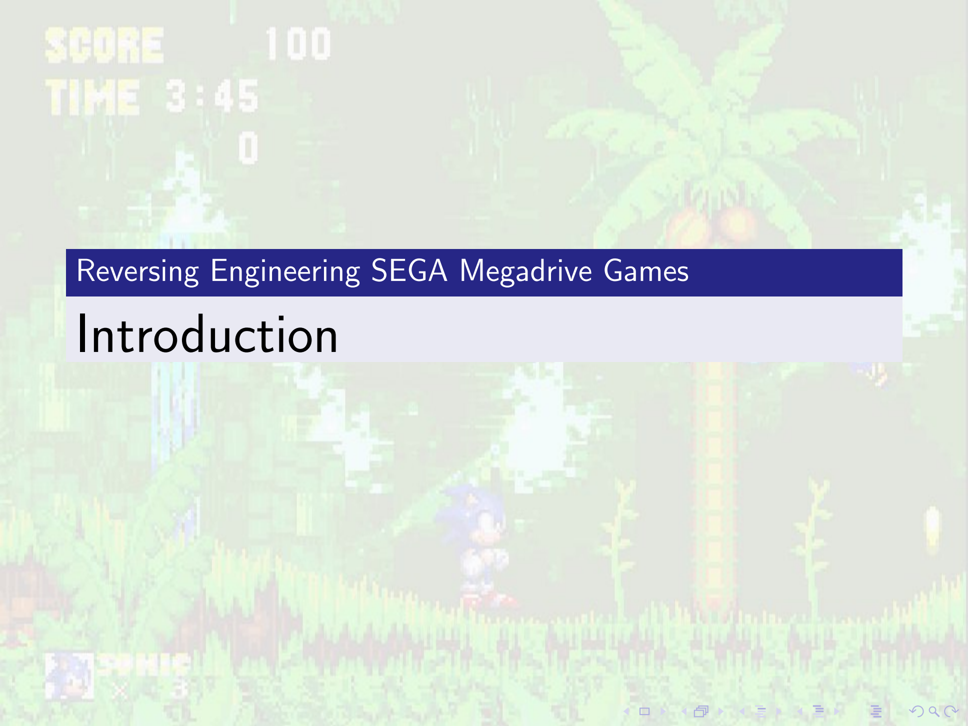
Reversing Engineering SEGA Megadrive Games

