```
----------------Gumball-----------------
A 4am & san inc crack         2016-06-08
-------------------. updated 2016-09-09
                   |___________________

Name: Gumball
Genre: arcade
Year: 1983
Credits:
  by Robert Cook
  concept by Doug Carlston
Publisher: Broderbund Software
Platform: Apple ][+ or later (48K)
Media: single-sided 5.25-inch floppy
OS: custom
Other versions:
  Mr. Krac-Man & The Disk Jockey
  several uncredited cracks
```

Chapter 0
In Which Various Automated Tools Fail In Interesting Ways

COPYA
  immediate disk read error

Locksmith Fast Disk Backup
  unable to read any track

EDD 4 bit copy (no sync, no count)
  Disk seeks off track 0, then hangs
  with the drive motor on

Copy][+ nibble editor
  T00 has a modified address prologue
    (D5 AA B5) and modified epilogues
  T01+ appears to be 4-4 encoded data
    (2 nibbles on disk = 1 byte in
    memory) with a custom prologue/
    delimiter. In any case, it's
    neither 13 nor 16 sectors.

Disk Fixer
  not much help

Why didn't COPYA work?
  not a 16-sector disk

Why didn't Locksmith FDB work?
  ditto

Why didn't my EDD copy work?
  I don't know. Early Broderbund games
  loved using half tracks and quarter
  tracks, not to mention the runtime
  protection checks, so it could be
  literally anything. Or, more likely,
  any combination of things.

This is decidedly not a single-load
game. There is a classic crack that is
a single binary, but it cuts out a lot
of the introduction and some cut scenes
later. All other cracks are whole-disk,
multi-loaders.

Combined with the early indications of
a custom bootloader and 4-4 encoded
sectors, this is not going to be a
straightforward crack by any definition
of "straight" or "forward."

Let's start at the beginning.

Chapter 1
In Which We Brag About Our Humble Beginnings

I have two floppy drives, one in slot 6
and the other in slot 5. My "work disk"
(in slot 5) runs Diversi-DOS 64K, which
is compatible with Apple DOS 3.3 but
relocates most of DOS to the language
card on boot. This frees up most of
main memory (only using a single page
at $BF00..$BFFF), which is useful for
loading large files or examining code
that lives in areas typically reserved
for DOS.

[S6,D1=original disk]
[S5,D1=my work disk]

The floppy drive firmware code at $C600
is responsible for aligning the drive
head and reading sector 0 of track 0
into main memory at $0800. Because the
drive can be connected to any slot, the
firmware code can't assume it's loaded
at $C600. If the floppy drive card were
removed from slot 6 and reinstalled in
slot 5, the firmware code would load at
$C500 instead.

To accommodate this, the firmware does
some fancy stack manipulation to detect
where it is in memory (which is a neat
trick, since the 6502 program counter
is not generally accessible). However,
due to space constraints, the detection
code only cares about the lower 4 bits
of the high byte of its own address.

Stay with me, this is all about to come
together and go boom.

$C600 (or $C500, or anywhere in $Cx00)
is read-only memory. I can't change it,
which means I can't stop it from
transferring control to the boot sector
of the disk once it's in memory. BUT!
The disk firmware code works unmodified
at any address. Any address that ends
with $x600 will boot slot 6, including
$B600, $A600, $9600, &c.

```
; copy drive firmware to $9600
*9600<C600.C6FFM

; and execute it
*9600G
...reboots slot 6, loads game...
```

Now then:

```
]PR#5
...
]CALL -151

*9600<C600.C6FFM

*96F8L

96F8-   4C 01 08    JMP   $0801
```

That's where the disk controller ROM
code ends and the on-disk code begins.
But $9600 is part of read/write memory.
I can change it at will. So I can
interrupt the boot process after the
drive firmware loads the boot sector
from the disk but before it transfers
control to the disk's bootloader.

```
; instead of jumping to on-disk code,
; copy boot sector to higher memory so
; it survives a reboot
96F8-   A0 00         LDY   #$00
96FA-   B9 00 08      LDA   $0800,Y
96FD-   99 00 28      STA   $2800,Y
9700-   C8            INY
9701-   D0 F7         BNE   $96FA

; turn off slot 6 drive motor
9703-   AD E8 C0      LDA   $C0E8

; reboot to my work disk in slot 5
9706-   4C 00 C5      JMP   $C500

*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT0,A$2800,L$100
```

Now we get to(*) trace the boot process one sector, one page, one instruction at a time.

(*) If you replace the words "need to" with the words "get to," life becomes amazing.

Chapter 2
In Which We Get To Dip Our Toes Into An Ocean Of Raw Sewage

```
]CALL -151

; copy code back to $0800 where it was
; originally loaded, to make it easier
; to follow
*800<2800.28FFM

*801L

; immediately move this code to the
; input buffer at $0200
0801-   A2 00       LDX   #$00
0803-   BD 00 08    LDA   $0800,X
0806-   9D 00 02    STA   $0200,X
0809-   E8          INX
080A-   D0 F7       BNE   $0803
080C-   4C 0F 02    JMP   $020F
```

OK, I can do that too. Well, mostly.
The page at $0200 is the text input
buffer, used by both Applesoft BASIC
and the built-in monitor (which I'm in
right now). But I can copy enough of it
to examine this code in situ.

```
*20F<80F.8FFM
```

```
*20FL

; set up a nibble translation table at
; $0800
020F-   A0 AB       LDY   #$AB
0211-   98          TYA
0212-   85 3C       STA   $3C
0214-   4A          LSR
0215-   05 3C       ORA   $3C
0217-   C9 FF       CMP   #$FF
0219-   D0 09       BNE   $0224
021B-   C0 D5       CPY   #$D5
021D-   F0 05       BEQ   $0224
021F-   8A          TXA
0220-   99 00 08    STA   $0800,Y
0223-   E8          INX
0224-   C8          INY
0225-   D0 EA       BNE   $0211
0227-   84 3D       STY   $3D

; #$00 into zero page $26 and #$03 into
; $27 means we're probably going to be
; loading data into $0300..$03FF later,
; because ($26) points to $0300.
0229-   84 26       STY   $26
022B-   A9 03       LDA   #$03
022D-   85 27       STA   $27

; zero page $2B holds the boot slot x16
022F-   A6 2B       LDX   $2B
0231-   20 5D 02    JSR   $025D
```

```
*25DL

; read a sector from track $00 (this is
; actually derived from the code in the
; disk controller ROM routine at $C65C,
; but looking for an address prologue
; of "D5 AA B5" instead of "D5 AA 96")
; and using the nibble translation
; table we set up earlier at $0800
025D-   18          CLC
025E-   08          PHP
025F-   BD 8C C0    LDA   $C08C,X
0262-   10 FB       BPL   $025F
0264-   49 D5       EOR   #$D5
0266-   D0 F7       BNE   $025F
0268-   BD 8C C0    LDA   $C08C,X
026B-   10 FB       BPL   $0268
026D-   C9 AA       CMP   #$AA
026F-   D0 F3       BNE   $0264
0271-   EA          NOP
0272-   BD 8C C0    LDA   $C08C,X
0275-   10 FB       BPL   $0272
```

```
; #$B5 for third prologue nibble
0277-   C9 B5       CMP   #$B5
0279-   F0 09       BEQ   $0284
027B-   28          PLP
027C-   90 DF       BCC   $025D
027E-   49 AD       EOR   #$AD
0280-   F0 1F       BEQ   $02A1
0282-   D0 D9       BNE   $025D
0284-   A0 03       LDY   #$03
0286-   84 2A       STY   $2A
0288-   BD 8C C0    LDA   $C08C,X
028B-   10 FB       BPL   $0288
028D-   2A          ROL
028E-   85 3C       STA   $3C
0290-   BD 8C C0    LDA   $C08C,X
0293-   10 FB       BPL   $0290
0295-   25 3C       AND   $3C
0297-   88          DEY
0298-   D0 EE       BNE   $0288
029A-   28          PLP
029B-   C5 3D       CMP   $3D
029D-   D0 BE       BNE   $025D
029F-   B0 BD       BCS   $025E
02A1-   A0 9A       LDY   #$9A
02A3-   84 3C       STY   $3C
02A5-   BC 8C C0    LDY   $C08C,X
02A8-   10 FB       BPL   $02A5
```

```
; use the nibble translation table we
; set up earlier to convert nibbles on
; disk into bytes in memory
02AA-   59 00 08    EOR   $0800,Y
02AD-   A4 3C       LDY   $3C
02AF-   88          DEY
02B0-   99 00 08    STA   $0800,Y
02B3-   D0 EE       BNE   $02A3
02B5-   84 3C       STY   $3C
02B7-   BC 8C C0    LDY   $C08C,X
02BA-   10 FB       BPL   $02B7
02BC-   59 00 08    EOR   $0800,Y
02BF-   A4 3C       LDY   $3C

; store the converted bytes at $0300
02C1-   91 26       STA   ($26),Y
02C3-   C8          INY
02C4-   D0 EF       BNE   $02B5

; verify the data with a one-nibble
; checksum
02C6-   BC 8C C0    LDY   $C08C,X
02C9-   10 FB       BPL   $02C6
02CB-   59 00 08    EOR   $0800,Y
02CE-   D0 8D       BNE   $025D
02D0-   60          RTS
```

Continuing from $0234...

```
*234L

0234-   20 D1 02    JSR   $02D1
```

```
*2D1L

; finish decoding nibbles
02D1-   A8          TAY
02D2-   A2 00       LDX   #$00
02D4-   B9 00 08    LDA   $0800,Y
02D7-   4A          LSR
02D8-   3E CC 03    ROL   $03CC,X
02DB-   4A          LSR
02DC-   3E 99 03    ROL   $0399,X
02DF-   85 3C       STA   $3C
02E1-   B1 26       LDA   ($26),Y
02E3-   0A          ASL
02E4-   0A          ASL
02E5-   0A          ASL
02E6-   05 3C       ORA   $3C
02E8-   91 26       STA   ($26),Y
02EA-   C8          INY
02EB-   E8          INX
02EC-   E0 33       CPX   #$33
02EE-   D0 E4       BNE   $02D4
02F0-   C6 2A       DEC   $2A
02F2-   D0 DE       BNE   $02D2

; verify final checksum
02F4-   CC 00 03    CPY   $0300
02F7-   D0 03       BNE   $02FC

; checksum passed, return to caller and
; continue with the boot process
02F9-   60          RTS

; checksum failed, print "ERR" and exit
02FC-   4C 2D FF    JMP   $FF2D
```

Continuing from $0237...

```
*237L

; jump into the code we just read
0237-   4C 01 03    JMP   $0301
```

This is where I get to interrupt the boot, before it jumps to $0301.

Chapter 3
In Which We Do A Bellyflop Into A Decrypted Stack And Discover That I Am Very Bad At Metaphors

```
*9600<C600.C6FFM

; patch boot0 so it calls my routine
; instead of jumping to $0301
96F8-   A9 05       LDA   #$05
96FA-   8D 38 08    STA   $0838
96FD-   A9 97       LDA   #$97
96FF-   8D 39 08    STA   $0839

; start the boot
9702-   4C 01 08    JMP   $0801

; (callback is here) copy the code at
; $0300 to higher memory so it survives
; a reboot
9705-   A0 00       LDY   #$00
9707-   B9 00 03    LDA   $0300,Y
970A-   99 00 23    STA   $2300,Y
970D-   C8          INY
970E-   D0 F7       BNE   $9707

; turn off slot 6 drive motor and
; reboot to my work disk in slot 5
9710-   AD E8 C0    LDA   $C0E8
9713-   4C 00 C5    JMP   $C500

*BSAVE TRACE,A$9600,L$116
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT1 0300-03FF,A$2300,L$100
]CALL -151

*2301L

2301-   84 48       STY   $48
```

```
; clear hi-res graphics screen 2
2303-   A0 00        LDY   #$00
2305-   98           TYA
2306-   A2 20        LDX   #$20
2308-   99 00 40     STA   $4000,Y
230B-   C8           INY
230C-   D0 FA        BNE   $2308
230E-   EE 0A 03     INC   $030A
2311-   CA           DEX
2312-   D0 F4        BNE   $2308

; and show it (appears blank)
2314-   AD 57 C0     LDA   $C057
2317-   AD 52 C0     LDA   $C052
231A-   AD 55 C0     LDA   $C055
231D-   AD 50 C0     LDA   $C050

; decrypt the rest of this page to the
; stack page at $0100
2320-   B9 00 03     LDA   $0300,Y
2323-   45 48        EOR   $48
2325-   99 00 01     STA   $0100,Y
2328-   C8           INY
2329-   D0 F5        BNE   $2320

; set the stack pointer
232B-   A2 CF        LDX   #$CF
232D-   9A           TXS

; and exit via RTS
232E-   60           RTS
```

Oh joy, stack manipulation. The stack on an Apple II is just $100 bytes in main memory ($0100..$01FF) and a single byte register that serves as an index into that page. This allows for all manner of mischief -- overwriting the stack page (as we're doing here), manually changing the stack pointer (also doing that here), or even putting executable code directly on the stack.

The upshot is that I have no idea where execution continues next, because I don't know what ends up on the stack page. I get to interrupt the boot again to see the decrypted data that ends up at $0100.

Chapter 4
Mischief Managed

```
*BLOAD TRACE

[first part is the same as the
 previous trace]

; reproduce the decryption loop, but
; store the result at $2100 so it
; survives a reboot
9705-   84 48       STY   $48
9707-   A0 00       LDY   #$00
9709-   B9 00 03    LDA   $0300,Y
970C-   45 48       EOR   $48
970E-   99 00 21    STA   $2100,Y
9711-   C8          INY
9712-   D0 F5       BNE   $9709

; turn off drive motor and reboot to
; my work disk
9714-   AD E8 C0    LDA   $C0E8
9717-   4C 00 C5    JMP   $C500

*BSAVE TRACE2,A$9600,L$11A
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT1 0100-01FF,A$2100,L$100
]CALL -151
```

The original code at $0300 manually reset the stack pointer to #$CF and exited via RTS. The Apple II will increment the stack pointer before using it as an index into $0100 to get the next address. (For reasons I won't get into here, it also increments the address before passing execution to it.)

```
*21D0.

21D0- 2F 01 FF 03 FF 04 4F 04
      ^^^^^
 next return address
```

$012F + 1 = $0130, which is already in memory at $2130.

Oh joy. Code on the stack. (Remember, the "stack" is just a page in main memory. If you want to use that page for something else, it's up to you to ensure that it doesn't conflict with the stack functioning as a stack.)

```
*2130L

2130-   A2 04       LDX   #$04
2132-   86 86       STX   $86
2134-   A0 00       LDY   #$00
2136-   84 83       STY   $83
2138-   86 84       STX   $84
```

Now ($83) points to $0400.

```
; get slot number (x16)
213A-   A6 2B       LDX   $2B
```

```
; find a 3-nibble prologue ("BF D7 D5")
213C-   BD 8C C0     LDA   $C08C,X
213F-   10 FB        BPL   $213C
2141-   C9 BF        CMP   #$BF
2143-   D0 F7        BNE   $213C
2145-   BD 8C C0     LDA   $C08C,X
2148-   10 FB        BPL   $2145
214A-   C9 D7        CMP   #$D7
214C-   D0 F3        BNE   $2141
214E-   BD 8C C0     LDA   $C08C,X
2151-   10 FB        BPL   $214E
2153-   C9 D5        CMP   #$D5
2155-   D0 F3        BNE   $214A

; read 4-4-encoded data
2157-   BD 8C C0     LDA   $C08C,X
215A-   10 FB        BPL   $2157
215C-   2A           ROL
215D-   85 85        STA   $85
215F-   BD 8C C0     LDA   $C08C,X
2162-   10 FB        BPL   $215F
2164-   25 85        AND   $85

; store in $0400 (text page, but it's
; hidden right now because we switched
; to hi-res graphics screen 2 at $0314)
2166-   91 83        STA   ($83),Y
2168-   C8           INY
2169-   D0 EC        BNE   $2157

; find a 1-nibble epilogue ("D4")
216B-   0E 00 C0     ASL   $C000
216E-   BD 8C C0     LDA   $C08C,X
2171-   10 FB        BPL   $216E
2173-   C9 D4        CMP   #$D4
2175-   D0 B9        BNE   $2130
```

```
; increment target memory page
2177-   E6 84        INC   $84

; decrement sector count (initialized
; at $0132)
2179-   C6 86        DEC   $86
217B-   D0 DA        BNE   $2157

; exit via RTS
217D-   60           RTS
```

Wait, what? Ah, we're using the same trick we used to call this routine -- the stack has been prefilled with a series of "return" addresses. It's time to "return" to the next one.

```
*21D0.

21D0- 2F 01 FF 03 FF 04 4F 04
            ^^^^^
     next return address
```

$03FF + 1 = $0400, and that's where I get to interrupt the boot.

Chapter 5
Seek And Ye Shall Find

```
*BLOAD TRACE2
.
. [same as previous trace]
.
; reproduce the decryption loop that
; was originally at $0320
9705-   84 48       STY   $48
9707-   A0 00       LDY   #$00
9709-   B9 00 03    LDA   $0300,Y
970C-   45 48       EOR   $48
970E-   99 00 01    STA   $0100,Y
9711-   C8          INY
9712-   D0 F5       BNE   $9709

; now that the stack is in place at
; $0100, change the first return
; address so it points to a callback
; under my control (instead of
; continuing to $0400)
9714-   A9 21       LDA   #$21
9716-   8D D2 01    STA   $01D2
9719-   A9 97       LDA   #$97
971B-   8D D3 01    STA   $01D3

; continue the boot
971E-   A2 CF       LDX   #$CF
9720-   9A          TXS
9721-   60          RTS

; (callback is here) copy the contents
; of the text page to higher memory
9722-   A2 04       LDX   #$04
9724-   A0 00       LDY   #$00
9726-   B9 00 04    LDA   $0400,Y
9729-   99 00 24    STA   $2400,Y
972C-   C8          INY
972D-   D0 F7       BNE   $9726
972F-   EE 28 97    INC   $9728
9732-   EE 2B 97    INC   $972B
9735-   CA          DEX
9736-   D0 EE       BNE   $9726
```

```
; turn off the drive and reboot to my
; work disk
9738-   AD E8 C0    LDA   $C0E8
973B-   4C 00 C5    JMP   $C500

*BSAVE TRACE3,A$9600,L$13E
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT1 0400-07FF,A$2400,L$400
]CALL -151
```

I'm going to leave this code at $2400, since I can't put it on the text page and examine it at the same time. Relative branches will look correct, but absolute addresses will be off by $2000.

```
*2400L

; copy three pages to the top of main
; memory
2400-   A0 00       LDY   #$00
2402-   B9 00 05    LDA   $0500,Y
2405-   99 00 BD    STA   $BD00,Y
2408-   B9 00 06    LDA   $0600,Y
240B-   99 00 BE    STA   $BE00,Y
240E-   B9 00 07    LDA   $0700,Y
2411-   99 00 BF    STA   $BF00,Y
2414-   C8          INY
2415-   D0 EB       BNE   $2402
```

I can replicate that.

```
*FE89G FE93G       ; disconnect DOS
*BD00<2500.27FFM   ; simulate copy loop

2417-   A6 2B       LDX   $2B
2419-   8E 66 BF    STX   $BF66
241C-   20 48 BF    JSR   $BF48

*BF48L

; zap contents of language card
BF48-   AD 81 C0    LDA   $C081
BF4B-   AD 81 C0    LDA   $C081
BF4E-   A0 00       LDY   #$00
BF50-   A9 D0       LDA   #$D0
BF52-   84 A0       STY   $A0
BF54-   85 A1       STA   $A1
BF56-   B1 A0       LDA   ($A0),Y
BF58-   91 A0       STA   ($A0),Y
BF5A-   C8          INY
BF5B-   D0 F9       BNE   $BF56
BF5D-   E6 A1       INC   $A1
BF5F-   D0 F5       BNE   $BF56
BF61-   2C 80 C0    BIT   $C080
BF64-   60          RTS
```

```
Continuing from $041F...

; set low-level reset vectors and page
; 3 vectors to point to $BF00 --
; presumably The Badlands (from which
; there is no return)
241F-   AD 83 C0    LDA   $C083
2422-   AD 83 C0    LDA   $C083
2425-   A0 00       LDY   #$00
2427-   A9 BF       LDA   #$BF
2429-   8C FC FF    STY   $FFFC
242C-   8D FD FF    STA   $FFFD
242F-   8C F2 03    STY   $03F2
2432-   8D F3 03    STA   $03F3
2435-   A0 03       LDY   #$03
2437-   8C F0 03    STY   $03F0
243A-   8D F1 03    STA   $03F1
243D-   84 38       STY   $38
243F-   85 39       STA   $39
2441-   49 A5       EOR   #$A5
2443-   8D F4 03    STA   $03F4

*BF00L

; There are multiple entry points here:
; $BF00, $BF03, $BF06, and $BF09
; (hidden in this listing by the "BIT"
; opcodes).
BF00-   A9 D2       LDA   #$D2
BF02-   2C A9 D0    BIT   $D0A9
BF05-   2C A9 CC    BIT   $CCA9
BF08-   2C A9 A1    BIT   $A1A9
BF0B-   48          PHA

; zap the language card again
BF0C-   20 48 BF    JSR   $BF48
```

```
; TEXT/HOME/NORMAL
BF0F-   20 2F FB     JSR   $FB2F
BF12-   20 58 FC     JSR   $FC58
BF15-   20 84 FE     JSR   $FE84

; Depending on the initial entry point,
; this displays a different character
; in the top left corner of the screen
BF18-   68           PLA
BF19-   8D 00 04     STA   $0400

; now wipe all of main memory
BF1C-   A0 00        LDY   #$00
BF1E-   98           TYA
BF1F-   99 00 BE     STA   $BE00,Y
BF22-   C8           INY
BF23-   D0 FA        BNE   $BF1F
BF25-   CE 21 BF     DEC   $BF21

; while playing a sound
BF28-   2C 30 C0     BIT   $C030
BF2B-   AD 21 BF     LDA   $BF21
BF2E-   C9 08        CMP   #$08
BF30-   B0 EA        BCS   $BF1C

; munge the reset vector
BF32-   8D F3 03     STA   $03F3
BF35-   8D F4 03     STA   $03F4
```

```
; and reboot from whence we came
BF38-   AD 66 BF     LDA   $BF66
BF3B-   4A           LSR
BF3C-   4A           LSR
BF3D-   4A           LSR
BF3E-   4A           LSR
BF3F-   09 C0        ORA   #$C0
BF41-   E9 00        SBC   #$00
BF43-   48           PHA
BF44-   A9 FF        LDA   #$FF
BF46-   48           PHA
BF47-   60           RTS
```

Yeah, let's try not to end up there.

