The words in a Minimal Thread Code Forth

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the inner interpreter

```
: NEXT IP )+ W MOV W )+ ) JMP ;
```

“ Now Forth was complete. And I knew it.”

Charles H. Moore,

“Forth - The Early Years”, PDP-11

The inner interpreter is Forth's *heartbeat*.

The dictionary is the Forth’s *DNA*.

Notes

In the following examples:

The names NEXT, NEST (aka DOCOL), UNNEST (aka SEMIS), are classic names for Forth inner interpreter.

Using reference ITC from FIG-Forth for PDP-11

Using PDP-11, Instruction Set Architecture (ISA)

By convention, stacks grows downward memory,

(X) indirect access, increment+ (pós)+, -decrement -(pré),

ISA order is: *operator “from”, “into”*

The ‘jump and link’ concept was used by Charles H. Moore in 70’s when --IP holds the address to next instruction--.

thread code models

STC: header | call word | sequence of “call words” | jmp EXIT

ITC: header | DOCOL | list of references to words | EXIT

DTC: header | call DOCOL | list of references to words | EXIT

MTC: header | list of references to words | EXIT

STC subroutine thread code, ITC indirect thread code

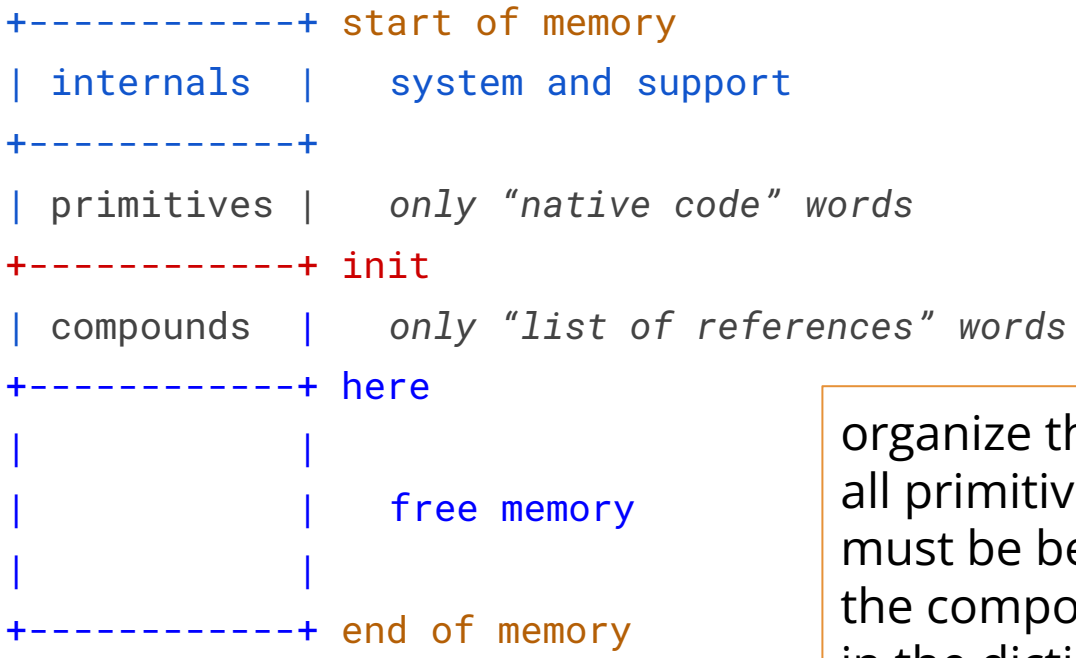
DTC direct thread code, MTC minimal thread code

DOCOL is NEST and EXIT is UNNEST

the Minimal (and direct) Thread Code

1. *Any primitive word contains only native machine code*
2. *Any compound word contains only a list of word references*
3. *All compound words have the references 'pushed and pulled' at the return stack*
4. *Any compound word should only access the return stack using >R R> R@*
5. *All primitives words must be before the compounds words in the dictionary*