Edd Barrett

April 28, 2012

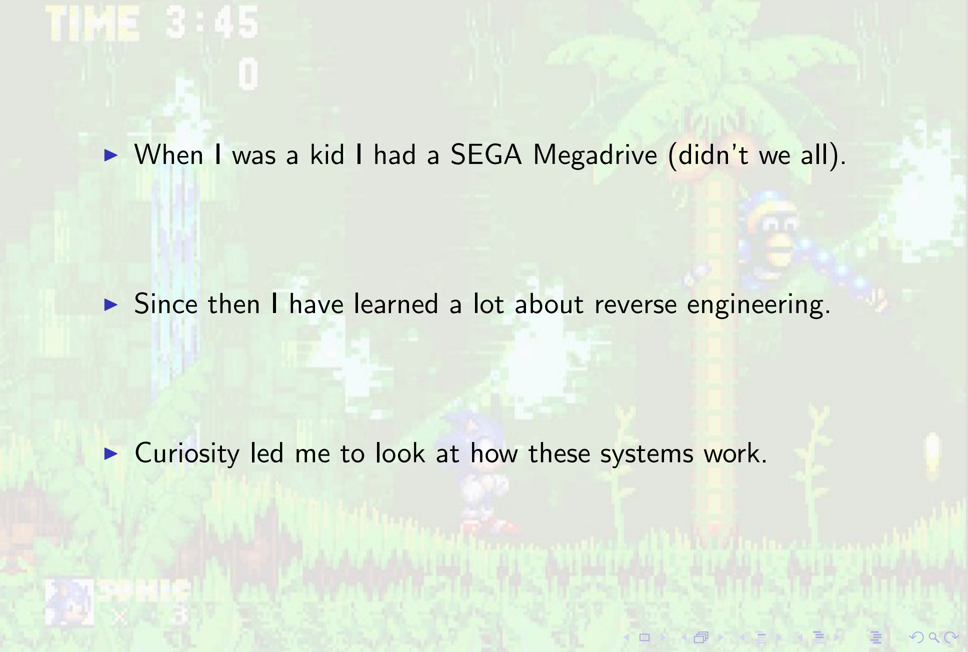
Twitter: @vext01



Reversing Engineering SEGA Megadrive Games

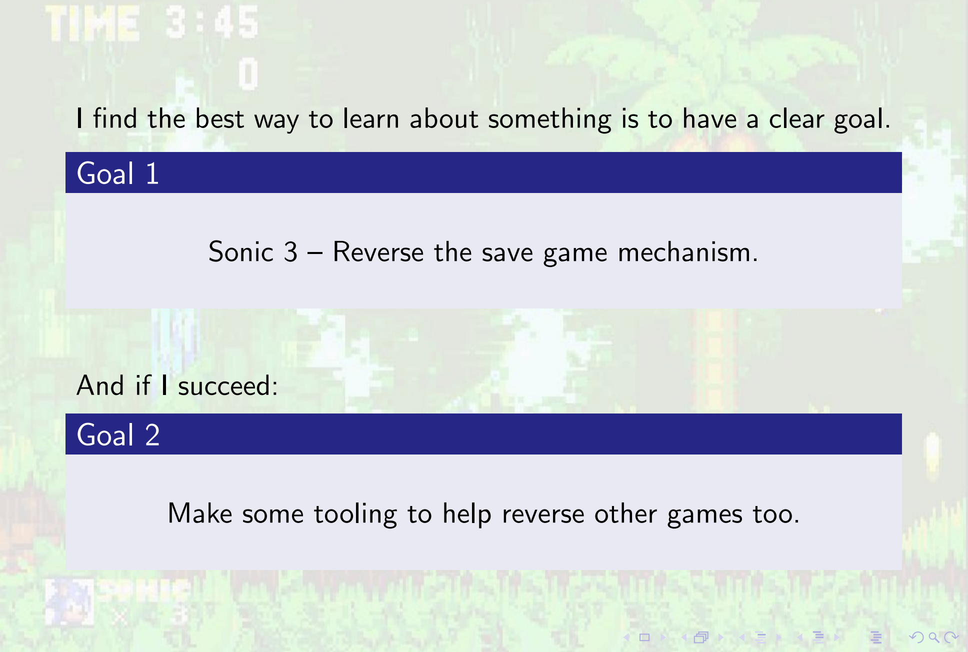
Introduction

Why?



- When I was a kid I had a SEGA Megadrive (didn’t we all).
- Since then I have learned a lot about reverse engineering.
- Curiosity led me to look at how these systems work.

Starting Out



I find the best way to learn about something is to have a clear goal.

Goal 1

Sonic 3 – Reverse the save game mechanism.

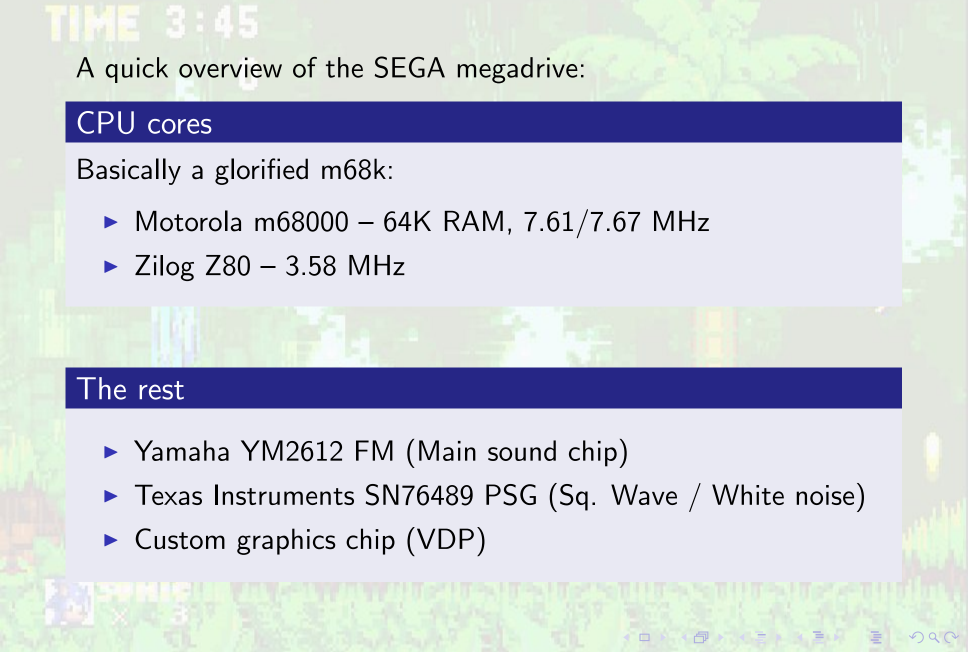
And if I succeed:

Goal 2

Make some tooling to help reverse other games too.

SEGA Megadrive – Overview

Basic Architcture



A quick overview of the SEGA megadrive:

CPU cores

Basically a glorified m68k:

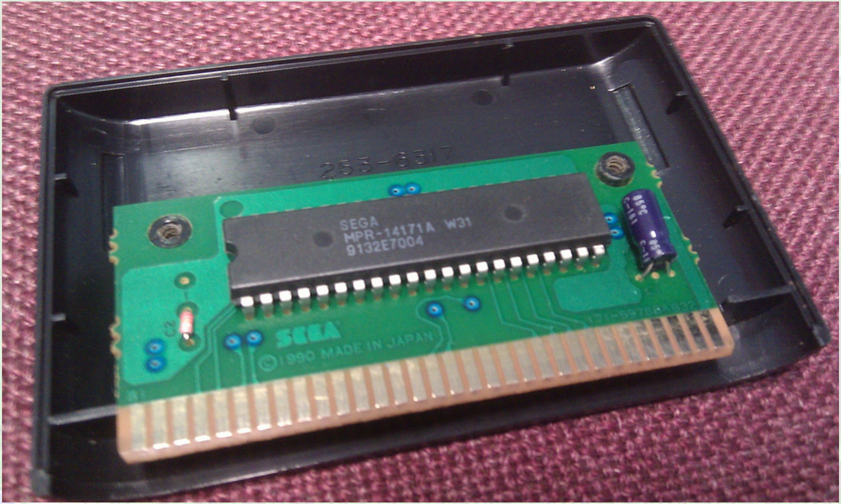
- Motorola m68000 – 64K RAM, 7.61/7.67 MHz
- Zilog Z80 – 3.58 MHz

The rest

- Yamaha YM2612 FM (Main sound chip)
- Texas Instruments SN76489 PSG (Sq. Wave / White noise)
- Custom graphics chip (VDP)

Game Cartridges

Game Cartridges

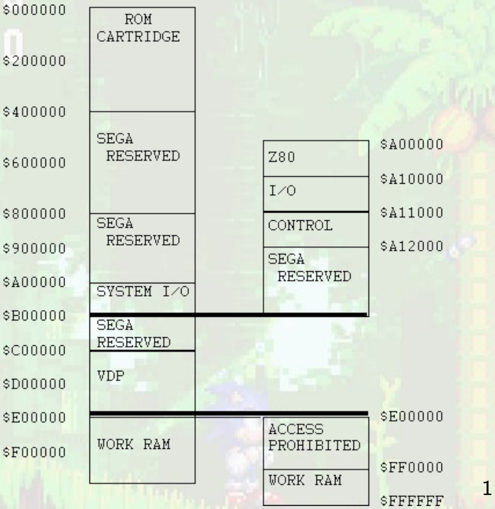


Game Cartridges

Inside a Typical Cart

- ROM
  - Game instructions
  - Sprites
  - Music
- Save RAM (Optional)
  - Stores persistent state. High scores, saves etc.
  - Usually a lithium cell retain memory
- Additional graphics hardware (Optional)
  - For any “special” graphics capabilities
  - Eg. Sega Virtua Processor

Memory Map of the Megadrive



[1]