Continuing from $0446...

```
2446-   A9 07        LDA   #$07
2448-   20 00 BE     JSR   $BE00

*BE00L

; entry point #1
BE00-   A2 13        LDX   #$13

; entry point #2 (hidden behind a BIT
; opcode, but it's "LDX #$0A")
BE02-   2C A2 0A     BIT   $0AA2

; /!\ modify the code later based on
; which entry point we called
BE05-   8E 6E BE     STX   $BE6E
```

```
; The rest of this routine is a garden
; variety drive seek. The target phase
; (track x 2) is in the accumulator on
; entry.
BE08-    8D 90 BE     STA   $BE90
BE0B-    CD 65 BF     CMP   $BF65
BE0E-    F0 59        BEQ   $BE69
BE10-    A9 00        LDA   #$00
BE12-    8D 91 BE     STA   $BE91
BE15-    AD 65 BF     LDA   $BF65
BE18-    8D 92 BE     STA   $BE92
BE1B-    38           SEC
BE1C-    ED 90 BE     SBC   $BE90
BE1F-    F0 37        BEQ   $BE58
BE21-    B0 07        BCS   $BE2A
BE23-    49 FF        EOR   #$FF
BE25-    EE 65 BF     INC   $BF65
BE28-    90 05        BCC   $BE2F
BE2A-    69 FE        ADC   #$FE
BE2C-    CE 65 BF     DEC   $BF65
BE2F-    CD 91 BE     CMP   $BE91
BE32-    90 03        BCC   $BE37
BE34-    AD 91 BE     LDA   $BE91
BE37-    C9 0C        CMP   #$0C
BE39-    B0 01        BCS   $BE3C
BE3B-    A8           TAY
BE3C-    38           SEC
BE3D-    20 5C BE     JSR   $BE5C
BE40-    B9 78 BE     LDA   $BE78,Y
BE43-    20 6D BE     JSR   $BE6D
BE46-    AD 92 BE     LDA   $BE92
BE49-    18           CLC
BE4A-    20 5F BE     JSR   $BE5F
BE4D-    B9 84 BE     LDA   $BE84,Y
BE50-    20 6D BE     JSR   $BE6D
BE53-    EE 91 BE     INC   $BE91
BE56-    D0 BD        BNE   $BE15
BE58-    20 6D BE     JSR   $BE6D
BE5B-    18           CLC
BE5C-    AD 65 BF     LDA   $BF65
                                  [...]
```

```
BE5F-   29 03           AND   #$03
BE61-   2A              ROL
BE62-   0D 66 BF        ORA   $BF66
BE65-   AA              TAX
BE66-   BD 80 C0        LDA   $C080,X
BE69-   AE 66 BF        LDX   $BF66
BE6C-   60              RTS

; (value of X may be modified depending
; on which entry point was called)
BE6D-   A2 13           LDX   #$13
BE6F-   CA              DEX
BE70-   D0 FD           BNE   $BE6F
BE72-   38              SEC
BE73-   E9 01           SBC   #$01
BE75-   D0 F6           BNE   $BE6D
BE77-   60              RTS
BE78-  [01 30 28 24 20 1E 1D 1C]
BE80-  [1C 1C 1C 1C 70 2C 26 22]
BE88-  [1F 1E 1D 1C 1C 1C 1C 1C]
```

The fact that there are two entry points is interesting. Calling $BE00 will set X to #$13, which will end up in $BE6E, so the wait routine at $BE6D will wait long enough to go to the next phase (a.k.a. half a track). Nothing unusual there; that's how all drive seek routines work. But calling $BE03 instead of $BE00 will set X to #$0A, which will make the wait routine burn fewer CPU cycles while the drive head is moving, so it will only move half a phase (a.k.a. a quarter track). That is potentially very interesting.

Continuing from $044B...

```
244B-   A9 05          LDA   #$05
244D-   85 33          STA   $33
244F-   A2 03          LDX   #$03
2451-   86 36          STX   $36
2453-   A0 00          LDY   #$00
2455-   A5 33          LDA   $33
2457-   84 34          STY   $34
2459-   85 35          STA   $35
```

Now ($34) points to $0500.

```
; find a 3-nibble prologue ("B5 DE F7")
245B-   AE 66 BF       LDX   $BF66
245E-   BD 8C C0       LDA   $C08C,X
2461-   10 FB          BPL   $245E
2463-   C9 B5          CMP   #$B5
2465-   D0 F7          BNE   $245E
2467-   BD 8C C0       LDA   $C08C,X
246A-   10 FB          BPL   $2467
246C-   C9 DE          CMP   #$DE
246E-   D0 F3          BNE   $2463
2470-   BD 8C C0       LDA   $C08C,X
2473-   10 FB          BPL   $2470
2475-   C9 F7          CMP   #$F7
2477-   D0 F3          BNE   $246C
```

```
; read 4-4-encoded data into $0500+
2479-   BD 8C C0     LDA   $C08C,X
247C-   10 FB        BPL   $2479
247E-   2A           ROL
247F-   85 37        STA   $37
2481-   BD 8C C0     LDA   $C08C,X
2484-   10 FB        BPL   $2481
2486-   25 37        AND   $37
2488-   91 34        STA   ($34),Y
248A-   C8           INY
248B-   D0 EC        BNE   $2479
248B-   D0 EC        BNE   $2479
248D-   0E FF FF     ASL   $FFFF

; find a 1-nibble epilogue ("D5")
2490-   BD 8C C0     LDA   $C08C,X
2493-   10 FB        BPL   $2490
2495-   C9 D5        CMP   #$D5
2497-   D0 B6        BNE   $244F
2499-   E6 35        INC   $35

; 3 sectors (initialized at $0451)
249B-   C6 36        DEC   $36
249D-   D0 DA        BNE   $2479

; and exit via RTS
249F-   60           RTS
```

We've read 3 more sectors into $0500+, overwriting the code we read earlier (but moved to $BD00+), and once again we simply exit and let the stack tell us where we're going next.

```
*21D0.

21D0- 2F 01 FF 03 FF 04 4F 04
                  ^^^^^
           next return address
```

$04FF + 1 = $0500, the code we just read.

And that's where I get to interrupt the boot.

Chapter 6
Return of the Jedi

```
; reboot because I disconnected and
; overwrote DOS to examine the previous
; code chunk at $BD00+
*C500G
...
]CALL -151

*BLOAD TRACE3
.
. [same as previous trace]
.
; Patch the stack again, but slightly
; later, at $01D4. (The previous trace
; patched it at $01D2.)
9714-   A9 21        LDA   #$21
9716-   8D D4 01     STA   $01D4
9719-   A9 97        LDA   #$97
971B-   8D D5 01     STA   $01D5

; continue the boot
971E-   A2 CF        LDX   #$CF
9720-   9A           TXS
9721-   60           RTS
```

```
; (callback is here) We just executed
; all the code up to and including the
; "RTS" at $049F, so now let's copy the
; latest code at $0500..$07FF to higher
; memory so it survives a reboot.
9722-   A2 04       LDX   #$03
9724-   A0 00       LDY   #$00
9726-   B9 00 05    LDA   $0500,Y
9729-   99 00 25    STA   $2500,Y
972C-   C8          INY
972D-   D0 F7       BNE   $9726
972F-   EE 28 97    INC   $9728
9732-   EE 2B 97    INC   $972B
9735-   CA          DEX
9736-   D0 EE       BNE   $9726

; reboot to my work disk
9738-   AD E8 C0    LDA   $C0E8
973B-   4C 00 C5    JMP   $C500

*BSAVE TRACE4,A$9600,L$13E
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT2 0500-07FF,A$2500,L$300
]CALL -151
```

Again, I'm going to leave this at $2500 because I can't examine code on the text page. Relative branches will look correct, but absolute addresses will be off by $2000.

```
*2500L

; seek to track 1
2500-   A9 02       LDA   #$02
2502-   20 00 BE    JSR   $BE00

; get slot number x16 (set a long time
; ago, at $0419)
2505-   AE 66 BF    LDX   $BF66
2508-   A0 00       LDY   #$00
250A-   A9 20       LDA   #$20
250C-   85 30       STA   $30
250E-   88          DEY
250F-   D0 04       BNE   $2515
2511-   C6 30       DEC   $30
2513-   F0 3C       BEQ   $2551

; find a 3-nibble prologue ("D5 FF DD")
2515-   BD 8C C0    LDA   $C08C,X
2518-   10 FB       BPL   $2515
251A-   C9 D5       CMP   #$D5
251C-   D0 F0       BNE   $250E
251E-   BD 8C C0    LDA   $C08C,X
2521-   10 FB       BPL   $251E
2523-   C9 FF       CMP   #$FF
2525-   D0 F3       BNE   $251A
2527-   BD 8C C0    LDA   $C08C,X
252A-   10 FB       BPL   $2527
252C-   C9 DD       CMP   #$DD
252E-   D0 F3       BNE   $2523
```

```
; read 4-4-encoded data
2530-   A0 00       LDY   #$00
2532-   BD 8C C0    LDA   $C08C,X
2535-   10 FB       BPL   $2532
2537-   38          SEC
2538-   2A          ROL
2539-   85 30       STA   $30
253B-   BD 8C C0    LDA   $C08C,X
253E-   10 FB       BPL   $253B
2540-   25 30       AND   $30

; into $B000 (hard-coded here, was not
; modified earlier unless I missed
; something)
2542-   99 00 B0    STA   $B000,Y
2545-   C8          INY
2546-   D0 EA       BNE   $2532

; find a 1-nibble epilogue ("D5")
2548-   BD 8C C0    LDA   $C08C,X
254B-   10 FB       BPL   $2548
254D-   C9 D5       CMP   #$D5
254F-   F0 0B       BEQ   $255C

; This is odd. If the epilogue doesn't
; match, it's not an error. Instead, it
; appears that we simply copy a page of
; data that we read earlier (at $0700).
2551-   A0 00       LDY   #$00
2553-   B9 00 07    LDA   $0700,Y
2556-   99 00 B0    STA   $B000,Y
2559-   C8          INY
255A-   D0 F7       BNE   $2553

; execution continues here regardless
255C-   20 F0 05    JSR   $05F0
```

```
*25F0L

; Weird, but OK. This ends up calling
; $BE00 with A=$07, which will seek to
; track 3.5.
25F0-   A0 56       LDY   #$56
25F2-   A9 BD       LDA   #$BD
25F4-   48          PHA
25F5-   A9 FF       LDA   #$FF
25F7-   48          PHA
25F8-   A9 07       LDA   #$07
25FA-   60          RTS
```

And now we're on half tracks.

Continuing from $055F...

```
; find a 3-nibble prologue ("DD EF AD")
255F-   BD 8C C0    LDA   $C08C,X
2562-   10 FB       BPL   $255F
2564-   C9 DD       CMP   #$DD
2566-   D0 F7       BNE   $255F
2568-   BD 8C C0    LDA   $C08C,X
256B-   10 FB       BPL   $2568
256D-   C9 EF       CMP   #$EF
256F-   D0 F3       BNE   $2564
2571-   BD 8C C0    LDA   $C08C,X
2574-   10 FB       BPL   $2571
2576-   C9 AD       CMP   #$AD
2578-   D0 F3       BNE   $256D
```

```
; read a 4-4 encoded byte (two nibbles
; on disk = 1 byte in memory)
257A-   A0 00       LDY   #$00
257C-   BD 8C C0    LDA   $C08C,X
257F-   10 FB       BPL   $257C
2581-   38          SEC
2582-   2A          ROL
2583-   85 00       STA   $00
2585-   BD 8C C0    LDA   $C08C,X
2588-   10 FB       BPL   $2585
258A-   25 00       AND   $00

; push the byte to the stack (WTF?)
258C-   48          PHA

; repeat for $100 bytes
258D-   88          DEY
258E-   D0 EC       BNE   $257C

; find a 1-nibble epilogue ("D5")
2590-   BD 8C C0    LDA   $C08C,X
2593-   10 FB       BPL   $2590
2595-   C9 D5       CMP   #$D5
2597-   D0 C3       BNE   $255C

2599-   CE 9C 05    DEC   $059C     /!\
259C-   61 00       ADC   ($00,X)

/!\ Self-modifying code alert! WOO WOO.
    I'll use this symbol whenever one
    instruction modifies the next
    instruction. When this happens, the
    disassembly listing is misleading
    because the opcode will be changed
    by the time the second instruction
    is executed.
```

In this case, the DEC at $0599 modifies the opcode at $059C, so that's not really an "ADC". By the time we execute the instruction at $059C, it will have been decremented to #$60, a.k.a. "RTS".

One other thing: we've read $100 bytes and pushed all of them to the stack. The stack is only $100 bytes ($0100..$01FF), so this completely obliterates any previous values.

We haven't changed the stack pointer, though. That means the "RTS" at $059C will still look at $01D6 to find the next "return" address. That used to be "4F 04", but now it's been overwritten with new values (along with the rest of the stack). That's some serious Jedi mind trick stuff.

"These aren't the return addresses
 you're looking for."

"These aren't the return addresses
 we're looking for."

"He can go about his bootloader."

"You can go about your bootloader."

"Move along."

"Move along... move along."

Chapter 7
In Which We Move Along

Luckily, there's plenty of room at $0599. I can insert a JMP to call back to code under my control, where I can save a copy of the stack (and $B000 as well, whatever that is). I get to ensure I don't disturb the stack before I save it, so no JSR, PHA, PHP, or TXS. I think I can manage that. JMP doesn't disturb the stack, so that's safe for the callback.

```
*BLOAD TRACE4
.
. [same as previous trace]
.
; set up a JMP $9734 at $0599
9722-   A9 4C       LDA   #$4C
9724-   8D 99 05    STA   $0599
9727-   A9 34       LDA   #$34
9729-   8D 9A 05    STA   $059A
972C-   A9 97       LDA   #$97
972E-   8D 9B 05    STA   $059B

; continue the boot
9731-   4C 00 05    JMP   $0500

; (callback is here) Copy $B000 and
; $0100 to higher memory so they
; survive a reboot
9734-   A0 00       LDY   #$00
9736-   B9 00 B0    LDA   $B000,Y
9739-   99 00 20    STA   $2000,Y
973C-   B9 00 01    LDA   $0100,Y
973F-   99 00 21    STA   $2100,Y
9742-   C8          INY
9743-   D0 F1       BNE   $9736
```

```
; reboot to my work disk
9745-   AD E8 C0    LDA   $C0E8
9748-   4C 00 C5    JMP   $C500

*BSAVE TRACE5,A$9600,L$14B
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT2 B000-B0FF,A$2000,L$100
]BSAVE BOOT2 0100-01FF,A$2100,L$100
]CALL -151
```

Remember, the stack *pointer* hasn't changed. Now that I have the new stack *data*, I can just look at the right index in the captured stack page to see where the bootloader continues once it issues the "RTS" at $059C.

```
*21D0.

21D0- F0 78 AD D8 02 85 25 01
                        ^^^^^
                 next return address

$0125 + 1 = $0126
```

That's part of the stack page I just captured, so it's already in memory.

```
*2126L
```

Another disk read routine! The fourth? Fifth? I've truly lost count.

```
; find a 3-nibble prologue ("BF BE D4")
2126-   BD 8C C0    LDA   $C08C,X
2129-   10 FB       BPL   $2126
212B-   C9 BF       CMP   #$BF
212D-   D0 F7       BNE   $2126
212F-   BD 8C C0    LDA   $C08C,X
2132-   10 FB       BPL   $212F
2134-   C9 BE       CMP   #$BE
2136-   D0 F3       BNE   $212B
2138-   BD 8C C0    LDA   $C08C,X
213B-   10 FB       BPL   $2138
213D-   C9 D4       CMP   #$D4
213F-   D0 F3       BNE   $2134

; read 4-4-encoded data
2141-   A0 00       LDY   #$00
2143-   BD 8C C0    LDA   $C08C,X
2146-   10 FB       BPL   $2143
2148-   38          SEC
2149-   2A          ROL
214A-   8D 00 02    STA   $0200
214D-   BD 8C C0    LDA   $C08C,X
2150-   10 FB       BPL   $214D
2152-   2D 00 02    AND   $0200

; decrypt the data from disk by using
; this entire page of code (in the
; stack page) as the decryption key
; (more on this later)
2155-   59 00 01    EOR   $0100,Y

; and store it in zero page
2158-   99 00 00    STA   $0000,Y
215B-   C8          INY
215C-   D0 E5       BNE   $2143
```

```
; find a 1-nibble epilogue ("D5")
215E-   BD 8C C0     LDA   $C08C,X
2161-   10 FB        BPL   $215E
2163-   C9 D5        CMP   #$D5
2165-   D0 BF        BNE   $2126

; and exit via RTS
2167-   60           RTS
```

And we're back on the stack again.

```
*21D0.

21D0- F0 78 AD D8 02 85 25 01
21D8- 57 FF 57 FF 57 FF 57 FF
      ^^^^^ ^^^^^ ^^^^^ ^^^^^
 next return addresses

21E0- 57 FF 22 01 FF 05 B1 4C
      ^^^^^ ^^^^^
```

$FF57 + 1 = $FF58, which is a well-known address in ROM that is always an "RTS" instruction. So this will burn through several return addresses on the stack in short order, then finally arrive at $0123 (in memory at $2123).

```
*2123L

2123-   6C 28 00     JMP   ($0028)
```

...which is in the new zero page that was just read from disk.

And to think, we've loaded basically nothing of consequence yet. The screen is still black. We have 3 pages of code at $BD00..$BFFF. There's still some code on the text screen, but who knows if we'll ever call it again. Now we're off to zero page for some reason.

Un. Be. Lievable.

Chapter 8
By Perseverance The Snail Reached The Ark

I can't touch the code on the stack, because it's used as a decryption key. I mean, I could theoretically change a few bytes of it, then calculate the proper decrypted bytes on zero page by hand. But no.