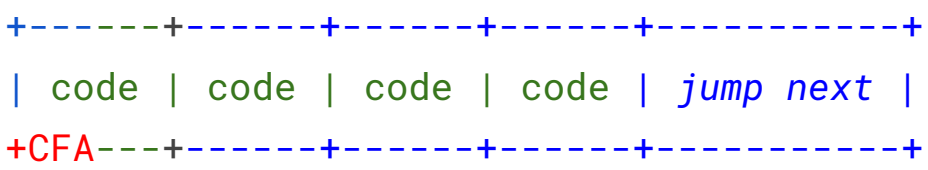
the MTC dictionary



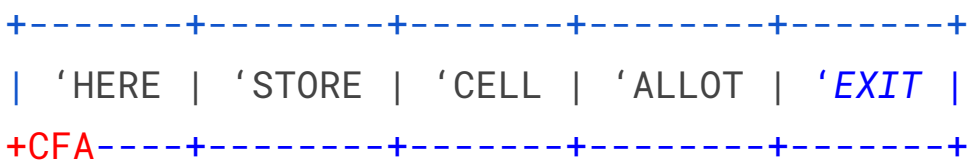
organize the dictionary:
all primitives words
must be before
the compounds words
in the dictionary

the MTC dictionary

primitive words: only native code



compound words: only list references



PS. Not showing the headers

No need “DOCOL” at CFA of compound words !

the PDP-11 code of MTC

```
unnest:  MOV (RP)+, IP      // .pull
next:    MOV (IP)+, W
pick:    CMP W, _init_      // .pick
         BMI jump
nest:    MOV IP, -(RP)      // .push
         MOV W, IP
         JMP next
jump:    JMP (W)
```

```
from ITC FIG-Forth, 1.3.3.1:

SEMIS :  MOV (RP)+, IP

NEXT :   MOV (IP)+, W
         JMP @(W)+

DOCOL :  MOV IP, -(RP)
         MOV W, IP
         JMP NEXT
```

*_init_* is the starting address of the compound words at dictionary

ITC, DTC and MTC

In ITC and DTC

1. in compound words, CFA must reference the DOCOL routine (or DOCON, DOVAR, DOLIT, DODOES, DODEFER, etc)
2. must jump twice for every compound word
   NEXT -> WORD -> DOCOL -> NEXT

In MTC

1. in compound words, CFA could reference any word
2. test all word references and jump ONLY when it is bellow the “init” address, the starting of compound words in dictionary

MTC

inside words

MTC, PDP-11

```
unnest:  MOV (RP)+, IP     // .pull
next:    MOV (IP)+, W
pick:    CMP W, init
         BMI jump
nest:    MOV IP, -(RP)     // .push
         MOV W, IP
         JMP next
jump:    JMP (W)           // .jump
```

pull, push, pick, jump

`syntax: operator from, into`

wp, word pointer, scratch
ip, link pointer, reserved
rp, return stack pointer, reserved

```
unnest:  lw IP, 0(RP)
         addi RP, RP, 1 * #CELL
next:    lw W, 0(IP)
         addi IP, IP, 1 * #CELL
pick:    BMI W, _init_, jump
nest:    addi RP, RP, -1 * CELL
         sw 0(RP), IP
         add IP, W, zero
         jal zero, next
jump:    jalr zero, 0(W)
```

MTC, Risc-V

pull, push, pick, jump

syntax: operator into, from

do not use default link register

let assembler decide offsets for
(jalr zero, zero, link)

MTC, 6502

An implementation of Minimal Thread Code (and Direct Thread Code) for 6502 CPU is at the milliforth-6502, https://github.com/agsb/milliforth-6502

The scope of milliforth-6502 is to make a near sector size (512) Forth as sectorForth and milliForth did for x86.

The original milliForth: https://github.com/fuzzballcat/milliForth

The inspirational sectorForth: https://github.com/cesarblum/sectorforth/

```
header "exit","exit"

_unnest: // .pull
     lw s6, 0(s5)
     addi s5, s5, 1*CELL
     // jal zero, _next

_next:   // .next
     lw s9, 0(s6)
     addi s6, s6, CELL

 pick:   // .pick
     bmi s9, _init_, _jump
     // jal zero, _nest

_nest:   // .push
     addi s5, s5, -1*CELL
     sw s6, 0(s5)
     add s6, s9, zero
     jal zero, _next
```

```
_jump: // .jump
     // insert debug info
     jalr zero, s9, 0

_link: // .link
     // alternative
     // insert debug info
     jal zero, _unnest

// not optimized :)
```

A inner example with RISC-V

RISC-V, R32i, word is 32 bit cell, inner interpreter
less than 12 instructions for Forth inner interpreter

Minimum Thread Code
s5, return stack (RS), ~ reserved
s6, next reference (IP), ~ reserved
s9, word reference (W), ~ free for use outside
zero, r0 register, is always zero, hardware wired
CELL is cell size in bytes

Notes

How allow further words been defined using native code, as like primitives ? MTC propose two primitives:

:$ “colon_code”, does a jump to (IP)

;$ “semis_code”, does a jump to NEXT

A primitive “colon_code” to execute native code, by doing a jump to address in IP.