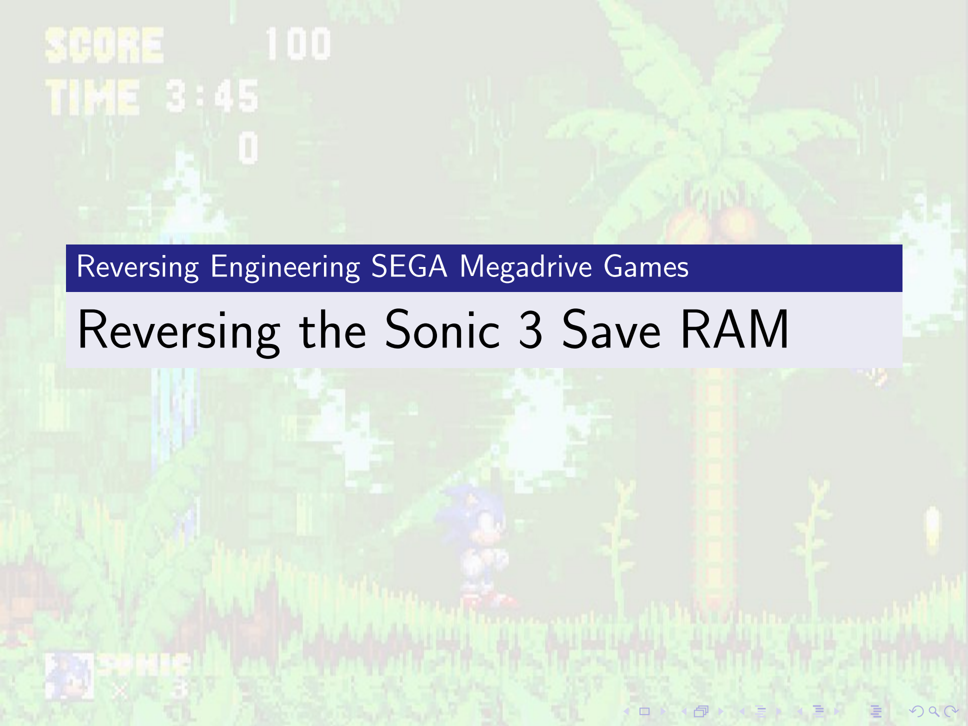
- Thanks to the leaked sega2.doc we know about the memory layout

[1] Image borrowed from Nemesis

Memory Map of a Game Cart

- First 512 bytes are the “cart header”.
- The layout of the rest of the cart is specified inside the header.

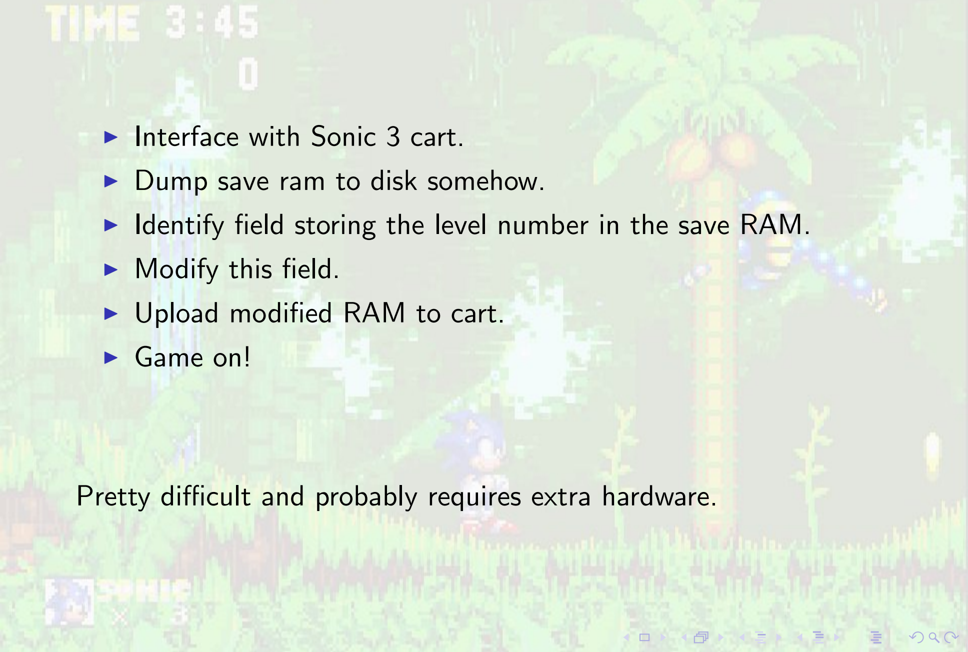
```
% ./dgm_hdump ~/roms/Sonic\ the\ Hedgehog\ 3.bin
Console Name : [SEGA GENESIS    ]
Copyright    : [(C)SEGA 1993.NOV]
Domestic Name: [SONIC THE             HEDGEHOG 3                ]
Overseas Name: [SONIC THE             HEDGEHOG 3                ]
Game Type    : [GM]
Product Code : [ MK-1079 -00]
Checksum     : a8 f2
IO Support   : [J       ]
ROM Start    : 00 00 00 00
ROM End      : 00 1f ff ff
RAM          : 00 ff 00 00 00 ff ff ff 52 41 f8 20 00 20 00 01 00 20 03 ff
RAM Present? : [RA]
RAM Start    : 0x200001
RAM End      : 0x2003ff
Modem Data   : [            ]
Memo         : [       ?                 ]
Release Country: []
```