Instead, I'm just going to copy this latest disk routine wholesale. It's short and has no external dependencies, so why not? Then I can capture the decrypted zero page and see where that JMP ($0028) is headed.

```
*BLOAD TRACE5

*9734<2126.2166M
```

Here's the entire disassembly listing of boot trace #6:

```
; patch boot0 so it calls my routine
; instead of jumping to $0301
96F8-   A9 05       LDA   #$05
96FA-   8D 38 08    STA   $0838
96FD-   A9 97       LDA   #$97
96FF-   8D 39 08    STA   $0839

; start the boot
9702-   4C 01 08    JMP   $0801
```

```
; (callback #1 is here) reproduce the
; decryption loop that was originally
; at $0320
9705-   84 48       STY   $48
9707-   A0 00       LDY   #$00
9709-   B9 00 03    LDA   $0300,Y
970C-   45 48       EOR   $48
970E-   99 00 01    STA   $0100,Y
9711-   C8          INY
9712-   D0 F5       BNE   $9709

; patch the stack so it jumps to my
; callback #2 instead of continuing to
; $0500
9714-   A9 21       LDA   #$21
9716-   8D D4 01    STA   $01D4
9719-   A9 97       LDA   #$97
971B-   8D D5 01    STA   $01D5

; continue the boot
971E-   A2 CF       LDX   #$CF
9720-   9A          TXS
9721-   60          RTS

; (callback #2) set up callback #3
; instead of passing control to the
; disk read routine at $0126
9722-   A9 4C       LDA   #$4C
9724-   8D 99 05    STA   $0599
9727-   A9 34       LDA   #$34
9729-   8D 9A 05    STA   $059A
972C-   A9 97       LDA   #$97
972E-   8D 9B 05    STA   $059B

; continue the boot
9731-   4C 00 05    JMP   $0500
```

```
; (callback #3) disk read routine
; copied wholesale from $0126..$0166
; that reads a sector and decrypts it
; into zero page
9734-   BD 8C C0    LDA   $C08C,X
9737-   10 FB       BPL   $9734
9739-   C9 BF       CMP   #$BF
973B-   D0 F7       BNE   $9734
973D-   BD 8C C0    LDA   $C08C,X
9740-   10 FB       BPL   $973D
9742-   C9 BE       CMP   #$BE
9744-   D0 F3       BNE   $9739
9746-   BD 8C C0    LDA   $C08C,X
9749-   10 FB       BPL   $9746
974B-   C9 D4       CMP   #$D4
974D-   D0 F3       BNE   $9742
974F-   A0 00       LDY   #$00
9751-   BD 8C C0    LDA   $C08C,X
9754-   10 FB       BPL   $9751
9756-   38          SEC
9757-   2A          ROL
9758-   8D 00 02    STA   $0200
975B-   BD 8C C0    LDA   $C08C,X
975E-   10 FB       BPL   $975B
9760-   2D 00 02    AND   $0200
9763-   59 00 01    EOR   $0100,Y
9766-   99 00 00    STA   $0000,Y
9769-   C8          INY
976A-   D0 E5       BNE   $9751
976C-   BD 8C C0    LDA   $C08C,X
976F-   10 FB       BPL   $976C
9771-   C9 D5       CMP   #$D5
9773-   D0 BF       BNE   $9734

; execution falls through here
; now capture the decrypted zero page
9775-    A0 00          LDY   #$00
9777-    B9 00 00       LDA   $0000,Y
977A-    99 00 20       STA   $2000,Y
977D-    C8             INY
977E-    D0 F7          BNE   $9777

; turn off the slot 6 drive motor
9780-    AD E8 C0       LDA   $C0E8

; reboot to my work disk
9783-    4C 00 C5       JMP   $C500

*BSAVE TRACE6,A$9600,L$186
```

Whew. Let's do it.

```
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE BOOT3 0000-00FF,A$2000,L$100
]CALL -151

*2028.2029

2028- D0 06
```

OK, the JMP ($0028) points to $06D0, which I captured earlier. It's part of the second chunk we read into the text page (not the first chunk -- that was copied to $BD00+ then overwritten). So it's in the "BOOT2 0500-07FF" file, not the "BOOT1 0400-07FF" file.

```
*BLOAD BOOT2 0500-07FF,A$2500
```

```
*26D0L

26D0-   A2 00       LDX   #$00
26D2-   EE D5 06    INC   $06D5      /!\
26D5-   C9 EE       CMP   #$EE
```

Oh joy, more self-modifying code.

```
*26D5:CA
*26D5L

26D5-   CA          DEX
26D6-   EE D9 06    INC   $06D9      /!\
26D9-   0F          ???

*26D9:10
*26D9L

; branch is never taken, because we
; just DEX'd from #$00 to #$FF
26D9-   10 FB       BPL   $26D6
26DB-   CE DE 06    DEC   $06DE      /!\
26DE-   61 A0       ADC   ($A0,X)

*26DE:60
*26DEL

26DE-   60          RTS
```

And now we're back on the stack.

```
*BLOAD BOOT2 0100-01FF,A$2100
```

```
*21E0.

21E0- 57 FF 22 01 FF 05 B1 4C
                        ^^^^^
              next return address
```

$05FF + 1 = $0600, which is already in memory at $2600.

```
*2600L

; destroy stack by pushing the same
; value $100 times
2600-    A0 00          LDY   #$00
2602-    48             PHA
2603-    88             DEY
2604-    D0 FC          BNE   $2602
```

I guess we're done with all that code on the stack page. I mean, I hope we're done with it, since it all just disappeared.

```
; reset the stack pointer
2606-    A2 FF          LDX   #$FF
2608-    9A             TXS

2609-    EE 0C 06       INC   $060C     /!\
260C-    A8             TAY
```

Oh joy.

```
*260C:A9
*260CL

260C-    A9 27          LDA   #$27
260E-    EE 11 06       INC   $0611     /!\
2611-    17             ???
```

```
*2611:18
*2611L

2611-   18          CLC
2612-   EE 15 06    INC   $0615     /!\
2615-   68          PLA

*2615:69
*2615L

2615-   69 D9       ADC   #$D9
2617-   EE 1A 06    INC   $061A     /!\
261A-   4B          ???

*261A:4C
*261AL

261A-   4C 90 FD    JMP   $FD90
```

Wait, what?

```
*FD90L

FD90-   D0 5B       BNE   $FDED
```

Despite the fact that the accumulator is #$00 (because #$27 + #$D9 = #$00), the INC at $0617 affects the Z register and causes this branch to be taken (because the final value of $061A was not zero).

```
*FDEDL

FDED-   6C 36 00    JMP   ($0036)
```

Of course, this is the standard output
character routine, which routes through
the output vector at ($0036). And we
just set that vector, along with the
rest of zero page. So what is it?

```
*2036.2037

2036- 6F BF
```

Oh joy. Let's see, $BD00..$BFFF was
copied earlier from $0500..$07FF, but
from the first time we read into the
text page, not the second time we read
into text page. So it's in the "BOOT1
0400-07FF" file, not the "BOOT2
0500-07FF" file.

```
*BLOAD BOOT1 0400-07FF,A$2400

*FE89G FE93G      ; disconnect DOS

*BD00<2500.27FFM ; move code into place

*BF6FL

BF6F-   C9 07         CMP   #$07
BF71-   90 03         BCC   $BF76
BF73-   6C 3A 00      JMP   ($003A)

*203A.203B

203A- F0 FD

; save input value
BF76-   85 5F         STA   $5F
```

```
; use value as an index into an array
BF78-   A8          TAY
BF79-   B9 68 BF    LDA   $BF68,Y

; /!\ self-modifying code alert -- this
; changes the upcoming JSR at $BF81
BF7C-   8D 82 BF    STA   $BF82
BF7F-   A9 00       LDA   #$00
BF81-   20 D0 BE    JSR   $BED0
```

Amazing. So this "output" vector does actually print characters through the standard $FDF0 text print routine, but only if the character to be printed is at least #$07. If it's less than #$07, the "character" is treated as a command. Each command gets routed to a different routine somewhere in $BExx. The low byte of each routine is stored in the array at $BF68, and the "STA" at $BF7C modifies the "JSR" at $BF81 to call the appropriate address.

```
*BF68.

BF68- D0 DF D0 D0 FD FD D0
```

Since A = #$00 this time, the call is unchanged and we JSR $BED0. Other input values may call $BEDF or $BEFD instead.

```
*BED0L

; use the "value" of $C050 to produce
; a pseudo-random number between #$01
; and #$0E
BED0-   A5 60       LDA   $60
BED2-   4D 50 C0    EOR   $C050
BED5-   85 60       STA   $60
BED7-   29 0F       AND   #$0F

; not #$00
BED9-   F0 F5       BEQ   $BED0

; not #$0F
BEDB-   C9 0F       CMP   #$0F
BEDD-   F0 F1       BEQ   $BED0

; set the lo-res plotting color (in
; zero page $30) to the random-ish
; value we just produced
BEDF-   20 66 F8    JSR   $F866

; fill the lo-res graphics screen with
; blocks of that color
BEE2-   A9 17       LDA   #$17
BEE4-   48          PHA

; calculates the base address for this
; line in memory and puts it in $26/$27
BEE5-   20 47 F8    JSR   $F847
BEE8-   A0 27       LDY   #$27
BEEA-   A5 30       LDA   $30
BEEC-   91 26       STA   ($26),Y
BEEE-   88          DEY
BEEF-   10 FB       BPL   $BEEC
BEF1-   68          PLA
```

```
; do it for all 24 ($17) rows of the
; screen
BEF2-   38              SEC
BEF3-   E9 01           SBC   #$01
BEF5-   10 ED           BPL   $BEE4

; and switch to lo-res graphics mode
BEF7-   AD 56 C0        LDA   $C056
BEFA-   AD 54 C0        LDA   $C054
BEFD-   60              RTS
```

This explains why the original disk fills the screen with a different color every time it boots.

But wait, these commands do so much more than just fill the screen.

Continuing from $BF84...

```
BF84-   A5 5F           LDA   $5F
BF86-   C9 04           CMP   #$04
BF88-   D0 03           BNE   $BF8D
BF8A-   4C 00 BD        JMP   $BD00
```

If A = #$04, we exit via $BD00, which I'll investigate later.

```
BF8D-   C9 05           CMP   #$05
BF8F-   D0 03           BNE   $BF94
BF91-   6C 82 BF        JMP   ($BF82)
```

If A = #$05, we exit via ($BF82), which is the same thing we just called via the self-modified JSR at $BF81.

For all other values of A, we do this:

```
BF94-   20 B0 BE     JSR   $BEB0
```

```
*BEB0L
```

```
; another layer of encryption!
BEB0-   A2 60        LDX   #$60
BEB2-   BD 9F BF     LDA   $BF9F,X
BEB5-   5D 00 BE     EOR   $BE00,X

; and it's decrypting the code that
; we're about to run
BEB8-   9D 9F BF     STA   $BF9F,X
BEBB-   CA           DEX
BEBC-   10 F4        BPL   $BEB2
BEBE-   AE 66 BF     LDX   $BF66
BEC1-   60           RTS
```

This is self-contained, so I can just run it right now and see what ends up at $BF9F.

```
*BEB0G
```

Continuing from $BF97...

```
BF97-   A0 00        LDY   #$00
BF99-   A9 B2        LDA   #$B2
BF9B-   84 44        STY   $44
BF9D-   85 45        STA   $45

; everything beyond this point was
; encrypted, but we just decrypted it
; in $BEB0
BF9F-   BD 89 C0     LDA   $C089,X
```

```
; find a 3-nibble prologue (varies,
; based on whatever the hell is in
; zero page $40/$41/$42 at this point)
BFA2-   BD 8C C0    LDA   $C08C,X
BFA5-   10 FB       BPL   $BFA2
BFA7-   C5 40       CMP   $40
BFA9-   D0 F7       BNE   $BFA2
BFAB-   BD 8C C0    LDA   $C08C,X
BFAE-   10 FB       BPL   $BFAB
BFB0-   C5 41       CMP   $41
BFB2-   D0 F3       BNE   $BFA7
BFB4-   BD 8C C0    LDA   $C08C,X
BFB7-   10 FB       BPL   $BFB4
BFB9-   C5 42       CMP   $42
BFBB-   D0 F3       BNE   $BFB0

; read 4-4-encoded data
BFBD-   BD 8C C0    LDA   $C08C,X
BFC0-   10 FB       BPL   $BFBD
BFC2-   38          SEC
BFC3-   2A          ROL
BFC4-   85 46       STA   $46
BFC6-   BD 8C C0    LDA   $C08C,X
BFC9-   10 FB       BPL   $BFC6
BFCB-   25 46       AND   $46

; store in memory starting at $B200
; (set at $BF9B)
BFCD-   91 44       STA   ($44),Y
BFCF-   C8          INY
BFD0-   D0 EB       BNE   $BFBD
BFD2-   E6 45       INC   $45
BFD4-   BD 8C C0    LDA   $C08C,X
BFD7-   10 FB       BPL   $BFD4
BFD9-   C5 43       CMP   $43
BFDB-   D0 BA       BNE   $BF97
```

```
; read into $B200, $B300, and $B400,
; then stop
BFDD-   A5 45         LDA   $45
BFDF-   49 B5         EOR   #$B5
BFE1-   D0 DA         BNE   $BFBD
BFE3-   48            PHA         ;   A=00
BFE4-   A5 45         LDA   $45   ;   A=B5
BFE6-   49 8E         EOR   #$8E  ;   A=3B
BFE8-   48            PHA
BFE9-   60            RTS
```

So we push ##$00 and ##$3B to the stack,
then exit via RTS. That will "return"
to $003C, which is in memory at $203C.

```
*203CL

203C-   4C 00 B2      JMP   $B200
```

And that's the code we just read from
disk, which means I get to set up
another boot trace to capture it.

Chapter 9
In Which We Flutter For A Day And Think It Is Forever

I'll reboot my work disk again, since I
disconnected DOS to examine the code at
$BD00..$BFFF.

```
*C500G
...
]CALL -151

*BLOAD TRACE6
.
. [same as previous trace, up to and
.  including the inline disk read
.  routine copied from $0126 that
.  decrypts a sector into zero page]
.
; change the JMP address at $003C so it
; points to my callback instead of
; continuing to $B200
9775-   A9 80       LDA   #$80
9777-   85 3D       STA   $3D
9779-   A9 97       LDA   #$97
977B-   85 3E       STA   $3E

; continue the boot
977D-   4C 00 06    JMP   $0600

; (callback is here) copy the new code
; to the graphics page so it survives a
; reboot
9780-   A2 03       LDX   #$03
9782-   B9 00 B2    LDA   $B200,Y
9785-   99 00 22    STA   $2200,Y
9788-   C8          INY
9789-   D0 F7       BNE   $9782
978B-   EE 84 97    INC   $9784
978E-   EE 87 97    INC   $9787
9791-   CA          DEX
9792-   D0 EE       BNE   $9782
```

```
; reboot to my work disk
9794-   AD E8 C0    LDA   $C0E8
9797-   4C 00 C5    JMP   $C500

*BSAVE TRACE7,A$9600,L$19A
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE OBJ.B200-B4FF,A$2200,L$300
]CALL -151

*B200<2200.24FFM
*B200L

B200-   A9 04       LDA   #$04
B202-   20 00 B4    JSR   $B400
B205-   A9 00       LDA   #$00
B207-   85 5A       STA   $5A
B209-   20 00 B3    JSR   $B300
B20C-   4C 00 B5    JMP   $B500
```

$B400 is a disk seek routine, identical to the one at $BE00. (It even has the same dual entry points for seeking by half track and quarter track, at $B400 and $B403.) There's nothing at $B500 yet, so the routine at $B300 must be another disk read.

```
*B300L

; some zero page initialization
B300-   A0 00       LDY   #$00
B302-   A9 B5       LDA   #$B5
B304-   84 59       STY   $59
B306-   48          PHA
B307-   20 30 B3    JSR   $B330
```

```
*B330L

; more zero page initialization
B330-   48              PHA
B331-   A5 5A           LDA   $5A
B333-   29 07           AND   #$07
B335-   A8              TAY
B336-   B9 50 B3        LDA   $B350,Y
B339-   85 50           STA   $50
B33B-   A5 5A           LDA   $5A
B33D-   4A              LSR
B33E-   09 AA           ORA   #$AA
B340-   85 51           STA   $51
B342-   A5 5A           LDA   $5A
B344-   09 AA           ORA   #$AA
B346-   85 52           STA   $52
B348-   68              PLA
B349-   E6 5A           INC   $5A
B34B-   4C 60 B3        JMP   $B360

*B350.

B350- D5 B5 B7 BC DF D4 B4 DB
```

That could be an array of nibbles. Maybe a rotating prologue? Or a decryption key?

```
*B360L
```

Oh joy. Another disk read routine.

```
B360-   85 54           STA   $54
B362-   A2 02           LDX   #$02
B364-   86 57           STX   $57
B366-   A0 00           LDY   #$00
B368-   A5 54           LDA   $54
B36A-   84 55           STY   $55
B36C-   85 56           STA   $56
```

```
; find a 3-nibble prologue (varies,
; based on the zero page locations that
; were initialized at $B330 based on
; the array at $B350)
B36E-    AE 66 BF     LDX   $BF66
B371-    BD 8C C0     LDA   $C08C,X
B374-    10 FB        BPL   $B371
B376-    C5 50        CMP   $50
B378-    D0 F7        BNE   $B371
B37A-    BD 8C C0     LDA   $C08C,X
B37D-    10 FB        BPL   $B37A
B37F-    C5 51        CMP   $51
B381-    D0 F3        BNE   $B376
B383-    BD 8C C0     LDA   $C08C,X
B386-    10 FB        BPL   $B383
B388-    C5 52        CMP   $52
B38A-    D0 F3        BNE   $B37F

; read a 4-4-encoded sector
B38C-    BD 8C C0     LDA   $C08C,X
B38F-    10 FB        BPL   $B38C
B391-    2A           ROL
B392-    85 58        STA   $58
B394-    BD 8C C0     LDA   $C08C,X
B397-    10 FB        BPL   $B394
B399-    25 58        AND   $58

; store the data into ($55)
B39B-    91 55        STA   ($55),Y
B39D-    C8           INY
B39E-    D0 EC        BNE   $B38C
```

```
; find a 1-nibble epilogue ("D4")
B3A0-   0E FF FF    ASL   $FFFF
B3A3-   BD 8C C0    LDA   $C08C,X
B3A6-   10 FB       BPL   $B3A3
B3A8-   C9 D4       CMP   #$D4
B3AA-   D0 B6       BNE   $B362
B3AC-   E6 56       INC   $56
B3AE-   C6 57       DEC   $57
B3B0-   D0 DA       BNE   $B38C
B3B2-   60          RTS
```

Let's see:

$57 is the sector count. Initially #$02 (set at $B364), decremented at $B3AE.

$56 is the target page in memory. Set at $B36C to the accumulator, which is set at $B368 to the value of address $54, which is set at $B360 to the accumulator, which is set at $B348 by the PLA, which was pushed to the stack at $B330, which was originally set at $B302 to a constant value of #$B5. Then $56 is incremented (at $B3AC) after reading and decoding $100 bytes worth of data from disk.

$55 is #$00 (set at $B36A).

So this reads two sectors into $B500..$B6FF and returns to the caller.

Backtracking to $B30A...

```
; $59 is initially #$00 (set at $B304)
B30A-   A4 59       LDY   $59
B30C-   18          CLC
```

```
; current phase (track x 2)
B30D-   AD 65 BF    LDA   $BF65

; new phase
B310-   79 28 B3    ADC   $B328,Y

; move the drive head to the new phase,
; but using the second entry point,
; which uses a reduced timing loop (!)
B313-   20 03 B4    JSR   $B403

; this pulls the value that was pushed
; to the stack at $B306, which was the
; target memory page to store the data
; being read from disk by the routine
; at $B360
B316-   68          PLA

; page += 2
B317-   18          CLC
B318-   69 02       ADC   #$02

; counter += 1
B31A-   A4 59       LDY   $59
B31C-   C8          INY

; loop for 4 iterations
B31D-   C0 04       CPY   #$04
B31F-   90 E3       BCC   $B304
B321-   60          RTS
```

So we're reading two sectors at a time, four times, into $B500+. 2 x 4 = 8, so we're loading into $B500..$BCFF. That completely fills the gap in memory between the code at $B200..$B4FF (this chunk) and the code at $BD00..$BFFF (copied much earlier), which strongly suggests that my analysis is correct.

But what's going on with the weird drive seeking?

There is some definite weirdness here, and it's centered around the array at $B328. At $B200, we called the main entry point for the drive seek routine at $B400 to seek to track 2. Now, after reading two sectors, we're calling the secondary entry point (at $B403) to seek... where exactly?

```
*B328.

B328- 01 FF 01 00 00 00 00 00
```

Aha! This array is the differential to get the drive to seek forward or back. At $B200, we seeked to track 2. The first time through this loop at $B304, we read two sectors into $B500..$B6FF, then add 1 to the current phase (because $B328 = #$01). Normally this would seek forward a half track, to track 2.5, but because we're using the reduced timing loop, we only seek forward by a quarter track, to track 2.25.

The second time through the loop, we
read two sectors into $B700..$B8FF,
then subtract 1 from the phase (because
$B329 = #$FF) and seek backwards by a
quarter track. Now we're back on track
2.0.

The third time, we read two sectors
from track 2.25 into $B900..$BAFF, then
seek forward by a quarter track
(because $B32A = #$01).

The fourth and final time, we read the
final two sectors from track 2.25 into
$BB00..$BCFF.

```
 1.75    2.0     2.25    2.5     2.75
--+-------+-------+-------+-------+----
  .      B500     .       .       .
  .      B600     .       .       .
  .       .   \   .       .       .
  .       .      B700     .       .
  .       .      B800     .       .
  .       .   /   .       .       .
  .      B900     .       .       .
  .      BA00     .       .       .
  .       .   \   .       .       .
  .       .      BB00     .       .
  .       .      BC00     .       .
```

This explains the little "fluttering"
noise the original disk makes during
this phase of the boot. It's flipping
back and forth between adjacent quarter
tracks, reading two sectors from each.

Boy am I glad I'm not trying to copy
this disk with a generic bit copier.
That would be nearly impossible, even
if I knew exactly which tracks were
split like this.

