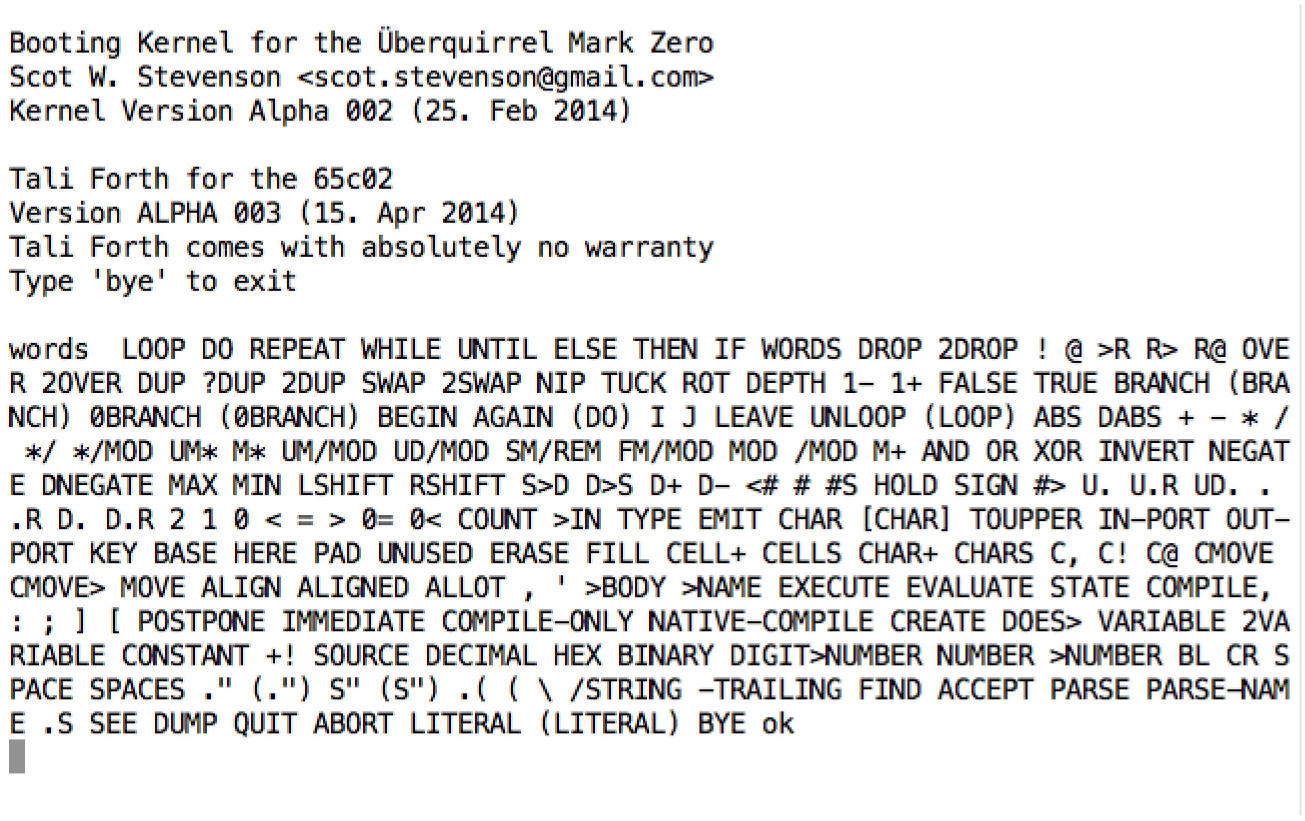
Reporting Problems

The best way to point out a bug or make any other form of a comment is on Tali Forth’s page on GitHub at https://github.com/SamCoVT/TaliForth2 There, you can "open an issue", which allows other people who might have the same problem to help even when the author is not available.

FAQ

What happened to Tali Forth 1 anyway?