A primitive “semis_code” to return to MTC engine, by doing a jump to NEXT.

compare

```
NEXT      (ITC, INSIDE CODE, EXECUTE FORTH WORD WHOSE CODE ADDRESS IS ON IP)
     MOV  (IP)+,W
     JMP  @(W)+
EXEC      (ITC, PRIMITIVE, EXECUTE FORTH WORD WHOSE CODE ADDRESS IS ON STACK)
     MOV  (S)+,W
     JMP  @(W)+
COLON_CODE (MTC, PRIMITIVE, EXECUTE NATIVE CODE WHOSE CODE ADDRESS IS IN IP)
     JMP  (IP)
SEMIS_CODE (MTC, PRIMITIVE, RETURN TO MTC ENGINE)
     JMP  NEXT
```

Easy summary

In ITC and DTC, as the inner interpreter

Always jumps to address at first cell (CFA) of word definition,

In compounds words, the CFA must be DOCOL (or DOVAR, DOCON, DOLIT, etc)

In MTC, as the inner interpreter

Only jumps when CFA is a reference to primitive word.

All primitives words must be before the compounds words in the dictionary,

In compounds words, the CFA could be any word.

Uses less memory in dictionary, without DOCOL at each word.

conclusion

When reinvent the wheel ?

MTC is a faster inner interpreter;

MTC needs little changes at thread code;

MTC uses less memory and less jumps;

MTC shortens the dictionary;

MTC effective as DTC and ITC;

Why PDP-11 ?

the PiDP-11 is a replica of the PDP-11/70, with a Raspberry Pi running the simh simulator for PDP-11/70, in a Linux Debian.

```
: NEXT IP )+ W MOV W )+ ) JMP ;
   IP )+ W  MOVis W = (IP), IP++
   W )+ ) JMP      is PC = W, W++
```

https://github.com/agsb

references

https://library.nrao.edu/public/memos/comp/CDIR_17.pdf

https://pdos.csail.mit.edu/6.828/2005/readings/pdp11-40.pdf

http://www.stackosaurus.com/figforth-1.3.3.1/FORTH.MAC

http://www.forth.org/fd/FD-V01N3.pdf

http://www.complang.tuwien.ac.at/forth/threaded-code.html

http://www.bradrodriguez.com/papers/moving1.htm

https://muforth.nimblemachines.com/threaded-code/

http://git.annexia.org/?p=jonesforth.git;a=tree

https://home.hccnet.nl/a.w.m.van.der.horst/lina.html

https://github.com/simh/simh

myself

Myself,

Geologist, Master in Geophysics,

I use computers for data acquisition and calculations,

and an electronics and circuits hobbyist.

I discovered Forth in 1980, in Byte Magazine, in the UFRJ-BR library,

and rediscovered Forth in 2019, with the Forth2020 forum.

My projects at https://github.com/agsb

Primitive Sequences of Forth

docol	call
docon	lit @
dovar	lit
douser	useraddr
dodefer	lit @ exec
dofield	lit +
dodoes	lit call

`Lit` places the next cell of dictionary at top of data stack

`Call` is a jump to subroutine in native code

`Exec` is a jump to native code

https://www.academia.edu/105385974/Primitive_sequences_in_general_purpose_Forth_programs

call or link

from PDP-11 ISA

```
JSR Ri, Src     // Jump into subroutine
     -(SP) ← Ri; Ri ← +PC; PC ← Src;
RTS             // Return from subroutine
     PC ← Ri; Ri ← (SP)+;
```

push and pull // same, only use SP, as many CPUs ISA:

```
CALL Src
     -(SP) ← Ri; Ri ← +PC; PC ← Src;
RETURN
     PC ← Ri; Ri ← (SP)+;
```

link and jump // same, do not use SP, in RISC-V ISA:

```
JAL Ri, Src
     -(SP) ← Ri; Ri ← +PC; PC ← Src;
JR Ri
     PC ← Ri; Ri ← (SP)+;
```

That’s all, folks.