Chapter 10
In Which The Floodgates Burst Open

```
*BLOAD TRACE7
.
. [same as previous trace]
.
; interrupt the boot at $B20C after it
; calls $B300 but before it jumps to
; the new code at $B500
9780-    A9 8D        LDA   #$8D
9782-    8D 0D B2     STA   $B20D
9785-    A9 97        LDA   #$97
9787-    8D 0E B2     STA   $B20E

; continue the boot
978A-    4C 00 B2     JMP   $B200

; (callback is here) capture the code
; at $B500..$BCFF so it survives a
; reboot
978D-    A2 08        LDX   #$08
978F-    A0 00        LDY   #$00
9791-    B9 00 B5     LDA   $B500,Y
9794-    99 00 25     STA   $2500,Y
9797-    C8           INY
9798-    D0 F7        BNE   $9791
979A-    EE 93 97     INC   $9793
979D-    EE 96 97     INC   $9796
97A0-    CA           DEX
97A1-    D0 EE        BNE   $9791

; reboot to my work disk
97A3-    AD E8 C0     LDA   $C0E8
97A6-    4C 00 C5     JMP   $C500

*BSAVE TRACE8,A$9600,L$1A9
*9600G
...reboots slot 6...
...reboots slot 5...

]BSAVE OBJ.B500-BCFF,A$2500,L$800
]CALL -151
```

```
*B500<2500.2CFFM
*B500L

; same command ID (saved at $BF76) that
; was "printed" earlier (passed to the
; routine at $BF6F via $FDED)
B500-   AE 5F 00    LDX   $005F

; use command ID as an index into this
; new array
B503-   BD 80 B5    LDA   $B580,X

; /!\ store the array value in the
; middle of the next JSR instruction
B506-   8D 0A B5    STA   $B50A

; and call it (modified based on the
; previous lookup)
B509-   20 50 B5    JSR   $B550

*B580.

B580- 50 58 68 70 00 00 58
```

The high byte of the JSR address never changes, so depending on the command ID we're calling

```
00 => $B550
01 => $B558
02 => $B568
03 => $B570
06 => $B558 again
```

A nice, compact jump table.

```
*B550L

B550-   A9 09           LDA   #$09
B552-   A0 00           LDY   #$00
B554-   4C 00 BA        JMP   $BA00

*B558L

B558-   A9 19           LDA   #$19
B55A-   A0 00           LDY   #$00
B55C-   20 00 BA        JSR   $BA00
B55F-   A9 29           LDA   #$29
B561-   A0 68           LDY   #$68
B563-   4C 00 BA        JMP   $BA00

*B568L

B568-   A9 31           LDA   #$31
B56A-   A0 00           LDY   #$00
B56C-   4C 00 BA        JMP   $BA00

*B570L

B570-   A9 41           LDA   #$41
B572-   A0 A0           LDY   #$A0
B574-   4C 00 BA        JMP   $BA00
```

Those all look quite similar. Let's see what's at $BA00.

```
*BA00L

; save the two input parameters (A & Y)
BA00-   48              PHA
BA01-   84 58           STY   $58

; seek the drive to a new phase (given
; in A)
BA03-   20 00 BE        JSR   $BE00
```

```
; copy a number of bytes from $B900,Y
; (Y was passed in from the caller) to
; $BB00
BA06-   A2 00        LDX   #$00
BA08-   A4 58        LDY   $58
BA0A-   B9 00 B9     LDA   $B900,Y
BA0D-   9D 00 BB     STA   $BB00,X
BA10-   C8           INY
BA11-   E8           INX

; $0C bytes. Always exactly $0C bytes.
BA12-   E0 0C        CPX   #$0C
BA14-   90 F4        BCC   $BA0A
```

What's at $B900? All kinds of fun(*) stuff.

(*) not guaranteed, actual fun may vary

```
*B900.

B900- 08 09 0A 0B 0C 0D 0E 0F
B908- 10 11 12 13 14 15 16 17
B910- 18 19 1A 1B 1C 1D 1E 1F
B918- 20 21 22 23 24 25 26 27
B920- 28 29 2A 2B 2C 2D 2E 2F
B928- 30 31 32 33 34 35 36 37
B930- 38 39 3A 3B 3C 3D 3E 3F
B938- 60 61 62 63 64 65 66 67
B940- 68 69 6A 6B 6C 6D 6E 6F
B948- 70 71 72 73 74 75 76 77
B950- 78 79 7A 7B 7C 7D 7E 7F
B958- 80 81 82 83 84 85 86 87
B960- 00 00 00 00 00 00 00 00
```

That looks suspiciously like a set of
high bytes for addresses in main
memory. Note how it starts at #$08
(immediately after the text page), then
later jumps from #$3F to #$60 (skipping
over hi-res page 2).

Continuing from $BA16...

```
BA16-   20 30 BA    JSR   $BA30

*BA30L

; current phase
BA30-   AD 65 BF    LDA   $BF65

; convert it to a track number
BA33-   4A          LSR
BA34-   A2 03       LDX   #$03

; (track MOD $10)
BA36-   29 0F       AND   #$0F

; use that as the index into an array
BA38-   A8          TAY
BA39-   B9 10 BC    LDA   $BC10,Y

; and store it in zero page
BA3C-   95 50       STA   $50,X
BA3E-   C8          INY
BA3F-   98          TYA
BA40-   CA          DEX
BA41-   10 F3       BPL   $BA36

*BC10.

BC10- F7 F5 EF EE DF DD D6 BE
BC18- BD BA B7 B6 AF AD AB AA
```

All of those are valid nibbles. Maybe this is setting up another rotating prologue for the next disk read routine?

Continuing from $BA43...

```
BA43-   4C 0C BB    JMP   $BB0C
```

```
*BB0CL
```

Oh joy. Another disk read routine.

```
; I think $54 is the sector count
BB0C-   A2 0C       LDX   #$0C
BB0E-   86 54       STX   $54

; and $55 is the logical sector number
BB10-   A0 00       LDY   #$00
BB12-   8C 54 BB    STY   $BB54
BB15-   84 55       STY   $55

; find a 3-nibble prologue (varies
; by track, set up at $BA39)
BB17-   AE 66 BF    LDX   $BF66
BB1A-   BD 8C C0    LDA   $C08C,X
BB1D-   10 FB       BPL   $BB1A
BB1F-   C5 50       CMP   $50
BB21-   D0 F7       BNE   $BB1A
BB23-   BD 8C C0    LDA   $C08C,X
BB26-   10 FB       BPL   $BB23
BB28-   C5 51       CMP   $51
BB2A-   D0 EE       BNE   $BB1A
BB2C-   BD 8C C0    LDA   $C08C,X
BB2F-   10 FB       BPL   $BB2C
BB31-   C5 52       CMP   $52
BB33-   D0 E5       BNE   $BB1A
```

```
; logical sector number (initialized to
; #$00 at $BB15)
BB35-    A4 55          LDY   $55

; use the sector number as an index
; into the $0C-length page array we
; set up at $BA06)
BB37-    B9 00 BB       LDA   $BB00,Y

; and modify the upcoming code
BB3A-    8D 55 BB       STA   $BB55
BB3D-    E6 55          INC   $55

; get the actual byte
BB3F-    BC 8C C0       LDY   $C08C,X
BB42-    10 FB          BPL   $BB3F
BB44-    B9 00 BC       LDA   $BC00,Y
BB47-    0A             ASL
BB48-    0A             ASL
BB49-    0A             ASL
BB4A-    0A             ASL
BB4B-    BC 8C C0       LDY   $C08C,X
BB4E-    10 FB          BPL   $BB4B
BB50-    19 00 BC       ORA   $BC00,Y

; modified earlier (at $BB3A) to be the
; desired page in memory
BB53-    8D 00 FF       STA   $FF00
BB56-    EE 54 BB       INC   $BB54
BB59-    D0 E4          BNE   $BB3F
BB5B-    EE 55 BB       INC   $BB55

; find a 1-nibble epilogue (also varies
; by track)
BB5E-    BD 8C C0       LDA   $C08C,X
BB61-    10 FB          BPL   $BB5E
BB63-    C5 53          CMP   $53
BB65-    D0 A5          BNE   $BB0C
```

```
; loop for all $0C sectors
BB67-   C6 54        DEC   $54
BB69-   D0 CA        BNE   $BB35
BB6B-   60           RTS
```

So we've read $0C sectors from the current track, which is the most you can fit on a track with this kind of "4-and-4" nibble encoding scheme.

Continuing from $BA19...

```
; increment the pointer to the next
; memory page
BA19-   A5 58        LDA   $58
BA1B-   18           CLC
BA1C-   69 0C        ADC   #$0C
BA1E-   A8           TAY

; if the next page is #$00, we're done
BA1F-   B9 00 B9     LDA   $B900,Y
BA22-   F0 07        BEQ   $BA2B

; otherwise loop back, where we'll move
; the drive head one full track forward
; and read another $0C sectors
BA24-   68           PLA
BA25-   18           CLC
BA26-   69 02        ADC   #$02
BA28-   D0 D6        BNE   $BA00

; execution continues here (from $BA22)
BA2B-   68           PLA
BA2C-   60           RTS
```

Now we have a whole bunch of new stuff
in memory. In this case, $B550 started
on track 4.5 (A = #$09 on entry to
$BA00) and filled $0800..$3FFF and
$6000..$87FF. If we "print" a different
character, the routine at $B500 will
route through one of the other
subroutines -- $B558, $B568, or $B570.
Each of them starts on a different
track (A) and uses a different starting
index (Y) into the page array at $B900.
The underlying routine at $BA00 doesn't
know anything else; it just seeks and
reads $0C sectors per track until the
target page = #$00.

Continuing from $B50C...

```
B50C-   20 00 B7    JSR   $B700

*B700L

; oh joy, another decryption loop
B700-   A2 00       LDX   #$00
B702-   BD 00 B6    LDA   $B600,X
B705-   5D 00 BE    EOR   $BE00,X
B708-   9D 00 03    STA   $0300,X
B70B-   E8          INX
B70C-   E0 D0       CPX   #$D0
B70E-   90 F2       BCC   $B702

B710-   CE 13 B7    DEC   $B713      /!\
B713-   6D 09 B7    ADC   $B709
B716-   60          RTS
```

And more self-modifying code.

```
*B713:6C
*B713L

B713-   6C 09 B7    JMP   ($B709)
```

...which will jump to the newly decrypted code at $0300.

To recap: after 7 boot traces, the bootloader prints a null character via $FD90, which jumps to $FDED, which jumps to ($0036), which jumps to $BF6F, which calls $BEB0, which decrypts the code at $BF9F and returns just in time to execute it. $BF9F reads 3 sectors into $B200-$B4FF, pushes #$00/#$3B to the stack and exits via RTS, which returns to $003C, which jumps to $B200. $B200 reads 8 sectors into $B500-$BCFF from tracks 2 and 2.5, shifting between the adjacent quarter tracks every two sectors, then jumps to $B500, which calls $B5[50|58|68|70], which reads actual game code from multiple tracks starting at track 4.5, 9.5, 24.5, or 32.5. Then it calls $B700, which decrypts $B600 into $0300 (using $BE00+ as the decryption key) and exits via a jump to $0300.

I'm sure(*) the code at $0300 will be straightforward and easy to understand.

(*) not actually sure

Chapter 11
In Which We Go Completely Insane

The code at $B600 is decrypted with the code at $BE00 as the key. That was originally copied from the text page (the first time, not the second time).

```
*BLOAD BOOT1 0400-07FF,A$2400

*BE00<2600.26FFM  ; move key into place
*B710:60          ; stop after loop
*B700G            ; decrypt

*300L

; wipe almost everything we've already
; loaded at the top of main memory (!)
0300-   A0 00       LDY   #$00
0302-   98          TYA
0303-   99 00 B1    STA   $B100,Y
0306-   C8          INY
0307-   D0 F9       BNE   $0302
0309-   EE 05 03    INC   $0305
030C-   AE 05 03    LDX   $0305

; stop at $BD00
030F-   E0 BD       CPX   #$BD
0311-   90 F0       BCC   $0303
```

OK, so all we're left with in memory is the RWTS at $BD00..$BFFF (including the $FDED vector at $BF6F) and the single page at $B000 (more on that later). Oh, and the game, but who cares about that? (Kidding!)

Moving on...

```
0313-   A9 07       LDA   #$07
0315-   20 80 03    JSR   $0380
```

```
*380L

; drive seek (A = #$07, so track 3.5)
0380-   20 00 BE    JSR   $BE00

; Pull 4 bytes from the stack, thus
; negating the JSR that got us here
; (at $0315) and the JSR before that
; (at $B50C).
0383-   A2 03       LDX   #$03
0385-   68          PLA
0386-   CA          DEX
0387-   10 FC       BPL   $0385

; continue by jumping directly to the
; place we would have returned to, if
; we hadn't just popped the stack
; (which we did)
0389-   4C 18 03    JMP   $0318
```

What. The. Fahrvergnugen.

```
*318L
```

Oh joy. Another disk routine.

```
0318-   AE 66 BF    LDX   $BF66

; Y = command ID (a.k.a. the character
; we "printed" way back when)
031B-   A4 5F       LDY   $5F
```

```
; find a 3-nibble prologue ("D4 D5 D7")
031D-   BD 8C C0    LDA   $C08C,X
0320-   10 FB       BPL   $031D
0322-   C9 D4       CMP   #$D4
0324-   D0 F7       BNE   $031D
0326-   BD 8C C0    LDA   $C08C,X
0329-   10 FB       BPL   $0326
032B-   C9 D5       CMP   #$D5
032D-   D0 F3       BNE   $0322
032F-   BD 8C C0    LDA   $C08C,X
0332-   10 FB       BPL   $032F
0334-   C9 D7       CMP   #$D7
0336-   D0 F3       BNE   $032B

; branch when Y goes negative
0338-   88          DEY
0339-   30 08       BMI   $0343

; read one byte from disk, store it in
; $5E (not shown)
033B-   20 51 03    JSR   $0351

; read 1 more byte from disk
033E-   20 51 03    JSR   $0351

; loop back, unless the byte is #$00
0341-   D0 F5       BNE   $0338
```

OK, I see it. It was hard to follow at first because the exit condition was checked before I knew it was a loop. But this is a loop. On track 3.5, there is a 3-nibble prologue ("D4 D5 D7"), then an array of values. Each value is two bytes. We're just finding the Nth value in the array. But to what end?

```
; execution continues here (from $0339)
; read 2 more bytes from disk and push
; them to the stack
0343-   20 51 03    JSR   $0351
0346-   48          PHA
0347-   20 51 03    JSR   $0351
034A-   48          PHA
```

Ah! A new "return" address!

Oh God. A new "return" address.

That's what this is: an array of addresses, indexed by the command ID. That's what we're looping through, and eventually pushing to the stack: the entry point for this block of the game.

But the entry point for each block is read directly from disk, so I have no idea what any of them are. Add that to the list of things I get to come back to later.

Onward...

```
; turn off the drive motor
034B-   BD 88 C0    LDA   $C088,X
034E-   4C 62 03    JMP   $0362

*362L

; wipe this routine from memory
0362-   A0 00       LDY   #$00
0364-   99 00 03    STA   $0300,Y
0367-   C8          INY
0368-   C0 65       CPY   #$65
036A-   90 F8       BCC   $0364
```

```
; push several values to the stack
036C-   A9 BE       LDA   #$BE
036E-   48          PHA
036F-   A9 AF       LDA   #$AF
0371-   48          PHA
0372-   A9 34       LDA   #$34
0374-   48          PHA
0375-   CE 78 03    DEC   $0378     /!\
0378-   29 CE       AND   #$CE
```

More self-modifying code.

```
*378:28
*378L

; pop that #$34 off the stack, but use
; it as status registers (weird, but
; legal -- if it turns out to matter,
; I can figure out exactly which status
; bits get set and cleared)
0378-   28          PLP
0379-   CE 7C 03    DEC   $037C     /!\
037C-   61 60       ADC   ($60,X)

*37C:60
*37CL

037C-   60          RTS
```

Now we "return" to $BEB0 (because we
pushed ##$BE/##$AF/##$34 but then popped
##$34). The routine at $BEB0 reencrypts
the code at $BF9F (because now we've
XOR'd it twice so it's back to its
original form) and exits via RTS, which
"returns" to the address we pushed to
the stack at $0346, which we read from
track 3.5 and varies based on the
command we're still executing, which is
really the character we "printed" via
the output vector.

Which is all completely insane.

Chapter 12
In Which We Are Restored To Sanity
LOL, Just Kidding
But Soon, Maybe

Since the "JSR $B700" at $B50C never returns (because of the crazy stack manipulation at $0383), that's the last chance I'll get to interrupt the boot and capture this chunk of game code in memory. I won't know what the entry point is (because it's read from disk), but one thing at a time.

```
*BLOAD TRACE8
.
. [same as previous trace]
.
; unconditionally break after loading
; the game code into main memory
978D-   A9 4C       LDA   #$4C
978F-   8D 0C B5    STA   $B50C
9792-   A9 59       LDA   #$59
9794-   8D 0D B5    STA   $B50D
9797-   A9 FF       LDA   #$FF
9799-   8D 0E B5    STA   $B50E

; continue the boot
979C-   4C 00 B5    JMP   $B500

*BSAVE TRACE9,A$9600,L$19F
*9600G
...reboots slot 6...
...read read read...
<beep>
```

Success!

```
*C050 C054 C057 C052
```

[displays a very nice picture of a gumball machine which is featured in the game's introduction sequence]

```
*C051
```

OK, let's save it. According to the table at $B900, we filled $0800..$3FFF and $6000..$87FF. $0800+ is overwritten on reboot by the boot sector and later by the HELLO program on my work disk. $8000+ is also overwritten by Diversi-DOS 64K, which is annoying but not insurmountable. So I'll save this in pieces.

```
*C500G
...
]BSAVE BLOCK 00.2000-3FFF,A$2000,L$2000
]BRUN TRACE9
...reboots slot 6...
<beep>
*2800<800.1FFFM
*C500G
...
]BSAVE BLOCK 00.0800-1FFF,A$2800,L$1800
]BRUN TRACE9
...reboots slot 6...
<beep>
*2000<6000.87FFM
*C500G
...
]BSAVE BLOCK 00.6000-87FF,A$2000,L$2800
```

Now what? Well this is only the first chunk of game code, loaded by printing a null character. By setting up another trace and changing the value of zero page $5F, I can route $B500 through a different subroutine at $B558 or $B568 or $B570 and load a different chunk of game code.

```
]CALL -151

*BLOAD OBJ.B500-BCFF,A$B500
```

According to the lookup table at $B580, $B500 routed through $B558 to load the game code. Here is that routine:

```
*B558L

B558-   A9 19       LDA   #$19
B55A-   A0 00       LDY   #$00
B55C-   20 00 BA    JSR   $BA00
B55F-   A9 29       LDA   #$29
B561-   A0 68       LDY   #$68
B563-   4C 00 BA    JMP   $BA00
```

The first call to $BA00 will fill up the same parts of memory as we filled when the character (in $5F) was #$00 -- $0800..$3FFF and $6000..$87FF. But it starts reading from disk at phase $19 (track $0C 1/2), so it's a completely different chunk of code.

The second call to $BA00 starts reading at phase $29 (track $14 1/2), and it looks at $B900 + Y = $B968 to get the list of pages to fill in memory.

```
*B968.

B968- 88 89 8A 8B 8C 8D 8E 8F
B970- 90 91 92 93 94 95 96 97
B978- 98 99 9A 9B 9C 9D 9E 9F
B980- A0 A1 A2 A3 A4 A5 A6 A7
B988- A8 A9 AA AB AC AD AE AF
B990- B2 B2 B2 B2 B2 B2 B2 B2
B998- 00 00 00 00 00 00 00 00
```

The first call to $BA00 stopped just
shy of $8800, and that's exactly where
we pick up in the second call. I'm
guessing that $B200 isn't really used,
but the track read routine at $BA00 is
"dumb" in that it always reads exactly
$0C sectors from each track. So we're
filling up $8800..$AFFF, then reading
the rest of the last track into $B200
over and over.

Let's capture it.

```
*BLOAD TRACE9
.
. [same as previous trace]
.
; again, break to the monitor at $B50C
; instead of continuing to $B700
978D-   A9 4C       LDA   #$4C
978F-   8D 0C B5    STA   $B50C
9792-   A9 59       LDA   #$59
9794-   8D 0D B5    STA   $B50D
9797-   A9 FF       LDA   #$FF
9799-   8D 0E B5    STA   $B50E

; change the character being "printed"
; to #$01 just before the bootloader
; uses it to load the appropriate chunk
; of game code
979C-   A9 01       LDA   #$01
979E-   85 5F       STA   $5F

; continue the boot
97A0-   4C 00 B5    JMP   $B500
```

```
*BSAVE TRACE10,A$9600,L$1A3
*9600G
...reboots slot 6...
...read read read...
<beep>

*C050 C054 C057 C052

[displays a very nice picture of the
 main game screen]

*C051

*C500G
...
]BSAVE BLOCK 01.2000-3FFF,A$2000,L$2000
]BRUN TRACE10
...reboots slot 6...
<beep>
*2800<800.1FFFM
*C500G
...
]BSAVE BLOCK 01.0800-1FFF,A$2800,L$1800
]BRUN TRACE9
...reboots slot 6...
<beep>
*2000<6000.AFFFM
*C500G
...
]BSAVE BLOCK 01.6000-AFFF,A$2000,L$5000
```

And similarly with blocks 2 and 3 (not shown here, but you can look at TRACE11 and TRACE12 on my work disk). Blocks 4 and 5 get special-cased earlier (at $BF86 and $BF8D, respectively), so they never reach $B500 to load anything from disk. Block 6 is the same as block 1.