Reversing Engineering SEGA Megadrive Games

Reversing the Sonic 3 Save RAM

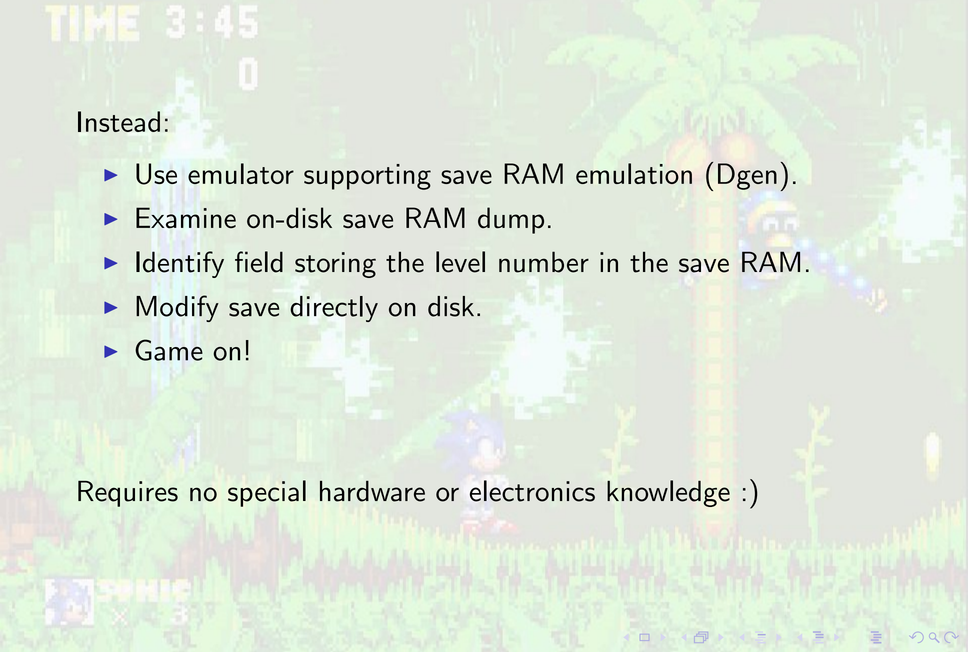
How Do We Start – The Electronic Engineer's Approach



- Interface with Sonic 3 cart.
- Dump save ram to disk somehow.
- Identify field storing the level number in the save RAM.
- Modify this field.
- Upload modified RAM to cart.
- Game on!

Pretty difficult and probably requires extra hardware.