Tali Forth 1, informally just Tali Forth, was my first Forth. As such, it is fondly remembered as a learning experience. You can still find it online at GitHub at https://github.com/scotws/TaliForth. When Tali Forth 2 entered BETA, Tali Forth was discontinued. It does not receive bug fixes. In fact, new bugs are not even documented.



```
Booting Kernel for the Überquirrel Mark Zero
Scot W. Stevenson <scot.stevenson@gmail.com>
Kernel Version Alpha 002 (25. Feb 2014)

Tali Forth for the 65c02
Version ALPHA 003 (15. Apr 2014)
Tali Forth comes with absolutely no warranty
Type 'bye' to exit

words  LOOP DO REPEAT WHILE UNTIL ELSE THEN IF WORDS DROP 2DROP ! @ >R R> R@ OVE
R 2OVER DUP ?DUP 2DUP SWAP 2SWAP NIP TUCK ROT DEPTH 1- 1+ FALSE TRUE BRANCH (BRA
NCH) 0BRANCH (0BRANCH) BEGIN AGAIN (DO) I J LEAVE UNLOOP (LOOP) ABS DABS + - * /
 */ */MOD UM* M* UM/MOD UD/MOD SM/REM FM/MOD MOD /MOD M+ AND OR XOR INVERT NEGAT
E DNEGATE MAX MIN LSHIFT RSHIFT S>D D>S D+ D- <# # #S HOLD SIGN #> U. U.R UD. .
.R D. D.R 2 1 0 < = > 0= 0< COUNT >IN TYPE EMIT CHAR [CHAR] TOUPPER IN-PORT OUT-
PORT KEY BASE HERE PAD UNUSED ERASE FILL CELL+ CELLS CHAR+ CHARS C, C! C@ CMOVE
CMOVE> MOVE ALIGN ALIGNED ALLOT , ' >BODY >NAME EXECUTE EVALUATE STATE COMPILE,
: ; ] [ POSTPONE IMMEDIATE COMPILE-ONLY NATIVE-COMPILE CREATE DOES> VARIABLE 2VA
RIABLE CONSTANT +! SOURCE DECIMAL HEX BINARY DIGIT>NUMBER NUMBER >NUMBER BL CR S
PACE SPACES ." (.") S" (S") .( ( \ /STRING -TRAILING FIND ACCEPT PARSE PARSE-NAM
E .S SEE DUMP QUIT ABORT LITERAL (LITERAL) BYE ok
```

Figure 4. Screenshot of the Tali Forth 1 boot screen, version Alpha 3, April 2014

Who's "Tali"?

I like the name, and we're probably not going to have any more kids I can give it to. If it sounds vaguely familiar, you're probably thinking of Tali'Zorah vas Normandy a character in the *Mass Effect* universe created by BioWare. This software has absolutely nothing to do with neither the game nor the companies and neither do I, expect that I've played the whole series and enjoyed it.[1]

And who is "Liara"?

Liara Forth is another STC Forth for the big sibling of the 6502, the 65816. Tali Forth 1 came first, then I wrote Liara with that knowledge and learned even more, and now Tali 2 is such much better for the experience. And yes, it's another *Mass Effect* character.

[1] Though I do wish they would tell us what happened to the quarian ark in *Andromeda*.

Testing Tali Forth 2

Tali Forth 2 comes with a test suite in the `tests` folder. It is based on the official ANS test code by John Hayes and was first adapted for Tali Forth by Sam Colwell.

To run the complete test, type `make test` from the main folder (this assumes a Unix-type system). Alternatively, switch to the test folder and start the `talitest.py` program with Python3. The tests should take only a very few minutes to run and produce a lot of output, including, at the end, a list of words that didn't work. A detailed list of results is saved to the file `results.txt`.

User Tests

A special test file named `user.fs` is available for users to add their own tests. The results of this will be found just before the cycle tests near the end of `results.txt`. To run only this set of tests, you can use the command:

```
./talitest.py -t user
```

in the tests folder.

Cycle Tests

The last set of tests, found in `cycles.fs`, determines cycle counts for the various built-in words. Users who are adding words may want to add cycle tests as well and there are instructions for doing that in that file. The cycle tests only work with the simulator and will not work on real hardware.

The cycle tests time (in 65C02 clock cycles) from the jsr that calls a word to the rts that returns from the word, including the jsr and rts. These cycle counts are the number of cycles if the word was used directly in interpreted mode. Some words will use more or fewer cycles depending on their input, so the cycles reported are for the input provided in the `cycles.fs` file.

The cycle tests work with some help from the py65mon simulator and extensions to it in `talitest.py`. Accesses to special addresses in the 65C02 memory map are used to start, stop, and read back the cycle counter in the simulator. A special word named `cycle_test` is created near the top of `cycles.fs` to help with this. It accepts the xt of the word you want to test (you can get the xt of any word by using the word `'`) and runs that word with the special memory accesses before and after, printing out the results.

Cycle Tests and Native Compiling

Because Tali Forth 2 has native compiling capability, small words used in a word declaration will have their assembly code compiled directly into the word being defined, rather than using a `jsr`. This means that small words will not have the overhead of a `jsr` and `rts` when they are compiled into other words.