That's it. I've captured all the game code. Here's what the "game" looks like at this point:

```
]CATALOG

C1983 DSR^C#254
019 FREE

 A 002 HELLO
 B 003 BOOT0
*B 003 TRACE
 B 003 BOOT1 0300-03FF
*B 003 TRACE2
 B 003 BOOT1 0100-01FF
*B 003 TRACE3
 B 006 BOOT1 0400-07FF
*B 003 TRACE4
 B 005 BOOT2 0500-07FF
*B 003 TRACE5
 B 003 BOOT2 B000-B0FF
 B 003 BOOT2 0100-01FF
*B 003 TRACE6
 B 003 BOOT3 0000-00FF
*B 003 TRACE7
 B 005 OBJ.B200-B4FF
*B 003 TRACE8
 B 010 OBJ.B500-BCFF
*B 003 TRACE9
 B 026 BLOCK 00.0800-1FFF
 B 034 BLOCK 00.2000-3FFF
 B 042 BLOCK 00.6000-87FF
*B 003 TRACE10
 B 026 BLOCK 01.0800-1FFF
 B 034 BLOCK 01.2000-3FFF
 B 082 BLOCK 01.6000-AFFF
*B 003 TRACE11
 B 026 BLOCK 02.0800-1FFF
 B 034 BLOCK 02.2000-3FFF
 B 042 BLOCK 02.6000-87FF
                              [...]
```

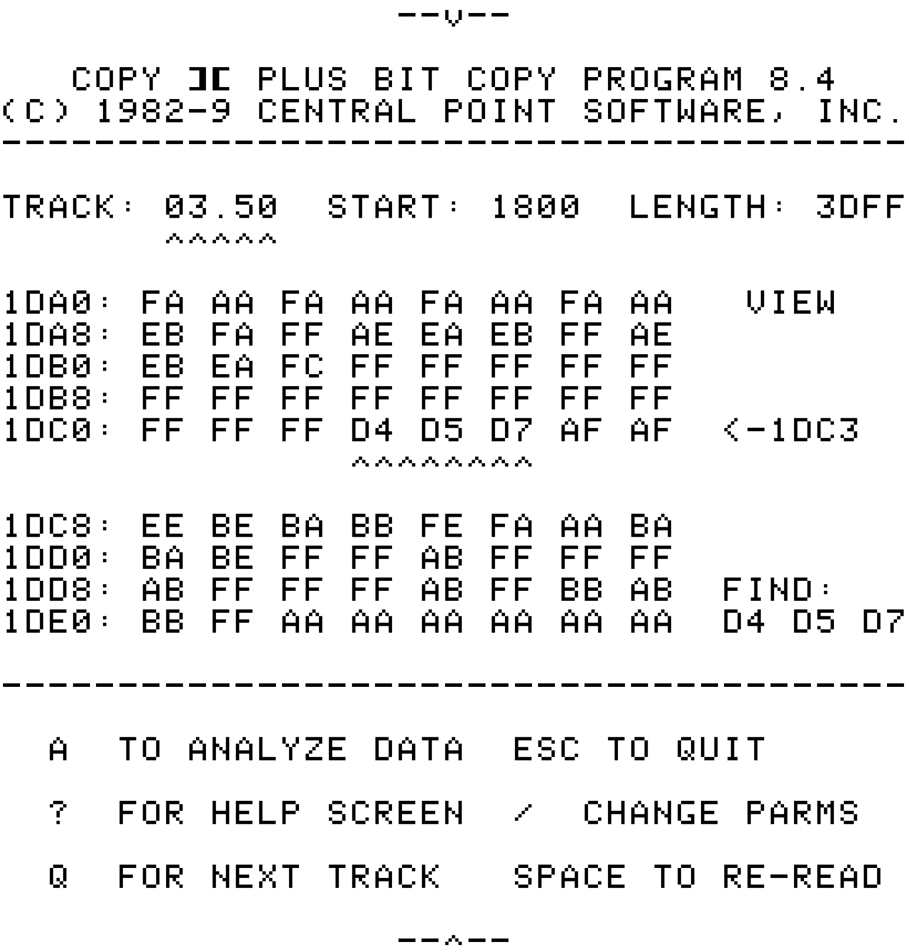
```
*B 003 TRACE12
 B 034 BLOCK 03.2000-3FFF
```

It's... it's beautiful. *wipes tear*

Chapter 13
In Which Every Exit Is An Entrance Somewhere Else

I've captured all the blocks of the game code (I think), but I still have no idea how to run it. The entry points for each block are read directly from disk, in the loop at $031D.

Rather than try to boot trace every possible block, I'm going to load up the original disk in a nibble editor and do the calculations myself. The array of entry points is on track 3.5. Firing up Copy II Plus nibble editor, I searched for the same 3-nibble prologue that the code at $031D searches for ("D4 D5 D7"), and lo and behold!



```
                 --v--

   COPY ][ PLUS BIT COPY PROGRAM 8.4
(C) 1982-9 CENTRAL POINT SOFTWARE, INC.
---------------------------------------

TRACK: 03.50  START: 1800  LENGTH: 3DFF
       ^^^^^

1DA0: FA AA FA AA FA AA FA AA   VIEW
1DA8: EB FA FF AE EA EB FF AE
1DB0: EB EA FC FF FF FF FF FF
1DB8: FF FF FF FF FF FF FF FF
1DC0: FF FF FF D4 D5 D7 AF AF  <-1DC3
               ^^^^^^^^

1DC8: EE BE BA BB FE FA AA BA
1DD0: BA BE FF FF AB FF FF FF
1DD8: AB FF FF FF AB FF BB AB  FIND:
1DE0: BB FF AA AA AA AA AA AA  D4 D5 D7

---------------------------------------

  A  TO ANALYZE DATA  ESC TO QUIT

  ?  FOR HELP SCREEN  /  CHANGE PARMS

  Q  FOR NEXT TRACK   SPACE TO RE-READ

                 --^--
```

After the "D4 D5 D7" prologue, I find an array of 4-and-4-encoded nibbles starting at offset $1DC6. Breaking them down into pairs and decoding them with the 4-4 encoding scheme, I get this list of bytes:

nibbles	byte
AF AF	#$0F
EE BE	#$9C
BA BB	#$31
FE FA	#$F8
AA BA	#$10
BA BE	#$34
FF FF	#$FF
AB FF	#$57
FF FF	#$FF
AB FF	#$57
FF FF	#$FF
AB FF	#$57
BB AB	#$23
BB FF	#$77

And now -- maybe! -- I have my list of entry points for each block of the game code.

Only one way to know for sure...

```
]PR#5
...
]CALL -151
```

```
; clear main memory so I'm not
; accidentally relying on random stuff
; left over from all my other testing
*800:0 N 801<800.BEFEM

; load all of block 0 into place
*BLOAD BLOCK 00.0800-1FFF,A$800
*BLOAD BLOCK 00.2000-3FFF,A$2000
*BLOAD BLOCK 00.6000-87FF,A$6000

; jump to the entry point I found on
; track 3.5 (+1, since the original
; code pushes it to the stack and
; "returns" to it)
*F9DG

[displays the game intro sequence]
```

does a little happy dance in my chair

We have no further use for the original disk. Now would be an excellent time to take it out of the drive and store it in a cool, dry place.

Chapter 14
In Which Two Wrongs Don't Make A Oh God I Can't Even With This Pun

Remember when I said I'd look at $BD00 later? The time has come. Later is now.

The output vector at $BF6F has special case handling if A = #$04. Instead of continuing to $0300 and $B500, it jumps directly to $BD00. What's so special about $BD00?

The code at $BD00 was moved there very early in the boot process, from page $0500 on the text screen (the first time we loaded code into the text screen, not the second time). So it's in "BOOT1 0400-07FF" on my work disk.

```
]PR#5
...
]BLOAD BOOT1 0400-07FF,A$2400
]CALL -151

*BD00<2500.25FFM
*BD00L

; turn on drive motor
BD00-    AE 66 BF     LDX   $BF66
BD03-    BD 89 C0     LDA   $C089,X

; wait for drive to settle
BD06-    A9 64        LDA   #$64
BD08-    20 A8 FC     JSR   $FCA8

; seek to phase $10 (track 8)
BD0B-    A9 10        LDA   #$10
BD0D-    20 00 BE     JSR   $BE00

; seek to phase $02 (track 1)
BD10-    A9 02        LDA   #$02
BD12-    20 00 BE     JSR   $BE00
```

```
; initialize data latches
BD15-   A0 FF        LDY   #$FF
BD17-   BD 8D C0     LDA   $C08D,X
BD1A-   BD 8E C0     LDA   $C08E,X
BD1D-   9D 8F C0     STA   $C08F,X
BD20-   1D 8C C0     ORA   $C08C,X

; wait
BD23-   A9 80        LDA   #$80
BD25-   20 A8 FC     JSR   $FCA8
BD28-   20 A8 FC     JSR   $FCA8

; Oh God
BD2B-   BD 8D C0     LDA   $C08D,X
BD2E-   BD 8E C0     LDA   $C08E,X
BD31-   98           TYA
BD32-   9D 8F C0     STA   $C08F,X
BD35-   1D 8C C0     ORA   $C08C,X
BD38-   48           PHA
BD39-   68           PLA
BD3A-   C1 00        CMP   ($00,X)
BD3C-   C1 00        CMP   ($00,X)
BD3E-   EA           NOP
BD3F-   C8           INY

; Oh God
BD40-   9D 8D C0     STA   $C08D,X
BD43-   1D 8C C0     ORA   $C08C,X
BD46-   B9 8F BD     LDA   $BD8F,Y
BD49-   D0 EF        BNE   $BD3A
BD4B-   A8           TAY
BD4C-   EA           NOP
BD4D-   EA           NOP
BD4E-   B9 00 B0     LDA   $B000,Y <-- !
BD51-   48           PHA
BD52-   4A           LSR
BD53-   09 AA        ORA   #$AA
```

```
; Oh God Oh God Oh God
BD55-   9D 8D C0    STA   $C08D,X
BD58-   DD 8C C0    CMP   $C08C,X
BD5B-   C1 00       CMP   ($00,X)
BD5D-   EA          NOP
BD5E-   EA          NOP
BD5F-   48          PHA
BD60-   68          PLA
BD61-   68          PLA
BD62-   09 AA       ORA   #$AA
BD64-   9D 8D C0    STA   $C08D,X
BD67-   DD 8C C0    CMP   $C08C,X
BD6A-   48          PHA
BD6B-   68          PLA
BD6C-   C8          INY
BD6D-   D0 DF       BNE   $BD4E
BD6F-   A9 D5       LDA   #$D5
BD71-   C1 00       CMP   ($00,X)
BD73-   EA          NOP
BD74-   EA          NOP
BD75-   9D 8D C0    STA   $C08D,X
BD78-   1D 8C C0    ORA   $C08C,X
BD7B-   A9 08       LDA   #$08
BD7D-   20 A8 FC    JSR   $FCA8
BD80-   BD 8E C0    LDA   $C08E,X
BD83-   BD 8C C0    LDA   $C08C,X

; seek back to track 3.5
BD86-   A9 07       LDA   #$07
BD88-   20 00 BE    JSR   $BE00

; turn off drive motor and exit
; gracefully
BD8B-   BD 88 C0    LDA   $C088,X
BD8E-   60          RTS
```

This is a disk write routine. It's
taking the data at $B000 (that mystery
sector that was loaded even earlier in
the boot) and writing it to track 1.

Because high scores.

That's what's at $B000. High scores.
[Edit from the future: also some
 persistent joystick options.]

Why is this so distressing? Because it
means I'll get to include a full read/
write RWTS on my crack (which I haven't
even starting building yet, but soon!)
so it can save high scores like the
original game. Because anything less is
obviously unacceptable.

Chapter 15
The Right Ones In The Right Order

Let's step back from the low-level code for a moment and talk about how this game interacts with the disk at a high level.

- There is no runtime protection check. All the "protection" is structural -- data is stored on whole tracks, half tracks, and even some consecutive quarter tracks. Once the game code is in memory, there are no nibble checks or secondary protections.

- The game code itself contains no disk code. They're completely isolated. I proved this by loading the game code from my work disk and jumping to the entry point. (I tested the animated introduction, but you can also run the game itself by loading the block $01 files into memory and jumping to $31F9. The game runs until you finish the level and it tries to load the first cut scene from disk.)

- The game code communicates with the disk subsystem through the output vector, i.e. by printing #$00..#$06 to $FDED. The disk code handles filling the screen with a pseudo-random color, reading the right chunks from the right places on disk and putting them into the right places in memory, then jumping to the right address to continue. (In the case of printing #$04, it handles writing the right data in memory to the right place on disk.)

- Game code lives at $0800..$AFFF, zero
  page, and one page at $B000 for high
  scores. The disk subsystem clobbers
  the text screen at $0400 (using lo-
  res graphics for the color fills).
  All memory above $B100 is available;
  in fact, most of it is wiped (at
  $0300) after every disk command.

This is great news. It gives us total
flexibility to recreate the game from
its constituent pieces.

Chapter 16
A Man, A Plan, A Canal, &c.

Here's the plan:

1. Write the game code to a standard 16-sector disk

2. Write a bootloader and RWTS that can read the game code into memory

3. Write some glue code to mimic the original output vector at $BF6F (A = command ID from #$00-#$06, all other values actually print) so I don't need to change any game code

4. Declare victory (*)

(*) take a nap

Looking at the length of each block and dividing by 16, I can space everything out on separate tracks and still have plenty of room. This means each block can start on its own track, which saves a few bytes by being able to hard-code the starting sector for each block.

The disk map will look like this:

tr	memory range	notes
00	$BD00..$BFFF	Gumboot
01	$B000..$B3FF	scores/zpage/glue
02	$0800..$17FF	block 0
03	$1800..$27FF	block 0
04	$2800..$37FF	block 0
05	$3800..$3FFF	block 0
06	$6000..$67FF	block 0
07	$6800..$77FF	block 0
08	$7000..$87FF	block 0
09	$0800..$17FF	block 1
0A	$1800..$27FF	block 1
0B	$2800..$37FF	block 1
0C	$3800..$3FFF	block 1
0D	$6000..$6FFF	block 1
0E	$7000..$7FFF	block 1
0F	$8000..$8FFF	block 1
10	$9000..$9FFF	block 1
11	$A000..$AFFF	block 1
12	$0800..$17FF	block 2
13	$1800..$27FF	block 2
14	$2800..$37FF	block 2
15	$3800..$3FFF	block 2
16	$6000..$6FFF	block 2
17	$7000..$7FFF	block 2
18	$8000..$87FF	block 2
19	$2000..$2FFF	block 3
1A	$3000..$3FFF	block 3

I wrote a build script to take all the chunks of game code I captured way back in chapter 12. And by "script," I mean "BASIC program."

```
]PR#5
...

 10  REM  MAKE GUMBALL
 11  REM  S6,D1=BLANK DISK
 12  REM  S5,D1=WORK DISK
 20  D$ =  CHR$ (4)
```

Load the first part of block 0:

```
 30  PRINT D$"BLOAD BLOCK 00.0800-1FFF,
     A$1000"
 40  PRINT D$"BLOAD BLOCK 00.2000-3FFF,
     A$2800"
```

Write it to tracks $02-$05:

```
 50  PAGE = 16:COUNT = 56:TRK = 2:
     SEC = 0: GOSUB 1000
```

Load the second part of block 0:

```
 60  PRINT D$"BLOAD BLOCK 00.6000-87FF,
     A$6000"
```

Write it to tracks $06-$08:

```
 70  PAGE = 96:COUNT = 40:TRK = 6:
     SEC = 0: GOSUB 1000
```

And so on, for all the other blocks:

```
 80  PRINT D$"BLOAD BLOCK 01.0800-1FFF,
     A$1000"
 90  PRINT D$"BLOAD BLOCK 01.2000-3FFF,
     A$2800"
 100 PAGE = 16:COUNT = 56:TRK = 9:
     SEC = 0: GOSUB 1000
 110 PRINT D$"BLOAD BLOCK 01.6000-AFFF,
     A$6000"
 120 PAGE = 96:COUNT = 80:TRK = 13:
     SEC = 0: GOSUB 1000
 130 PRINT D$"BLOAD BLOCK 02.0800-1FFF,
     A$1000"
 140 PRINT D$"BLOAD BLOCK 02.2000-3FFF,
     A$2800"
 150 PAGE = 16:COUNT = 56:TRK = 18:
     SEC = 0: GOSUB 1000
 160 PRINT D$"BLOAD BLOCK 02.6000-87FF,
     A$6000"
 170 PAGE = 96:COUNT = 40:TRK = 22:
     SEC = 0: GOSUB 1000
 180 PRINT D$"BLOAD BLOCK 03.2000-3FFF,
     A$2000"
 190 PAGE = 32:COUNT = 32:TRK = 25:
     SEC = 0: GOSUB 1000
 200 PRINT D$"BLOAD BOOT2 0500-07FF,
     A$2500"
 210 PAGE = 39:COUNT = 1:TRK = 1:
     SEC = 0: GOSUB 1000
 220 PRINT D$"BLOAD BOOT3 0000-00FF,
     A$1000"
 230 POKE 4150,0: POKE 4151,178: REM
     SET ($36) TO $B200
 240 PAGE = 16:COUNT = 1:TRK = 1:
     SEC = 7: GOSUB 1000
 999  END
```

[...]

```
 1000  REM  WRITE TO DISK
 1010  PRINT D$"BLOAD WRITE"
 1020  POKE 908,TRK
 1030  POKE 909,SEC
 1040  POKE 913,PAGE
 1050  POKE 769,COUNT
 1060  CALL 768
 1070  RETURN

]SAVE MAKE
```

The BASIC program relies on a short assembly language routine to do the actual writing to disk. Here is that routine (loaded on line 1010):

```
]CALL -151

; page count (set from BASIC)
0300-   A9 D1          LDA   #$D1       o_O
0302-   85 FF          STA   $FF

; logical sector (incremented)
0304-   A9 00          LDA   #$00
0306-   85 FE          STA   $FE

; call RWTS to write sector
0308-   A9 03          LDA   #$03
030A-   A0 88          LDY   #$88
030C-   20 D9 03       JSR   $03D9

; increment logical sector, wrap around
; from $0F to $00 and increment track
030F-   E6 FE          INC   $FE
0311-   A4 FE          LDY   $FE
0313-   C0 10          CPY   #$10
0315-   D0 07          BNE   $031E
0317-   A0 00          LDY   #$00
0319-   84 FE          STY   $FE
031B-   EE 8C 03       INC   $038C
```

```
; convert logical to physical sector
031E-   B9 40 03    LDA   $0340,Y
0321-   8D 8D 03    STA   $038D

; increment page to write
0324-   EE 91 03    INC   $0391

; loop until done with all sectors
0327-   C6 FF       DEC   $FF
0329-   D0 DD       BNE   $0308
032B-   60          RTS

*340.34F

; logical to physical sector mapping
0340- 00 07 0E 06 0D 05 0C 04
0348- 0B 03 0A 02 09 01 08 0F

*388.397

; RWTS parameter table, pre-initialized
; with slot (#$06), drive (#$01), and
; RWTS write command (#$02)
0388- 01 60 01 00 D1 D1 FB F7
                  ^^ ^^
               track/sector
             (set from BASIC)

0390- 00 D1 00 00 02 00 00 60
         ^^
      address (set from BASIC)
```

```
*BSAVE WRITE,A$300,L$98
```

[S6,D1=blank disk]

```
]RUN MAKE
...write write write...
```

Boom! The entire game is on tracks
$02-$1A of a standard 16-sector disk.

Now we get to write an RWTS.

Chapter 17
Introducing Gumboot

Gumboot is a fast bootloader and full read/write RWTS. It fits in 4 sectors on track 0, including a boot sector. It uses only 6 pages of memory for all its code + data + scratch space. It uses no zero page addresses after boot. It can start the game from a cold boot in 3 seconds (not a typo). That's twice as fast as the original disk.

qkumba wrote it from scratch, because of course he did. I, um, mostly just cheered.

After boot-time initialization, Gumboot is dead simple and always ready to use:

entry	command	parameters
$BD00	read	A = first track
		Y = first page
		X = sector count
$BE00	write	A = sector
		Y = page
$BF00	seek	A = track

That's it. It's so small, there's $80 unused bytes at $BF80. You could fit a cute message in there! (We didn't.)

Some important notes:

- The read routine reads consecutive
  tracks in physical sector order into
  consecutive pages in memory. There
  is no translation from physical to
  logical sectors.

- The write routine writes one sector,
  and also assumes a physical sector
  number.

- The seek routine can seek forward or
  back to any whole track. (I mention
  this because some fastloaders can
  only seek forward.)

I said Gumboot takes 6 pages in memory,
but I've only mentioned 3. The other 3
are for data:

```
$BA00..$BB55 - scratch space for write
  (technically available as long as you
  don't mind them being clobbered
  during disk write)
$BB00..$BCFF - data tables (initialized
  once during boot)
```

Chapter 18
Gumboot Boot0

Gumboot starts, as all disks start, on
track $00. Sector $00 (boot0) reuses
the disk controller ROM routine to read
sector $0E, $0D, and $0C (boot1). Boot0
creates a few data tables, modifies the
boot1 code to accommodate booting from
any slot, and jumps to it.