How Do We Start – The Software Engineer's Approach

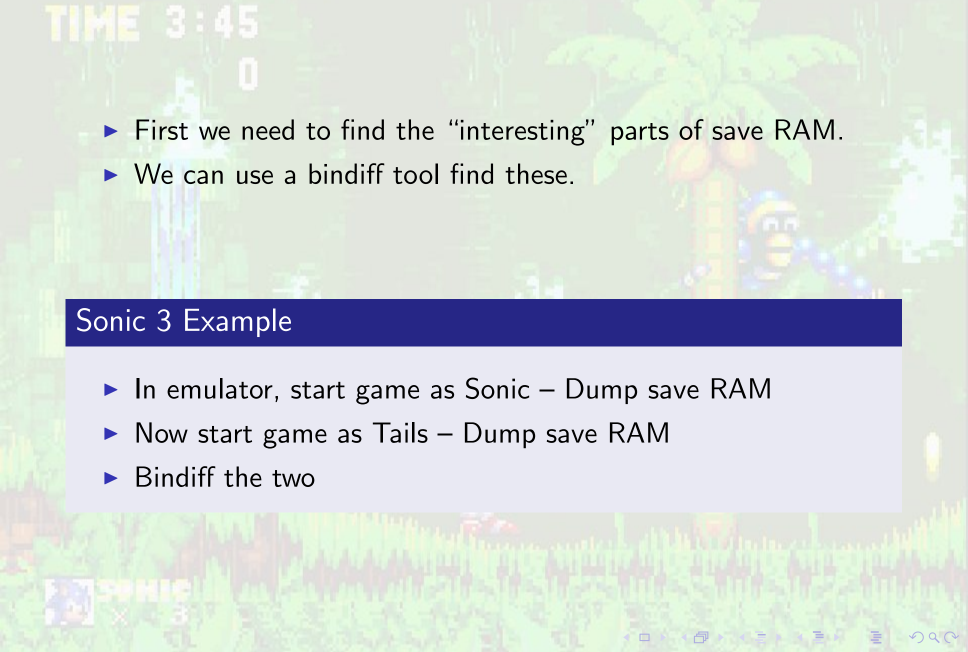


Instead:

- Use emulator supporting save RAM emulation (Dgen).
- Examine on-disk save RAM dump.
- Identify field storing the level number in the save RAM.
- Modify save directly on disk.
- Game on!

Requires no special hardware or electronics knowledge :)

Bindiffing Save RAM

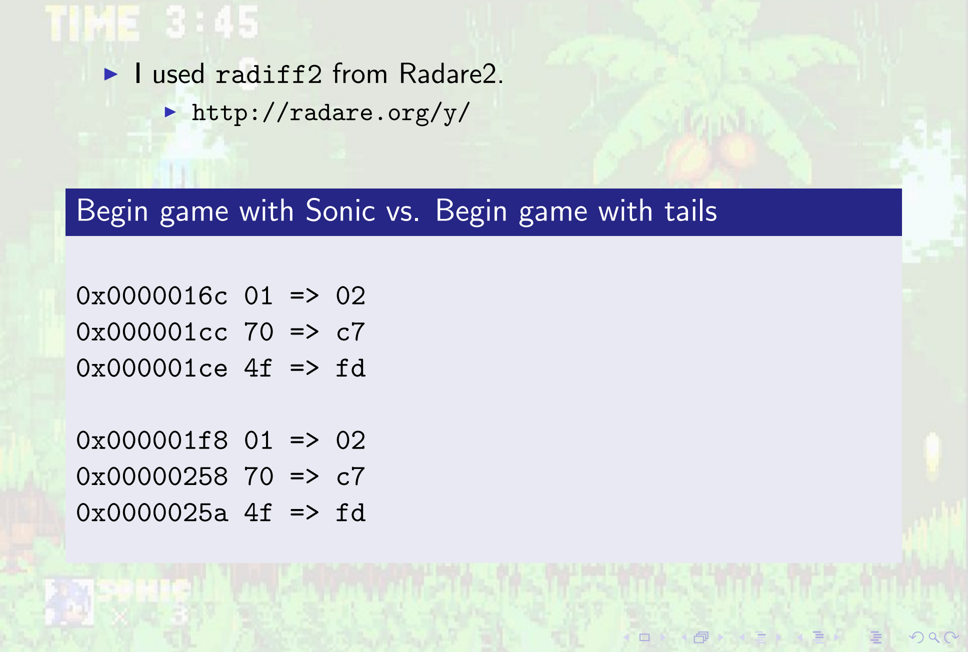


- First we need to find the “interesting” parts of save RAM.
- We can use a bindiff tool find these.