A perfect example of that is the built-in word `ALIGN`. This word has no assembly instructions (except for an `rts`), but the cycle testing shows it takes 12 cycles. This is the number of cycles to run the word by itself, and it's the number of cycles to run a `jsr` instruction followed immediately by an `rts` instruction.

When this word is compiled into another word, however, Tali will use native compiling and will put the (empty) body of this word into the word being compiled rather than using a `jsr`. This results in 0 extra cycles for the word being defined. Twelve cycles will be saved for each small word that is natively compiled into a new definition. See the section on Native Compiling for more information.

Old Tests

During early development, testing was done by hand with a list of words that has since been placed in the `old` folder. These tests might be still useful if you are in the very early stages of developing your own Forth.

The Simpler Assembler Notation (SAN) format

This is a condensed version of the main SAN Guide at https://github.com/scotws/SAN , see there for more detail.)

Background

The Simpler Assembler Notation (SAN) for the 6502/65c02/65816 family of CPUs cleanly separates the opcode and the operand in an assembler instruction. For instance, the traditional notation

```
STA 1000,X
```

adds the marker for the X-indexed mode to the operand. Though this is not hard to read or use for the programmer on the 65c02, it makes building asssemblers and disassemblers harder. SAN keeps the mnemonic's "stem" - `STA` in this case - though it is converted to lower case. The mode is added as a "suffix" after a single dot:

```
sta.x 1000
```

In a Forth environment, this lets us trivially switch the notation to postfix. The operand is pushed to the stack like any normal number, and the mnemonic is a simple Forth word that picks it up there.

```
1000 sta.x
```

As part of SAN, Zero Page modes are explicitly indicated with a `z` in the suffix. This removes any confusion that can come from

```
STA 10          ; zero page addressing, two-byte instruction
STA 0010        ; absolut addressing, three-byte instruction
STA 010         ; really not sure what will happen
```

by replacing the instruction with (prefix notation):

```
sta 10          ; absolute addressing, three-byte instruction
sta.z 10        ; zero page addressing, two-byte instruction
```

SAN was originally invented to fix various issues with the traditional mnemonics for the 65816. The advantages for the 65c02 outside a specialized environment such as a small Forth assembler here are limited at best.

Complete list of 65c02 addressing modes

Mode	Traditional Notation	SAN (Forth Postfix)
Implied	`DEX`	`dex`
Absolute	`LDA $1000`	`1000 lda`
Accumulator	`INC A`	`inc.a`
Immediate	`LDA #$00`	`00 lda.#`
Absolute X indexed	`LDA $1000,X`	`1000 lda.x`
Absolute Y indexed	`LDA $1000,Y`	`1000 lda.y`
Absolute indirect	`JMP ($1000)`	`1000 jmp.i`
Indexed indirect	`JMP ($1000,X)`	`1000 jmp.xi`
Zero Page (DP)	`LDA $10`	`10 lda.z`
Zero Page X indexed	`LDA $10,X`	`10 lda.zx`
Zero Page Y indexed	`LDX $10,Y`	`10 ldx.zy``
Zero Page indirect	`LDA ($10)`	`10 lda.zi`
ZP indirect X indexed	`LDA ($10,X)`	`10 lda.zxi`
ZP indirect Y indexed	`LDA ($10),Y`	`10 lda.ziy`
Relative	`BRA <LABEL>`	`<LABEL> bra`

Note for indirect modes, the `i` in the suffix is at the same relative position to the index register X or Y as the closing bracket is in the traditional mode. This way, `LDA ($10,X)` turns into `lda.zxi 10` in postfix SAN, while `LDA ($10),Y` will be `lda.ziy 10`.

Thanks

Tali Forth would never have been possible without the help of a very large number of people, very few of whom I have actually met.

First, there is the crew at 6502.org who not only helped me build my own actual, working 6502 computer, but also introduced me to Forth. Tali would not exist without their inspiration, support, and feedback.

Special thanks go out to Mike Barry and Lee Pivonka, who both suggested vast improvements to the code in size, structure, and speed. And then there is Sam Colwell who contributed the invaluable test suite and a whole lot of code.

Thank you, everybody.

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Colophon

The Tali Forth 2 Manual was written with the vim editor in AsciiDoc format, formatted to HTML with AsciiDoctor, and version controlled with Git, all under Ubuntu Linux 16.04 LTS.

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