Boot0 is loaded at $0800 by the disk
controller ROM routine.

```
; tell the ROM to load only this sector
; (we'll do the rest manually)
0800-  [01]

; The accumulator is #$01 after loading
; sector $00, #$03 after loading sector
; $0E, #$05 after loading sector $0D,
; and #$07 after loading sector $0C.
; We shift it right to divide by 2,
; then use that to calculate the load
; address of the next sector.
0801-   4A          LSR

; Sector $0E => $BD00
; Sector $0D => $BE00
; Sector $0C => $BF00
0802-   69 BC       ADC   #$BC

; store the load address
0804-   85 27       STA   $27

; shift the accumulator again (now that
; we've stored the load address)
0806-   0A          ASL
0807-   0A          ASL
```

```
; transfer X (boot slot x16) to the
; accumulator, which will be useful
; later but doesn't affect the carry
; flag we may have just tripped with
; the two "ASL" instructions
0808-   8A          TXA

; if the two "ASL" instructions set the
; carry flag, it means the load address
; was at least #$C0, which means we've
; loaded all the sectors we wanted to
; load and we should exit this loop
0809-   B0 0D       BCS   $0818

; Set up next sector number to read.
; The disk controller ROM does this
; once already, but due to quirks of
; timing, it's much faster to increment
; it twice so the next sector you want
; to load is actually the next sector
; under the drive head. Otherwise you
; end up waiting for the disk to spin
; an entire revolution, which is quite
; slow.
080B-   E6 3D       INC   $3D

; Set up the "return" address to jump
; to the "read sector" entry point of
; the disk controller ROM. This could
; be anywhere in $Cx00 depending on the
; slot we booted from, which is why we
; put the boot slot in the accumulator
; at $0808.
080D-   4A          LSR
080E-   4A          LSR
080F-   4A          LSR
0810-   4A          LSR
0811-   09 C0       ORA   #$C0
```

```
; push the entry point on the stack
0813-   48          PHA
0814-   A9 5B       LDA   #$5B
0816-   48          PHA

; "Return" to the entry point via RTS.
; The disk controller ROM always jumps
; to $0801 (remember, that's why we
; had to move it and patch it to trace
; the boot all the way back in chapter
; 1), so this entire thing is a loop
; that only exits via the "BCS" branch
; at $0809.
0817-   60          RTS

; Execution continues here (from $0809)
; after three sectors have been loaded
; into memory at $BD00..$BFFF.
; There are a number of places in boot1
; that hit a slot-specific soft switch
; (read a nibble from disk, turn off
; the drive, &c). Rather than the usual
; form of "LDA $C08C,X", we will use
; "LDA $C0EC" and modify the $EC byte
; in advance, based on the boot slot.
; $08A4 is an array of all the places
; in the Gumboot code that get this
; adjustment.
0818-   09 8C       ORA   #$8C
081A-   A2 00       LDX   #$00
081C-   BC AF 08    LDY   $08AF,X
081F-   84 26       STY   $26
0821-   BC B0 08    LDY   $08B0,X
0824-   F0 0A       BEQ   $0830
0826-   84 27       STY   $27
0828-   A0 00       LDY   #$00
082A-   91 26       STA   ($26),Y
082C-   E8          INX
082D-   E8          INX
082E-   D0 EC       BNE   $081C
```

```
; munge $EC -> $E8 (used later to turn
; off the drive motor)
0830-   29 F8       AND   #$F8
0832-   8D FC BD    STA   $BDFC

; munge $E8 -> $E9 (used later to turn
; on the drive motor)
0835-   09 01       ORA   #$01
0837-   8D 0B BD    STA   $BD0B
083A-   8D 07 BE    STA   $BE07

; munge $E9 -> $E0 (used later to move
; the drive head via the stepper motor)
083D-   49 09       EOR   #$09
083F-   8D 54 BF    STA   $BF54

; munge $E0 -> $60 (boot slot x16, used
; during seek and write routines)
0842-   29 70       AND   #$70
0844-   8D 37 BE    STA   $BE37
0847-   8D 69 BE    STA   $BE69
084A-   8D 7F BE    STA   $BE7F
084D-   8D AC BE    STA   $BEAC
```

Chapter 19
6 + 2

Before I dive into the next chunk of code, I get to pause and explain a little bit of theory. As you probably know if you're the sort of person who's read this far already, Apple II floppy disks do not contain the actual data that ends up being loaded into memory. Due to hardware limitations of the original Disk II drive, data on disk is stored in an intermediate format called "nibbles." Bytes in memory are encoded into nibbles before writing to disk, and nibbles that you read from the disk must be decoded back into bytes. The round trip is lossless but requires some bit wrangling.

Decoding nibbles-on-disk into bytes-in-memory is a multi-step process. In "6-and-2 encoding" (used by DOS 3.3, ProDOS, and all ".dsk" image files), there are 64 possible values that you may find in the data field (in the range $96..$FF, but not all of those, because some of them have bit patterns that trip up the drive firmware). We'll call these "raw nibbles."

Step 1: read $156 raw nibbles from the data field. These values will range from $96 to $FF, but as mentioned earlier, not all values in that range will appear on disk.

Now we have $156 raw nibbles.

Step 2: decode each of the raw nibbles into a 6-bit byte between 0 and 63 (%00000000 and %00111111 in binary). $96 is the lowest valid raw nibble, so it gets decoded to 0. $97 is the next valid raw nibble, so it's decoded to 1. $98 and $99 are invalid, so we skip them, and $9A gets decoded to 2. And so on, up to $FF (the highest valid raw nibble), which gets decoded to 63.

Now we have $156 6-bit bytes.

Step 3: split up each of the first $56 6-bit bytes into pairs of bits. In other words, each 6-bit byte becomes three 2-bit bytes. These 2-bit bytes are merged with the next $100 6-bit bytes to create $100 8-bit bytes. Hence the name, "6-and-2" encoding.

The exact process of how the bits are split and merged is... complicated. The first $56 6-bit bytes get split up into 2-bit bytes, but those two bits get swapped (so %01 becomes %10 and vice-versa). The other $100 6-bit bytes each get multiplied by 4 (a.k.a. bit-shifted two places left). This leaves a hole in the lower two bits, which is filled by one of the 2-bit bytes from the first group.

```
A diagram might help. "a" through "x"
each represent one bit.

             -------------

1 decoded      3 decoded
nibble in  +   nibbles in   =  3 bytes
first $56      other $100


00abcdef       00ghijkl
               00mnopqr
   |           00stuvwx
   |
 split              |
   &           shifted
swapped        left x2
   |              |
   V              V

000000fe   +   ghijkl00   =   ghijklfe
000000dc   +   mnopqr00   =   mnoprqdc
000000ba   +   stuvwx00   =   stuvwxba

             -------------

Tada! Four 6-bit bytes

  00abcdef
  00ghijkl
  00mnopqr
  00stuvwx

become three 8-bit bytes

  ghijklfe
  mnoprqdc
  stuvwxba
```

When DOS 3.3 reads a sector, it reads the first $56 raw nibbles, decoded them into 6-bit bytes, and stashes them in a temporary buffer (at $BC00). Then it reads the other $100 raw nibbles, decodes them into 6-bit bytes, and puts them in another temporary buffer (at $BB00). Only then does DOS 3.3 start combining the bits from each group to create the full 8-bit bytes that will end up in the target page in memory. This is why DOS 3.3 "misses" sectors when it's reading, because it's busy twiddling bits while the disk is still spinning.

Gumboot also uses "6-and-2" encoding. The first $56 nibbles in the data field are still split into pairs of bits that will be merged with nibbles that won't come until later. But instead of waiting for all $156 raw nibbles to be read from disk, it "interleaves" the nibble reads with the bit twiddling required to merge the first $56 6-bit bytes and the $100 that follow. By the time Gumboot gets to the data field checksum, it has already stored all $100 8-bit bytes in their final resting place in memory. This means that we can read all 16 sectors on a track in one revolution of the disk. That's what makes it crazy fast.

To make it possible to twiddle the bits and not miss nibbles as the disk spins(*), we do some of the work in advance. We multiply each of the 64 possible decoded values by 4 and store those values. (Since this is done by bit shifting and we're doing it before we start reading the disk, this is called the "pre-shift" table.) We also store all possible 2-bit values in a repeating pattern that will make it easy to look them up later. Then, as we're reading from disk (and timing is tight), we can simulate bit math with a series of table lookups. There is just enough time to convert each raw nibble into its final 8-bit byte before reading the next nibble.

(*) The disk spins independently of the CPU, and we only have a limited time to read a nibble and do what we're going to do with it before WHOOPS HERE COMES ANOTHER ONE. So time is of the essence. Also, "As The Disk Spins" would make a great name for a retrocomputing-themed soap opera.

The first table, at $BC00..$BCFF, is three columns wide and 64 rows deep. Astute readers will notice that 3 x 64 is not 256. Only three of the columns are used; the fourth (unused) column exists because multiplying by 3 is hard but multiplying by 4 is easy (in base 2 anyway). The three columns correspond to the three pairs of 2-bit values in those first $56 6-bit bytes. Since the values are only 2 bits wide, each column holds one of four different values (%00, %01, %10, or %11).

The second table, at $BB96..$BBFF, is the "pre-shift" table. This contains all the possible 6-bit bytes, in order, each multiplied by 4 (a.k.a. shifted to the left two places, so the 6 bits that started in columns 0-5 are now in columns 2-7, and columns 0 and 1 are zeroes). Like this:

```
       00ghijkl   -->   ghijkl00
```

Astute readers will notice that there are only 64 possible 6-bit bytes, but this second table is larger than 64 bytes. To make lookups easier, the table has empty slots for each of the invalid raw nibbles. In other words, we don't do any math to decode raw nibbles into 6-bit bytes; we just look them up in this table (offset by $96, since that's the lowest valid raw nibble) and get the required bit shifting for free.

```
 addr  | raw  | decoded 6-bit  | pre-shift
-------+------+----------------+----------
$BB96  | $96  | 0  = %00000000 | %00000000
$BB97  | $97  | 1  = %00000001 | %00000100
$BB98  | $98        [invalid raw nibble]
$BB99  | $99        [invalid raw nibble]
$BB9A  | $9A  | 2  = %00000010 | %00001000
$BB9B  | $9B  | 3  = %00000011 | %00001100
$BB9C  | $9C        [invalid raw nibble]
$BB9D  | $9D  | 4  = %00000100 | %00010000
   .
   .
   .
$BBFE  | $FE  | 62  = %00111110 | %1111100
$BBFF  | $FF  | 63  = %00111111 | %1111110
```

Each value in this "pre-shift" table also serves as an index into the first table (with all the 2-bit bytes). This wasn't an accident; I mean, that sort of magic doesn't just happen. But the table of 2-bit bytes is arranged in such a way that we can take one of the raw nibbles to be decoded and split apart (from the first $56 raw nibbles in the data field), use each raw nibble as an index into the pre-shift table, then use that pre-shifted value as an index into the first table to get the 2-bit value we need.

Chapter 20
Back to Gumboot

This is the loop that creates the
pre-shift table at $BB96. As a special
bonus, it also creates the inverse
table that is used during disk write
operations (converting in the other
direction).

```
0850-    A2 3F          LDX    #$3F
0852-    86 FF          STX    $FF
0854-    E8             INX
0855-    A0 7F          LDY    #$7F
0857-    84 FE          STY    $FE
0859-    98             TYA
085A-    0A             ASL
085B-    24 FE          BIT    $FE
085D-    F0 18          BEQ    $0877
085F-    05 FE          ORA    $FE
0861-    49 FF          EOR    #$FF
0863-    29 7E          AND    #$7E
0865-    B0 10          BCS    $0877
0867-    4A             LSR
0868-    D0 FB          BNE    $0865
086A-    CA             DEX
086B-    8A             TXA
086C-    0A             ASL
086D-    0A             ASL
086E-    99 80 BB       STA    $BB80,Y
0871-    98             TYA
0872-    09 80          ORA    #$80
0874-    9D 56 BB       STA    $BB56,X
0877-    88             DEY
0878-    D0 DD          BNE    $0857
```

And this is the result (".." means the address is uninitialized and unused):

```
BB90-                              00 04
BB98- .. .. 08 0C .. 10 14 18
BBA0- .. .. .. .. .. .. 1C 20
BBA8- .. .. .. 24 28 2C 30 34
BBB0- .. .. 38 3C 40 44 48 4C
BBB8- .. 50 54 58 5C 60 64 68
BBC0- .. .. .. .. .. .. .. ..
BBC8- .. .. .. 6C .. 70 74 78
BBD0- .. .. .. 7C .. .. 80 84
BBD8- .. 88 8C 90 94 98 9C A0
BBE0- .. .. .. .. .. A4 A8 AC
BBE8- .. B0 B4 B8 BC C0 C4 C8
BBF0- .. .. CC D0 D4 D8 DC E0
BBF8- .. E4 E8 EC F0 F4 F8 FC
```

Next up: a loop to create the table of
2-bit values at $BC00, magically
arranged to enable easy lookups later.

```
087A-   84 FD         STY   $FD
087C-   46 FF         LSR   $FF
087E-   46 FF         LSR   $FF
0880-   BD BD 08      LDA   $08BD,X
0883-   99 00 BC      STA   $BC00,Y
0886-   E6 FD         INC   $FD
0888-   A5 FD         LDA   $FD
088A-   25 FF         AND   $FF
088C-   D0 05         BNE   $0893
088E-   E8            INX
088F-   8A            TXA
0890-   29 03         AND   #$03
0892-   AA            TAX
0893-   C8            INY
0894-   C8            INY
0895-   C8            INY
0896-   C8            INY
0897-   C0 03         CPY   #$03
0899-   B0 E5         BCS   $0880
089B-   C8            INY
089C-   C0 03         CPY   #$03
089E-   90 DC         BCC   $087C
```

And this is the result:

```
BC00- 00 00 00 .. 00 00 02 ..
BC08- 00 00 01 .. 00 00 03 ..
BC10- 00 02 00 .. 00 02 02 ..
BC18- 00 02 01 .. 00 02 03 ..
BC20- 00 01 00 .. 00 01 02 ..
BC28- 00 01 01 .. 00 01 03 ..
BC30- 00 03 00 .. 00 03 02 ..
BC38- 00 03 01 .. 00 03 03 ..
BC40- 02 00 00 .. 02 00 02 ..
BC48- 02 00 01 .. 02 00 03 ..
BC50- 02 02 00 .. 02 02 02 ..
BC58- 02 02 01 .. 02 02 03 ..
BC60- 02 01 00 .. 02 01 02 ..
BC68- 02 01 01 .. 02 01 03 ..
BC70- 02 03 00 .. 02 03 02 ..
BC78- 02 03 01 .. 02 03 03 ..
BC80- 01 00 00 .. 01 00 02 ..
BC88- 01 00 01 .. 01 00 03 ..
BC90- 01 02 00 .. 01 02 02 ..
BC98- 01 02 01 .. 01 02 03 ..
BCA0- 01 01 00 .. 01 01 02 ..
BCA8- 01 01 01 .. 01 01 03 ..
BCB0- 01 03 00 .. 01 03 02 ..
BCB8- 01 03 01 .. 01 03 03 ..
BCC0- 03 00 00 .. 03 00 02 ..
BCC8- 03 00 01 .. 03 00 03 ..
BCD0- 03 02 00 .. 03 02 02 ..
BCD8- 03 02 01 .. 03 02 03 ..
BCE0- 03 01 00 .. 03 01 02 ..
BCE8- 03 01 01 .. 03 01 03 ..
BCF0- 03 03 00 .. 03 03 02 ..
BCF8- 03 03 01 .. 03 03 03 ..
```

And with that, Gumboot is fully armed and operational.

```
; Push a "return" address on the stack.
; We'll come back to this later. (Ha
; ha, get it, come back to it? OK,
; let's pretend that never happened.)
08A0-   A9 B2         LDA   #$B2
08A2-   48            PHA
08A3-   A9 F0         LDA   #$F0
08A5-   48            PHA

; Set up an initial read of 3 sectors
; from track 1 into $B000..$B2FF. This
; contains the high scores data, zero
; page, and a new output vector that
; interfaces with Gumboot.
08A6-   A9 01         LDA   #$01
08A8-   A2 03         LDX   #$03
08AA-   A0 B0         LDY   #$B0

; Read all that from disk and exit via
; the "return" address we just pushed
; on the stack at $0895.
08AC-   4C 00 BD      JMP   $BD00
```

Execution will continue at $B2F1, once we read that from disk. $B2F1 is new code I wrote, and I promise to show it to you. But first, I get to finish showing you how the disk read routine works.

Chapter 21
Read & Go Seek

In a standard DOS 3.3 RWTS, the
softswitch to read the data latch is
"LDA $C08C,X", where X is the boot slot
times 16 (to allow disks to boot from
any slot). Gumboot also supports
booting and reading from any slot, but
instead of using an index, most fetch
instructions are set up in advance
based on the boot slot. Not only does
this free up the X register, it lets us
juggle all the registers and put the
raw nibble value in whichever one is
convenient at the time. (We take full
advantage of this freedom.) I've marked
each pre-set softswitch with "o_O".

There are several other instances of
addresses and constants that get
modified while Gumboot is executing.
I've left these with a bogus value $D1
and marked them with "o_O".

Gumboot's source code should be
available from the same place you found
this write-up. If you're looking to
modify this code for your own purposes,
I suggest you "use the source, Luke."

```
*BD00L

; A = the track number to seek to. We
; multiply it by 2 to convert it to a
; phase, then store it inside the seek
; routine which we will call shortly.
BD00-   0A            ASL
BD01-   8D 10 BF      STA   $BF10

; X = the number of sectors to read
BD04-   8E EF BD      STX   $BDEF
```

```
; Y = the starting address in memory
BD07-   8C 24 BD    STY   $BD24

; turn on the drive motor
BD0A-   AD E9 C0    LDA   $C0E9      o_O

; poll for real nibbles (##$FF followed
; by non-##$FF) as a way to ensure the
; drive has spun up fully
BD0D-   20 75 BF    JSR   $BF75

; are we reading this entire track?
BD10-   A9 10       LDA   #$10
BD12-   CD EF BD    CMP   $BDEF

; yes -> branch
BD15-   B0 01       BCS   $BD18

; no
BD17-   AA          TAX
BD18-   8E 94 BF    STX   $BF94

; seek to the track we want
BD1B-   20 04 BF    JSR   $BF04
```

```
; Initialize an array of which sectors
; we've read from the current track.
; The array is in physical sector
; order, thus the RWTS assumes data is
; stored in physical sector order on
; each track.  (This saves 18 bytes: 16
; for the table and 2 for the lookup
; command!) Values are the actual pages
; in memory where that sector should
; go, and they get zeroed once the
; sector is read (so we don't waste
; time decoding the same sector twice).
BD1E-   AE 94 BF     LDX   $BF94
BD21-   A0 00        LDY   #$00
BD23-   A9 D1        LDA   #$D1      o_O
BD25-   99 84 BF     STA   $BF84,Y
BD28-   EE 24 BD     INC   $BD24
BD2B-   C8           INY
BD2C-   CA           DEX
BD2D-   D0 F4        BNE   $BD23

BD2F-   20 D5 BE     JSR   $BED5
```

```
*BED5L

; This routine reads nibbles from disk
; until it finds the sequence "D5 AA",
; then it reads one more nibble and
; returns it in the accumulator. We
; reuse this routine to find both the
; address and data field prologues.
BED5-   20 E4 BE    JSR   $BEE4
BED8-   C9 D5       CMP   #$D5
BEDA-   D0 F9       BNE   $BED5
BEDC-   20 E4 BE    JSR   $BEE4
BEDF-   C9 AA       CMP   #$AA
BEE1-   D0 F5       BNE   $BED8
BEE3-   A8          TAY
BEE4-   AD EC C0    LDA   $C0EC     o_O
BEE7-   10 FB       BPL   $BEE4
BEE9-   60          RTS
```

Continuing from $BD32...

```
; If that third nibble is not #$AD, we
; assume it's the end of the address
; prologue. (#$96 would be the third
; nibble of a standard address
; prologue, but we don't actually
; check.) We fall through and start
; decoding the 4-4 encoded values in
; the address field.
BD32-   49 AD       EOR   #$AD
BD34-   F0 35       BEQ   $BD6B

BD36-   20 C2 BE    JSR   $BEC2
```

```
*BEC2L

; This routine parses the 4-4-encoded
; values in the address field. The
; first time through this loop, we'll
; read the disk volume number. The
; second time, we'll read the track
; number. The third time, we'll read
; the physical sector number. We don't
; actually care about the disk volume
; or the track number, and once we get
; the sector number, we don't verify
; the address field checksum.
BEC2-   A0 03       LDY   #$03
BEC4-   20 E4 BE    JSR   $BEE4
BEC7-   2A          ROL
BEC8-   8D E0 BD    STA   $BDE0
BECB-   20 E4 BE    JSR   $BEE4
BECE-   2D E0 BD    AND   $BDE0
BED1-   88          DEY
BED2-   D0 F0       BNE   $BEC4

; On exit, the accumulator contains the
; physical sector number.
BED4-   60          RTS
```

Continuing from $BD39...

```
; use physical sector number as an
; index into the sector address array
BD39-   A8          TAY

; get the target page (where we want to
; store this sector in memory)
BD3A-   BE 84 BF    LDX   $BF84,Y
```

```
; if the target page is #$00, it means
; we've already read this sector, so
; loop back to find the next address
; prologue
BD3D-   F0 F0         BEQ   $BD2F

; store the physical sector number
; later in this routine
BD3F-   8D E0 BD      STA   $BDE0

; store the target page in several
; places throughout this routine
BD42-   8E 64 BD      STX   $BD64
BD45-   8E C4 BD      STX   $BDC4
BD48-   8E 7C BD      STX   $BD7C
BD4B-   8E 8E BD      STX   $BD8E
BD4E-   8E A6 BD      STX   $BDA6
BD51-   8E BE BD      STX   $BDBE
BD54-   E8            INX
BD55-   8E D9 BD      STX   $BDD9
BD58-   CA            DEX
BD59-   CA            DEX
BD5A-   8E 94 BD      STX   $BD94
BD5D-   8E AC BD      STX   $BDAC

; Save the two bytes immediately after
; the target page, because we're going
; to use them for temporary storage.
; (We'll restore them later.)
BD60-   A0 FE         LDY   #$FE
BD62-   B9 02 D1      LDA   $D102,Y
BD65-   48            PHA
BD66-   C8            INY
BD67-   D0 F9         BNE   $BD62

; this is an unconditional branch
BD69-   B0 C4         BCS   $BD2F
```

```
; execution continues here (from $BD34)
; after matching the data prologue
BD6B-   E0 00       CPX   #$00

; If X is still #$00, it means we found
; a data prologue before we found an
; address prologue. In that case, we
; have to skip this sector, because we
; don't know which sector it is and we
; wouldn't know where to put it. Sad!
BD6D-   F0 C0       BEQ   $BD2F
```

Nibble loop #1 reads nibbles $00..$55, looks up the corresponding offset in the preshift table at $BB96, and stores that offset in the temporary two-byte buffer after the target page.

```
; initialize rolling checksum to #$00,
; or update it with the results from
; the calculations below
BD6F-   8D 7E BD    STA   $BD7E

; read one nibble from disk
BD72-   AE EC C0    LDX   $C0EC      o_O
BD75-   10 FB       BPL   $BD72

; The nibble value is in the X register
; now. The lowest possible nibble value
; is $96 and the highest is $FF. To
; look up the offset in the table at
; $BB96, we index off $BB00 + X. Math!
BD77-   BD 00 BB    LDA   $BB00,X
```

```
; Now the accumulator has the offset
; into the table of individual 2-bit
; combinations ($BC00..$BCFF). Store
; that offset in a temporary buffer
; towards the end of the target page.
; (It will eventually get overwritten
; by full 8-bit bytes, but in the
; meantime it's a useful $56-byte
; scratch space.)
BD7A-   99 02 D1    STA   $D102,Y    o_O

; The EOR value is set at $BD6F
; each time through loop #1.
BD7D-   49 D1       EOR   #$D1       o_O

; The Y register started at #$AA
; (set by the "TAY" instruction
; at $BD39), so this loop reads
; a total of #$56 nibbles.
BD7F-   C8          INY
BD80-   D0 ED       BNE   $BD6F
```

Here endeth nibble loop #1.