Sonic 3 Example

- In emulator, start game as Sonic – Dump save RAM
- Now start game as Tails – Dump save RAM
- Bindiff the two

Bindiffing Save RAM



- I used radiff2 from Radare2.
  - http://radare.org/y/

Begin game with Sonic vs. Begin game with tails

```
0x0000016c 01 => 02
0x000001cc 70 => c7
0x000001ce 4f => fd

0x000001f8 01 => 02
0x00000258 70 => c7
0x0000025a 4f => fd
```

Bindiffing Save RAM

- I used radiff2 from Radare2.
  - http://radare.org/y/

Begin game with Sonic vs. Begin game with tails

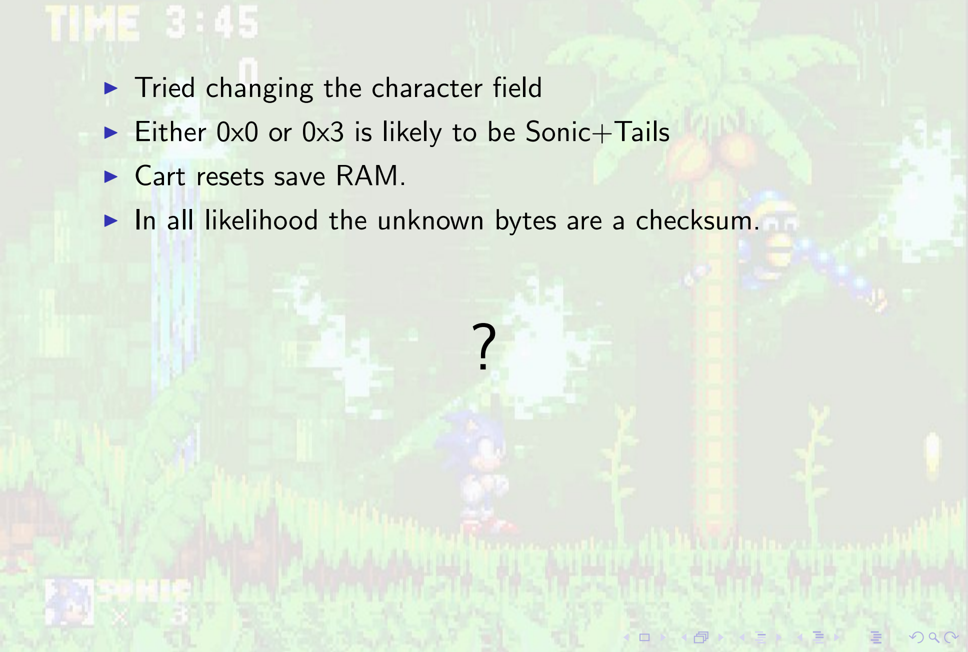
```
0x0000016c 01 => 02   <--- Looks like character field
0x000001cc 70 => c7   <--- ?
0x000001ce 4f => fd   <--- ?

0x000001f8 01 => 02   <--- Same as above
0x00000258 70 => c7   <--- just at different offset.
0x0000025a 4f => fd   <--- For redundancy?
```