Nibble loop #2 reads nibbles $56..$AB, combines them with bits 0-1 of the appropriate nibble from the first $56, and stores them in bytes $00..$55 of the target page in memory.

```
BD82-   A0 AA       LDY   #$AA
BD84-   AE EC C0    LDX   $C0EC      o_O
BD87-   10 FB       BPL   $BD84
BD89-   5D 00 BB    EOR   $BB00,X
BD8C-   BE 02 D1    LDX   $D102,Y    o_O
BD8F-   5D 02 BC    EOR   $BC02,X
```

```
; This address was set at $BD5A
; based on the target page (minus 1
; so we can add Y from #$AA..#$FF).
BD92-   99 56 D1    STA   $D156,Y   o_O
BD95-   C8          INY
BD96-   D0 EC       BNE   $BD84
```

Here endeth nibble loop #2.

Nibble loop #3 reads nibbles $AC..$101, combines them with bits 2-3 of the appropriate nibble from the first $56, and stores them in bytes $56..$AB of the target page in memory.

```
BD98-   29 FC       AND   #$FC
BD9A-   A0 AA       LDY   #$AA
BD9C-   AE EC C0    LDX   $C0EC     o_O
BD9F-   10 FB       BPL   $BD9C
BDA1-   5D 00 BB    EOR   $BB00,X
BDA4-   BE 02 D1    LDX   $D102,Y   o_O
BDA7-   5D 01 BC    EOR   $BC01,X

; This address was set at $BD5D
; based on the target page (minus 1
; so we can add Y from #$AA..#$FF).
BDAA-   99 AC D1    STA   $D1AC,Y   o_O
BDAD-   C8          INY
BDAE-   D0 EC       BNE   $BD9C
```

Here endeth nibble loop #3.

Loop #4 reads nibbles $102..$155,
combines them with bits 4-5 of the
appropriate nibble from the first $56,
and stores them in bytes $AC..$101 of
the target page in memory. (This
overwrites two bytes after the end of
the target page, but we'll restore
then later from the stack.)

```
BDB0-   29 FC        AND   #$FC
BDB2-   A2 AC        LDX   #$AC
BDB4-   AC EC C0     LDY   $C0EC      o_O
BDB7-   10 FB        BPL   $BDB4
BDB9-   59 00 BB     EOR   $BB00,Y
BDBC-   BC 00 D1     LDY   $D100,X    o_O
BDBF-   59 00 BC     EOR   $BC00,Y

; This address was set at $BD45
; based on the target page.
BDC2-   9D 00 D1     STA   $D100,X    o_O
BDC5-   E8           INX
BDC6-   D0 EC        BNE   $BDB4
```

Here endeth nibble loop #4.

```
; Finally, get the last nibble and
; convert it to a byte. This should
; equal all the previous bytes XOR'd
; together. (This is the standard
; checksum algorithm shared by all
; 16-sector disks.)
BDC8-   29 FC        AND   #$FC
BDCA-   AC EC C0     LDY   $C0EC      o_O
BDCD-   10 FB        BPL   $BDCA
BDCF-   59 00 BB     EOR   $BB00,Y
```

```
; set carry if value is anything
; but 0
BDD2-   C9 01       CMP   #$01

; Restore the original data in the
; two bytes after the target page.
; (This does not affect the carry
; flag, which we will check in a
; moment, but we need to restore
; these bytes now to balance out
; the pushing to the stack we did
; at $BD65.)
BDD4-   A0 01       LDY   #$01
BDD6-   68          PLA
BDD7-   99 00 D1    STA   $D100,Y    o_O
BDDA-   88          DEY
BDDB-   10 F9       BPL   $BDD6

; if data checksum failed at $BDD2,
; start over
BDDD-   B0 8A       BCS   $BD69

; This was set to the physical
; sector number (at $BD3F), so
; this is a index into the 16-
; byte array at $BF84.
BDDF-   A0 D1       LDY   #$D1       o_O
BDE1-   8A          TXA

; store #$00 at this location in
; the sector array to indicate
; that we've read this sector
BDE2-   99 84 BF    STA   $BF84,Y

; decrement sector count
BDE5-   CE EF BD    DEC   $BDEF
BDE8-   CE 94 BF    DEC   $BF94
BDEB-   38          SEC
```

```
; If the sectors-left-in-this-track
; count (in $BF94) isn't zero yet,
; loop back to read more sectors.
BDEC-   D0 EF         BNE   $BDDD

; If the total sector count (in
; $BDEF, set at $BD04 and decremented
; at $BDE5) is zero, we're done --
; no need to read the rest of
; the track. (This lets us have
; sector counts that are not
; multiples of 16, i.e. reading
; just a few sectors from the
; last track of a multi-track
; block.)
BDEE-   A2 D1         LDX   #$D1        o_O
BDF0-   F0 09         BEQ   $BDFB

; increment phase (twice, so it
; points to the next whole block)
BDF2-   EE 10 BF      INC   $BF10
BDF5-   EE 10 BF      INC   $BF10

; jump back to seek and read
; from the next track
BDF8-   4C 10 BD      JMP   $BD10

; Execution continues here (from
; $BDEF). We're all done, so
; turn off drive motor and exit.
BDFB-   AD E8 C0      LDA   $C0E8       o_O
BDFE-   60            RTS
```

And that's all she wrote^H^H^H^Hread.

Chapter 22
I Make My Verse For The Universe

How's our master plan (from chapter 16)
going? Pretty darn well, I'd say.

Step 1: write all the game code to a
standard disk. Done.

Step 2: write an RWTS. Done.

Step 3: make them talk to each other.

The "glue code" for this final step
lives on track 1. It was loaded into
memory at the very end of the boot
sector (chapter 20):

```
``'-.,_,.-'``'-.,_,.='``'-.,_,.-'``'-.,
``'-.,_,.-'``'-.,_,.='``'-.,_,.-'``'-.,
``                                    .,
``  089B-   A9 01       LDA   #$01    .,
``  089D-   A2 03       LDX   #$03    .,
``  089F-   A0 B0       LDY   #$B0    .,
``  08A1-   4C 00 BD    JMP   $BD00   .,
``                                    .,
``'-.,_,.-'``'-.,_,.='``'-.,_,.-'``'-.,
``'-.,_,.-'``'-.,_,.='``'-.,_,.-'``'-.,
```

That loads 3 sectors from track 1 into
$B000..$B2FF. $B000 is the high scores,
which stays at $B000. $B100 is moved to
zero page. $B200 is the output vector
and final initialization code. This
page is never used by the game. (It was
used by the original RWTS, but that has
been greatly simplified by stripping
out the copy protection. I love when
that happens!)

Here is my output vector, replacing the code that originally lived at $BF6F:

```
*B200L

; command or regular character?
B200-   C9 07        CMP   #$07

; command -> branch
B202-   90 03        BCC   $B207

; regular character -> print to screen
B204-   6C 3A 00     JMP   ($003A)

; store command in zero page
B207-   85 5F        STA   $5F

; set up the call to the screen fill
B209-   A8           TAY
B20A-   B9 97 B2     LDA   $B297,Y
B20D-   8D 19 B2     STA   $B219

; set up the call to Gumboot
B210-   B9 9E B2     LDA   $B29E,Y
B213-   8D 1C B2     STA   $B21C

; call the appropriate screen fill
B216-   A9 00        LDA   #$00
B218-   20 69 B2     JSR   $B269     o_O

; call Gumboot
B21B-   20 2B B2     JSR   $B22B     o_O

; find the entry point for this block
B21E-   A5 5F        LDA   $5F
B220-   0A           ASL
B221-   A8           TAY
```

```
; push the entry point to the stack
B222-   B9 A6 B2    LDA   $B2A6,Y
B225-   48          PHA
B226-   B9 A5 B2    LDA   $B2A5,Y
B229-   48          PHA

; and exit via "RTS"
B22A-   60          RTS
```

This is the routine that calls Gumboot to load the appropriate blocks of game code from the disk, according to the disk map in chapter 16. Here is the summary of which sectors are loaded by each block:

cmd	track (A)	count (X)	page (Y)
$00	$02	$38	$08
	$06	$28	$60
$01	$09	$38	$08
	$0D	$50	$60
$02	$12	$38	$08
	$16	$28	$60
$03	$19	$20	$20

(The parameters for command #$06 are the same as command #$01.)

The lookup at $B210 modified the "JSR" instruction at $B21B, so each command starts in a different place:

```
; command #$00
B22B-   A9 02       LDA   #$02
B22D-   20 56 B2    JSR   $B256
B230-   A9 06       LDA   #$06
B232-   D0 1C       BNE   $B250

; command #$01
B234-   A9 09       LDA   #$09
B236-   20 56 B2    JSR   $B256
B239-   A9 0D       LDA   #$0D
B23B-   A2 50       LDX   #$50
B23D-   D0 13       BNE   $B252

; command #$02
B23F-   A9 12       LDA   #$12
B241-   20 56 B2    JSR   $B256
B244-   A9 16       LDA   #$16
B246-   D0 08       BNE   $B250

; command #$03
B248-   A9 19       LDA   #$19
B24A-   A2 20       LDX   #$20
B24C-   A0 20       LDY   #$20
B24E-   D0 0A       BNE   $B25A
B250-   A2 28       LDX   #$28
B252-   A0 60       LDY   #$60
B254-   D0 04       BNE   $B25A
B256-   A2 38       LDX   #$38
B258-   A0 08       LDY   #$08
B25A-   4C 00 BD    JMP   $BD00
```

```
; command #$04: seek to track 1 and
; write $B000..$B0FF to sector 0
B25D-   A9 01       LDA   #$01
B25F-   20 00 BF    JSR   $BF00
B262-   A9 00       LDA   #$00
B264-   A0 B0       LDY   #$B0
B266-   4C 00 BE    JMP   $BE00

; exact replica of the screen fill code
; that was originally at $BEB0
B269-   A5 60       LDA   $60
B26B-   4D 50 C0    EOR   $C050
B26E-   85 60       STA   $60
B270-   29 0F       AND   #$0F
B272-   F0 F5       BEQ   $B269
B274-   C9 0F       CMP   #$0F
B276-   F0 F1       BEQ   $B269
B278-   20 66 F8    JSR   $F866
B27B-   A9 17       LDA   #$17
B27D-   48          PHA
B27E-   20 47 F8    JSR   $F847
B281-   A0 27       LDY   #$27
B283-   A5 30       LDA   $30
B285-   91 26       STA   ($26),Y
B287-   88          DEY
B288-   10 FB       BPL   $B285
B28A-   68          PLA
B28B-   38          SEC
B28C-   E9 01       SBC   #$01
B28E-   10 ED       BPL   $B27D
B290-   AD 56 C0    LDA   $C056
B293-   AD 54 C0    LDA   $C054
B296-   60          RTS

; lookup table for screen fills
B297-  [69 7B 69 69 96 96 69]

; lookup table for Gumboot calls
B29E-  [2B 34 3F 48 2A 2A 34]
```

```
; lookup table for entry points
B2A5-  [9C 0F]
B2A7-  [F8 31]
B2A9-  [34 10]
B2AB-  [57 FF]
B2AD-  [5C B2]
B2AF-  [95 B2]
B2B1-  [77 23]
```

Last but not least, a short routine at $B2F1 to move zero page into place and start the game. (This is called because we pushed #$B2/#$F0 to the stack in our boot sector, at $0895.)

```
*B2F1L

; copy $B100 to zero page
B2F1-   A2 00       LDX   #$00
B2F3-   BD 00 B1    LDA   $B100,X
B2F6-   95 00       STA   $00,X
B2F8-   E8          INX
B2F9-   D0 F8       BNE   $B2F3

; print a null character to start the
; game
B2FB-   A9 00       LDA   #$00
B2FD-   4C ED FD    JMP   $FDED
```

Quod erat liberand one more thing...

Chapter 23
Oops

Heeeeey there. Remember this code?

```
0372-   A9 34         LDA   #$34
0374-   48            PHA
...
0378-   28            PLP
```

Here's what I said about it when I first saw it:

```
; pop that #$34 off the stack, but use
; it as status registers (weird, but
; legal -- if it turns out to matter,
; I can figure out exactly which status
; bits get set and cleared)
```

Yeah, so that turned out to be more important than I thought. After extensive play testing, we(*) discovered the game becomes unplayable on level 3.

(*) not me, and not qkumba either, who beat the entire game twice. It was Marco V. Thanks, Marco!

How unplayable? Gates that are open won't close; balls pass through gates that are already closed; bins won't move more than a few pixels.

So, not a crash, and (contrary to our first guess) not an incompatibility with modern emulators. It affects real hardware too, and it was intentional. Deep within the game code, there are several instances of code like this:

```
                 --v--

T0A,S00
----------- DISASSEMBLY MODE ----------
0021:08                 PHP
0022:68                 PLA
0023:29 04              AND   #$04
0025:D0 0A              BNE   $0031
0027:A5 18              LDA   $18
0029:C9 02              CMP   #$02
002B:90 04              BCC   $0031
002D:A9 10              LDA   #$10
002F:85 79              STA   $79
0031:A5 79              LDA   $79
0033:85 7A              STA   $7A

                 --^--
```

"PHP" pushes the status registers on the stack, but "PLA" pulls a value from the stack and stores it as a byte, in the accumulator. That's... weird. Also, it's the reverse of the weird code we saw at $0372, which took a byte in the accumulator and blitted it into the status registers. Then "AND #$04" isolates one status bit in particular: the interrupt flag. The rest of the code is the game-specific way of making the game unplayable.

This is a very convoluted, obfuscated, sneaky way to ensure that the game was loaded through its original bootloader. Which, of course, it wasn't.

The solution: after loading each block of game code and pushing the new entry point to the stack, set the interrupt flag.

```
; push the entry point to the stack
B222-   B9 A6 B2     LDA   $B2A6,Y
B225-   48           PHA
B226-   B9 A5 B2     LDA   $B2A5,Y
B229-   48           PHA

; set the interrupt flag (new!)
B22A-   78           SEI

; and exit via "RTS"
B22B-   60           RTS
```

Many thanks to Marco V. for reporting this and helping reproduce it; qkumba for digging into it to find the check within the game code; Tom G. for making the connection between the interrupt flag and the weird "LDA/PHA/PLP" code at $0372.

Chapter 24
This Is Not The End, Though

This game holds one more secret, but it's not related to the copy protection (thank goodness). As far as I can tell, this secret has not been revealed in 33 years. qkumba found it because of course he did.

Once the game starts, press <Ctrl-J> to switch to joystick mode. Press and hold button 2 to activate "targeting" mode, then move your joystick to the bottom-left corner of the screen and also press button 1. The screen will be replaced by this message:

```
                 --v--

   PRESS CTRL-Z DURING THE CARTOONS

                 --^--
```

Now, the game has 5 levels. After you complete a level, your character gets promoted: worker, foreman, supervisor, manager, and finally vice president. Each of these is a little cartoon -- what kids today would call a "cut scene." When you complete the entire game, it shows a final screen and your character retires.

```
Pressing <Ctrl-Z> during each cartoon
reveals four ciphers.

After level 1:

                 --v--

              RBJRY JSYRR

                 --^--

After level 2:

                 --v--

              VRJJRY ZIAR

                 --^--

After level 3:

                 --v--

                 ESRB

                 --^--

After level 4:

                 --v--

              FIG YRJMYR

                 --^--
```

Taken together, they form a simple substitution cipher:

ENTER THREE

LETTER CODE

WHEN

YOU RETIRE

But what is the code?

It turns out that pressing <Ctrl-Z> *again*, while any of the pieces of the cipher are on screen, reveals another clue:

```
                 --v--

             DOUBLE HELIX

                 --^--
```

Entering the three-letter code "DNA" at the "retirement" screen reveals the final secret message:

```
                 --v--

AHA!  YOU MADE IT!
EITHER YOU ARE AN EXCELLENT GAME-PLAYER
OR (GAH!) PROGRAM-BREAKER!
YOU ARE CERTAINLY ONE OF THE FEW PEOPLE
THAT WILL EVER SEE THIS SCREEN.

THIS IS NOT THE END, THOUGH.

IN ANOTHER BR0DERBUND PRODUCT
TYPE 'Z0DWARE' FOR MORE PUZZLES.

HAVE FUN!  BYE!!

                      R.A.C.

                 --^--
```

At time of writing, no one has found the 'Z0DWARE' puzzle. You could be the first!

Transcript

This crack was a collaboration between 4am and qkumba of san inc. What follows is a transcript of our chat as we stepped through the insanity together over the course of several days. It has been lightly edited to remove temporary URLs.

May 23

```
|...qkumba...
|okay, so where are you up to with
|Gumball?
|it looks like a hybrid 6-2/5-3 booter
|reminds me of Captain Goodnight

                                    ...4am...|
       I traced the boot and got the 4|
   sectors that are loaded in the text|
                                  page|
                    check my work disk|
3 of those get copied to higher memory|
 $BD00..$BFFF and stay there (I think)|
that's the resident RWTS and API. Also|
       $BF00 is the reset/reboot code,|
                  standard Broderbund.|

|...qkumba...
|then it seeks to track 7 and loads
|over $500-7ff
|and jumps to $500

                                    ...4am...|
           yes, that's where I stopped|
      but just because of lack of time|
|...qkumba...
|okay, you have time now?
|how can I help?

                             ...4am...|
                                   yes|
       well let's just walk through it|
                              together|
$400 copies code, calls $BF48 (zap RAM|
card), sets reset vectors, calls $BE00|
 I assume that's the drive seek and/or|
                         read routine?|

|...qkumba...
|$be00 is seek
|reads appear to be inline

                             ...4am...|
   ah, manual read after that, at $44B|
                               yes, ok|

|...qkumba...
|yes, $36 is "sector" count, $34-35 is
|address

                             ...4am...|
 ah, then exit via RTS again. is $04FF|
 the next address on the stack at this|
                                point?|

|...qkumba...
|yes, continues at $500
|that it just read

                             ...4am...|
    OK, I'll write a tracer to capture|
                        that. Hang on.|
        BOOT2 0500-07FF on https://...|

|...qkumba...
|got it
```

```
                                       ...4am...|
      (very simple trace, really. just|
  change a different part of the stack|
  then capture the same memory range!)|

|...qkumba...
|very nice.  Funny thing at $599-59c

                                       ...4am...|
                                            haha|
   wtf is $500 doing. loading a sector|
into $B000 then JSR $05F0 to seek back|
                                    to track 7|

|...qkumba...
|so $500 seeks to track 2 for a 4x4
|read to $700 (copied to $B000), $5f0
|takes us back to track 2, 4x4 read
|directly onto stack

                                       ...4am...|
 ah, I missed the PHA at $058C. Jesus.|

|...qkumba...
|yes, it took me a few goes before I
|saw it, too
|go's?
|whatever

                                       ...4am...|
well there's no checksum on this code,|
    so let's just patch it at $0599 to|
                   capture $B000 and $0100|
anyway, maybe a callback jump at $599,|
      so we can capture $b000 and $100|

|...qkumba...
|ha, you type faster than I do
```

```
                                                   ...4am...|
                            great minds think alike|
                                                   ok, hang on|
BOOT2 B000-B0FF and BOOT2 0100-01FF on|
                                                   https://...|

|...qkumba...
|okay, back in a little while

                                                   ...4am...|
                                                        :-( |
     That's a straight dump of $0100..|
   $01FF, so need the stack pointer. I|
think it's $D5, so execution continues|
                                                   at $0125+1|

|...qkumba...
|okay, back again, and yes, continues
|at $126
|it would be a neat trick to use the
|nibbles as the stack pointer value
|ah, read is encoded using the stack
|content before storing to zpage
|and then a chain of RTSs
|and jump through ($28)

                                                   ...4am...|
                                                       lovely|
   wait, i'm not sure i captured $B000|
                                                     properly|
    gonna re-trace it on real hardware|
                                            ok, false alarm|

|...qkumba...
|callback at $123 and capture zpage?
```

...4am...|
i was thinking to just copy the read|
loop from $0126 into my boot tracer at|
$97xx somewhere|
so page 1 is undisturbed and we don't|
have to recalculate any EORs|
BOOT3 0000-00FF on https://...|
($0028) points to $06D0, which is in|
BOOT2 0500-07FF|
it's self-modifying, but ultimately|
just sets X to #$FF and exits via RTS|
so the next thing on the stack is|
FF 05 => $600|

|...qkumba...
|okay, good point - it decodes over the
|whole stack, so we can't touch any of
|it.

...4am...|
$600 destroys the entire stack by|
calling PHA $100 times|
more self-modifying code|

|...qkumba...
|jmp $fd90?

...4am...|
which branches back to $FDED, which|
jumps to $0036, which is...|
er, ($0036)|
=> $BF6F|
which is in BOOT1 0400-07FF|
(copied from $076F)|
[...]

```
   *BF6FL

   BF6F-   C9 07       CMP   #$07
   BF71-   90 03       BCC   $BF76
   BF73-   6C 3A 00    JMP   ($003A)
   BF76-   85 5F       STA   $5F
   BF78-   A8          TAY
   BF79-   B9 68 BF    LDA   $BF68,Y
   BF7C-   8D 82 BF    STA   $BF82
   BF7F-   A9 00       LDA   #$00
   BF81-   20 D0 BE    JSR   $BED0
   BF84-   A5 5F       LDA   $5F
   BF86-   C9 04       CMP   #$04
   BF88-   D0 03       BNE   $BF8D
   BF8A-   4C 00 BD    JMP   $BD00
   BF8D-   C9 05       CMP   #$05
   BF8F-   D0 03       BNE   $BF94
   BF91-   6C 82 BF    JMP   ($BF82)
   BF94-   20 B0 BE    JSR   $BEB0
   BF97-   A0 00       LDY   #$00
   BF99-   A9 B2       LDA   #$B2
   BF9B-   84 44       STY   $44
```

so printing a character prints a character, unless it's less than 7, in which case it executes a command at $BF76

|...qkumba...
|yes, that's correct

...4am...
That's wonderfully twisted. I love it.

|...qkumba...
|bf68 is a jump table

...4am...
well, half of a jump table. high byte is always $BE

```
|...qkumba...
|that's low8 style

                             ...4am...|
          glad it has a name, i guess?|

|...qkumba...
|I suppose so. looks like the commands
|are screen switching
|$bed0 is lowres animation
|so is $bedf, and a couple of rts
|command 4 is  a write
|command 5 just animates again
|the other commands decode $bf9f-bfff
|presumably recoding it after use
|ha, using the seek routine as the key
|not animate - screen fill
|then read to $b200-b4ff
|return to $3c, jumps to $b200

                             ...4am...|
ok, you work faster than i do, but yes|
               so how to capture that?|

|...qkumba...
|can we overwrite $3c-3e with callback
|jump?

                             ...4am...|
                              probably|

|...qkumba...
|right after boot 3 completes?
```

```
                                     ...4am...|
    no checksums or other dependencies|
                                         right|
                                       hang on|
        BOOT4 B200-B4FF on https://...|
          i need a better naming system|

|...qkumba...
|at least you have one

                                     ...4am...|
                 :look-of-disapproval:|
      so $B400 is another seek routine|

|...qkumba...
|yes, seek track 4, read to $b500+ with
|half-steps
|b500-b8ff?
|oh, it's a split track - reads 2
|sectors, advances, reads 2, steps back
|again, reads 2, advances, reads 2, so
|$b500-bcff

                                     ...4am...|
                                        agreed|
  that explains the funky drive noises|
                                   during boot|

|...qkumba...
|maybe it's quarter-track.  I can't
|tell from the timing.
|anyway, another callback jump at
|$b20c?

                                     ...4am...|
whatever it is, it's stepping forward,|
          then back, then forward again|
      because of the 01 FF 01 00 table|
                                      at $B328|
|...qkumba...
|right, the drive will "chatter" as a
|result.  Captain Goodnight did that
|over several tracks

                              ...4am...|
i see no checksums or dependencies, so|
i'll callback at $B20C before it jumps|
                               to $B500|
          oh, you said that already :)|

|...qkumba...
|lost in the storm of words
|you say things now

                              ...4am...|
          OBJ.B500-BCFF on https://...|
    I think $B500 is the main RWTS API|
 entry point. zp$5F is the command ID.|
   looks up low8 in $B580,X (X=zp$5F),|
   calls one of the routines at $B550,|
                $B558, $B568, or $B570|

|...qkumba...
|I've lost track of the value in $5f by
|this point

                              ...4am...|
                                 it's 0|
                (from BOOT3 0000-00FF)|

|...qkumba...
|seek track 9

                              ...4am...|
                                  b5501|
                 oops, wrong window :)|
|...qkumba...
|read 12 sectors to $800+
|at a time
|with partial stepping, all the way up
|to $87ff
|decode $b6xx to $3xx via $bexx
|then perhaps two other block reads of
|$8800-afff (with $b2xx as dummy page),
|and $2000-3fff
|either or both of which might be
|transient

                                                   ...4am...|
                                         eyes glazing over|

|...qkumba...
|I think the track numbers that I
|quoted are all doubled already

                                                   ...4am...|
                                     yes, they're phases|
          $B550 starts at phase $09, $B558|
   starts at $19 then $29, $B568 starts|
                    at $31, $B570 starts at $41|
   ok, so the routine at $B600 decrypts|
     to $0300, seeks to phase $07, reads|
 some nibbles, then continues at $0362|
       which wipes the routine and pushes|
   $BEAF to the stack (along with #$34,|
                  which is popped as the status|
                                                   registers)|

|...qkumba...
|so it loads that first big chunk from
|three locations on the disk, for
|commands 0-2.
```

```
                                       ...4am...|
 $BEB0 re-encrypts $BF9F and exits via|
                                           RTS|
   execution continues at $B50F, which|
turns off the drive and jumps to $16C4|
                                    maybe?|

|...qkumba...
|looks like it

                                       ...4am...|
                                          whew|

|...qkumba...
|so a callback at $b519 would capture
|the first part

                                       ...4am...|
                               out of time now|
pick this up later (probably tomorrow)|

|...qkumba...
|okay
|that was fun

                                       ...4am...|
       indeed. two pairs of eyes helps|
                                  immensely.|
```

May 24

|...qkumba...
|I'm back again, whenever you're ready.
|I was thinking this morning that the
|game might have a demo mode
|corresponding to command 0, cut scene
|is command 1 and 6, game is command 2,
|hiscores is command 3. something like
|that.
|4 and 5 are unassigned

...4am...|
ready|
setting up a JMP $FF59 at $B519 to see|
if we can capture the first block in|
memory|

|...qkumba...
|yes
|then we must save $0800-87FF

...4am...|
not working|
the JSR $B700 does not return|

|...qkumba...
|maybe lda $c08a first?
|or jmp $c500 to know for sure

...4am...|
putting JMP $C500 at $B50C reboots to|
work disk in slot 5|
putting JMP $C500 at $B50F runs game|
intro sequence, then hangs|
putting JMP $FF59 at $B50C|
successfully breaks to monitor|
this is on hi-res page 1:|
[screenshot]|
800-1FFF also filled with new code|
4000-5FFF untouched|
6000-87FF has new code|
8000+ untouched|
oops, no|
8800+ untouched|
(other than previous stages of boot|
code, which we've already captured)|
OBJ files are here: https://...|
need to re-trace $B700 and figure out|
why it never returns, and where it|
goes instead|
I still think $B500 is the highest-|
level entry point to the game-specific|
disk loading API|
(like $200 in Mr. Do)|
I'm going to try fiddling with zp$5F|
before calling $B500 and see if I can|
get the game to load the other blocks|
oooooooh. the routines at $B550,|
$B558, $B568, and $B570 load A with|
the starting disk phase and Y with the|
starting index into $B900. $B900 is|
the page array.|
$B550 => A=$09, Y=$00, so it seeks to|
phase $09 and reads sectors into the|
memory pages listed at $B900+ (because|
$B900 + $00 = $B900)|
[...]

```
   *B900.B960

   B900- 08 09 0A 0B 0C 0D 0E 0F
   B908- 10 11 12 13 14 15 16 17
   B910- 18 19 1A 1B 1C 1D 1E 1F
   B918- 20 21 22 23 24 25 26 27
   B920- 28 29 2A 2B 2C 2D 2E 2F
   B928- 30 31 32 33 34 35 36 37
   B930- 38 39 3A 3B 3C 3D 3E 3F
   B938- 60 61 62 63 64 65 66 67
   B940- 68 69 6A 6B 6C 6D 6E 6F
   B948- 70 71 72 73 74 75 76 77
   B950- 78 79 7A 7B 7C 7D 7E 7F
   B958- 80 81 82 83 84 85 86 87
   B960- 00
```

$00 at $B960 means stop that exactly matches the behavior I saw in TRACE9

$B558 sets A=$19, Y=$00 (again), JSR $BA00, so it's filling those exact pages again, but starting at disk phase $19 instead. Then $BA00 returns gracefully and execution continues at $B55F, which sets A=$29, Y=$68, and exits via $BA00. So it's doing another read starting at disk phase $29 and using the page array at $B968+

```
   *B968.B998

   B968- 88 89 8A 8B 8C 8D 8E 8F
   B970- 90 91 92 93 94 95 96 97
   B978- 98 99 9A 9B 9C 9D 9E 9F
   B980- A0 A1 A2 A3 A4 A5 A6 A7
   B988- A8 A9 AA AB AC AD AE AF
   B990- B2 B2 B2 B2 B2 B2 B2 B2
   B998- 00
```

[...]

So if I set zp$5F to $01 before|
calling $B500, and interrupt it at|
$B50C again, I can expect it to fill|
$0800-$3FFF, $6000-$87FF, $8800-$AFFF,|
and $B200-$B2FF (likely unused, it|
seems to use it as a filler page so|
the lower level disk read routine can|
always read a multiple of 8 sectors)|
testing that theory now...|

|...qkumba...
|yes, $b2xx is a dummy page so it can
|fill its 12-slot read array the
|different commands load different
|blocks, and some of them overlap,
|which is why I think that they're
|cutscenes and hiscores or somethign

...4am...|
confirmed that setting zp$5F to $01|
calling $B500 loads exactly what I|
thought it would|

|...qkumba...
|yes, we want the blocks for
|$5f=0, 1, 2, 3, and 6.

...4am...|
[screenshot]|
on hi-res page 1 after loading block 2|

|...qkumba...
|animated, surely

...4am...|
block 6 is identical to block 1|
because $B581 = $B586 (both #$58)|

```
|...qkumba...
|right, the actual code might display
|something different - win/lose, but
|it's not relevant to us
|block 3 has a picture

                                         ...4am...|
                           yes, capturing it now|

|...qkumba...
|this is exciting
|and this is why the file-based
|versions have only the main game.

                                         ...4am...|
                                    [screenshot]|

|...qkumba...
|niiiice

                                         ...4am...|
                        all files on https://...|

|...qkumba...
|rename BLOCK 00.2000-1FFF,
|BLOCK 00.2000-3FFF
|"ok, so the routine at $B600 decrypts
|to $0300, seeks to phase $07, reads
|some nibbles, then continues at $0362
|which wipes the routine and pushes
|$BEAF to the stack (along with #$34,
|which is popped as the status
|registers)" is probably why $B700
|never returns
```

```
                                    ...4am...|
           fixed filename: https://...|
   in theory, we have all the data we|
             need to recreate the game|

|...qkumba...
|okay, so... is the original write-
|protected?  No suggestion that it can
|save anything?

                                    ...4am...|
  i don't remember, and the picture I|
    took doesn't show it, and i'm not|
 physically near it so i can't verify|
 but agreed, i don't see any evidence|
 of high scores or saved games or any|
                   disk write routines|

|...qkumba...
|great.  any ideas for a new loader?
|qboot could do it.

                                    ...4am...|
                          works for me|
    needs to stay resident and fit in|
               $BD00..$BFFF (I think)|
   need to permanently decrypt $BF9F+|
   and $B600 (which ends up at $0300)|

|...qkumba...
|okay, qboot fits in $bd00-bfff.
|not sure if bf9f will be available,
|though. I will check

                                    ...4am...|
       and figure out where execution|
        continues after the JSR $B700|
        well $B2xx is available, yes?|
|...qkumba...
|right, yes.
|We can move one of the tables there,
|and free $bf7f+

                             ...4am...|
                             excellent|

|...qkumba...
|okay, just have to move preshift to
|$b200, and the rest should be fine.

                             ...4am...|
      out of time, pick it up tomorrow|

|...qkumba...
|okay
```

May 25

...4am...|
Uh oh. Ctrl-H during play displays|
"GUMBALL HALL OF FAME"|
$BD00 (copied from $0500 in BOOT1|
0400-07FF) is the disk write routine.|
It saves high scores on track $01|
(phase $02) then seeks back to phase|
$07. High scores are stored in $B000-|
$B0FF, which explains why one of the|
boot stages tried to read into that|
page but stored a page of default|
values instead if the disk read|
failed.|
Anyway, a full read/write RWTS will be|
required, although perhaps the write|
routine could be read from disk only|
when needed (like you did with Captain|
Goodnight).|
So I traced it again more carefully,|
and I figured out why the JSR $B700|
never returns. It decrypts $B600 into|
$0300 then exits via JMP ($B709),|
a.k.a. $0300. The decrypted routine at|
$0300 does this:|

```
  0313-   A9 07         LDA   #$07
  0315-   20 80 03      JSR   $0380
  0380-   20 00 BE      JSR   $BE00
  0383-   A2 03         LDX   #$03
  0385-   68            PLA
  0386-   CA            DEX
  0387-   10 FC         BPL   $0385
  0389-   4C 18 03      JMP   $0318
```

That negates both the JSR $0380 (at|
$0315) and the JSR $B700 (at $B50C).|
[...]

Then it does this:|
|
```
  0343-   20 51 03    JSR   $0351    |
  0346-   48          PHA            |
  0347-   20 51 03    JSR   $0351    |
  034A-   48          PHA            |
```
|
$0351 reads a 4-4 encoded byte from|
disk|
Later it pushes ##$BE and ##$AF, which|
re-encrypts the code at $BF9F and|
exits via RTS, so we "return" to the|
address that was read directly from|
disk and pushed to the stack (at|
$0343..$034A).|
Furthermore, the entry point that's|
read from disk varies by block. It|
reads a nibble prologue, then there's|
a loop at $0338 which reads through a|
null-delimited array of addresses on|
disk until it finds the Nth address|
(where N is the character a.k.a.|
command ID a.k.a. block number that|
was passed to the output vector in the|
first place)|
To unf*ck this routine, we need to|
find the entry point for each block.|
I can write another tracer, or I can|
look at the disk with a nibble editor|
and manually calculate the bytes it's|
reading.|
Oops, I was slightly wrong but mostly|
right. The entry point address array|
is on track 3.5 (phase 7), and it is|
after the "D4 D5 D7" prologue, and it|
is 4-4 encoded, but it's not null-|
delimited.|
I found the array in a nibble editor|
and converted the values. The|
"return" address for block 0 is $0F9C.|
[...]

```
    ]PR#5                                          |
    ...                                            |
    ]CALL -151                                     |
    *800:0 N 801<800.BEFEM                         |
    *BLOAD BLOCK 00.0800-1FFF,A$800                |
    *BLOAD BLOCK 00.2000-3FFF,A$2000               |
    *BLOAD BLOCK 00.6000-87FF,A$6000               |
    *BLOAD BOOT1 0400-07FF,A$4400                  |
    *FE89G FE93G                                   |
    *BD00<4500.47FFM                               |
    *F9DG                                          |
                                                   |
      displays intro sequence and runs|
     through it several times until it|
     eventually tries to load the next|
           phase from disk and crashes|
   updated draft with entry points for|
               each block: https://...|

|...qkumba...
|excellent work.
|I'm about to start reading.
|is the disk a dual-boot?
|the track 0 stuff looks like 5-and-3
|since everything else is 4-and-4, it
|could certainly be

                               ...4am...|
  Yeah, T00,S00 is virtually identical|
    to other games from that early 80s|
          that I've seen, like Falcons|
  auto-boots on 13-sector or 16-sector|
                                 drive|
|...qkumba...
|drive seek: the ldx #$13 is the whole
|track delay; the BIT masks the ldx
|#$0a, which I believe is half-track

                             ...4am...|
  Paul explained to me that disks like|
 that actually have TWO T00,S00 -- one|
  with the "D5 AA 96" prologue and one|
 with the "D5 AA B5" prologue. The one|
  I see is, of course, the D5AA96 one,|
      which includes enough of the 5-3|
firmware code to read the next sector.|
  And everything after that is 4-4 and|
    custom, so no further issues. Very|
       clever solution to the backward|
                compatibility problem.|

|...qkumba...
|yes, that's exactly correct
|and produces weird copy errors that
|make some people think that the copy
|won't work because one sector is
|missing
|excellent text so far

                             ...4am...|
                                thanks|
     honestly, if you're trying to bit|
  copy this disk, track 0 is the least|
                      of your problems|
```

May 27

...4am...|
Good news, everyone!|
Gumball's crazy encrypted routine at|
$0300 wipes $B100..$BCFF and the game|
never uses it until it reloads its|
loader into it.|
Which means we have TONS of space for|
any kind of RWTS we want. We could go|
with a full DOS 3.3 RWTS and still|
have $700 bytes left for our own glue|
code.|

|...qkumba...
|yay! but DOS RWTS is slow, and
|Gumball is fast.
|we should be fast.
|it's only proper.

...4am...|
Agreed, but maybe we could read in|
a DOS RWTS when we need to write|
the high scores|
Or is qboot already read/write|

|...qkumba...
|qboot is read-only, but I am working
|on a small write routine right now.
|Counting cycles intensively...

...4am...|
In fact, we can just keep the write|
routines in memory. Tons of space,|
and I verified that the game code|
communicates with the RWTS solely|
through the output vector (printing|
a "command" character via $FDED).|
So lots of flexibility.|

```
|...qkumba...
|or we could just use DOS RWTS,
|since it's only 2 sectors long
|DOS write routine is only 2 sectors,
|that is.

                                               ...4am...|
      Well, having a complete fast RWTS|
          would certainly be useful (and|
likely reusable), it's not a necessity|
   for this project. We could start by|
      reusing DOS routines and optimize|
               them on a future project.|

|...qkumba...
|okay, that gets us a release sooner.

                                               ...4am...|
                         Back in a few hours|

|...qkumba...
|okay

                                               ...4am...|
                                             ready|
   It's been 2 hours; have you written|
                               a new RWTS yet?|

|...qkumba...
|yes
|I just finished it

                                               ...4am...|
                     Damn it, I was kidding|
```

Keys and Controls

The game can be played with a joystick or keyboard.

<Ctrl-J>	switch to joystick mode
<Ctrl-K>	switch to keyboard mode

When using a keyboard:

S	move bins left
D	stop bins
F	move bins right
[Space]	switch in-tube gates
E	increase speed
C	decrease speed
[Return]	toggle target sighting

```
 U I O              move the target sight
 J K L              (for when the bombs
 M , .               start dropping)
```

When using a joystick:

buttons 0+1	toggle target sighting
<Ctrl-X>	flip joystick X axis
<Ctrl-Y>	flip joystick Y axis

Other keys:

<Ctrl-S>	toggle sound on/off
<Ctrl-R>	restart level
<Ctrl-Q>	restart game
<Ctrl-H>	view high scores
<Esc>	pause/resume game

After the game starts, press <Ctrl-U>
<Ctrl-C> <Ctrl-B> in sequence to see a
secret credits page that lists most of
the people involved in making the game
(but sadly, not the person responsible
for developing the copy protection).

Cheats

I have not enabled any cheats on our release, but I have verified that they work. You can use any or all of them.

Stop the clock:
T09,S0A,$B1 change 01 to 00

Start on level 2-5:
T09,S0C,$53 change 00 to <level-1>

Acknowledgements

Thanks to Alex, Andrew, John, Martin, Paul, Quinn, and Richard for reviewing drafts of this write-up.

And finally, many thanks to qkumba: Shifter of Bits, Master of the Stack, author of Gumboot, and my friend.

```
               Changelog


2016-09-09

- update Gumboot to poll for good data
  before seeking (compatibility with
  Floppy Emu)

2016-06-13

- defeat secondary protection (chapter
  23)
- more documented cheats
- clarify how to activate the first
  hint towards the secret final screen

2016-06-08

- initial release

---------------------------------------
A 4am & san inc crack           No. 683
------------------EOF------------------
```