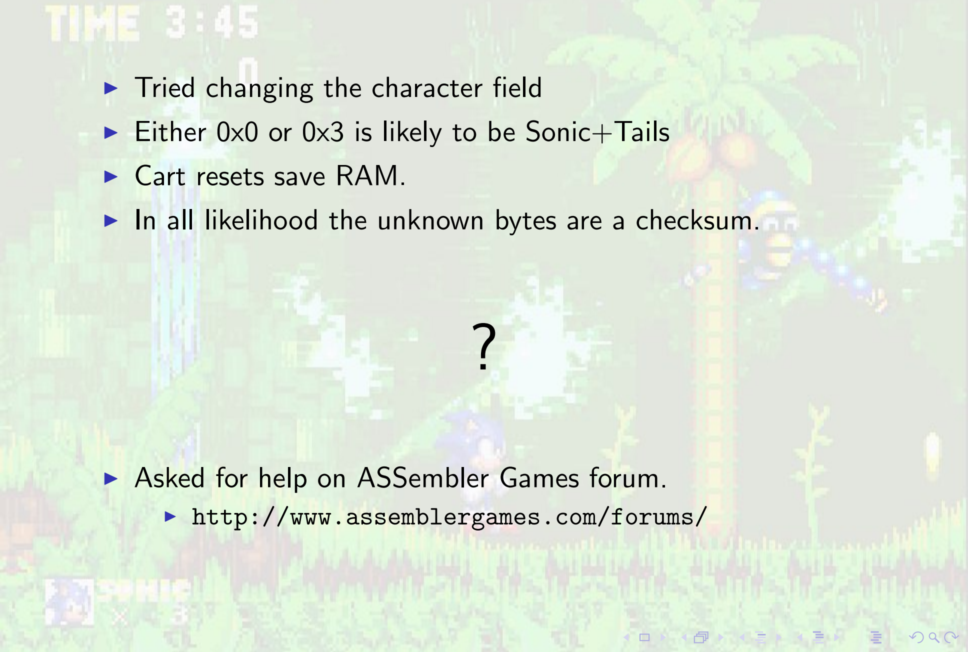
Bindiffing Save RAM

- Tried changing the character field
- Either 0x0 or 0x3 is likely to be Sonic+Tails
- Cart resets save RAM.
- In all likelihood the unknown bytes are a checksum.

?



Bindiffing Save RAM



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?

- Asked for help on ASSembler Games forum.
  - `http://www.assemblergames.com/forums/`

A Response

Someone called “Jorge Nuno” replied to my post:

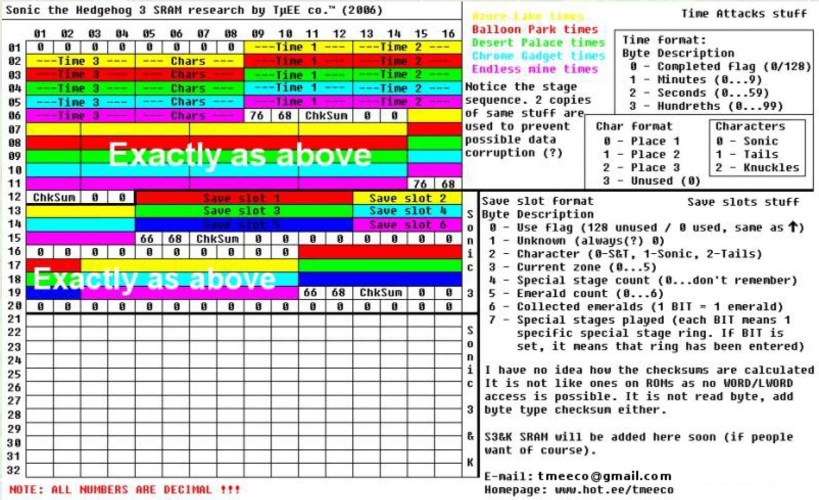
```
For the "checksum" this was from an old conversation between
me and him [Tmee]:

---8<---
OK Save Ram it is copied into 0xFFFFE600. And I think this
is the code that verifies the magic checksum:

sub_C362:
    moveq #0,d7
loc_C364:
    move.w (a6)+,d5
    eor.w d5,d7
    lsr.w #1,d7
    bcc.s loc_C370
    eori.w #$8810,d7
loc_C370:
    dbf d6,loc_C364
    rts

Need to checkout a6...
Probably d7 contains the result.
---8<---
```

A Response

Oh, and...

A Response

Oh, and...



Sonic the Hedgehog 3 SRAM research by TµEE co.™ (2006)

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	
01	0	0	0	0	0	0	0	0	---Time 1 ---				---Time 2 ---				
02	---Time 3 ---				--- Chars ---				---Time 1 ---				---Time 2 ---				
03	---Time 3 ---				--- Chars ---				---Time 1 ---				---Time 2 ---				
04	---Time 3 ---				--- Chars ---				---Time 1 ---				---Time 2 ---				
05	---Time 3 ---				--- Chars ---				---Time 1 ---				---Time 2 ---				
06	---Time 3 ---				--- Chars ---				76	68	ChkSum		0	0			
07																	
08																	
09			Exactly as above														
10																	
11															76	68	
12	ChkSum		0	0	Save slot 1								Save slot 2				
13					Save slot 3								Save slot 4				S
14					Save slot 5								Save slot 6				o
15					66	68	ChkSum		0	0	0	0	0	0	0	0	n
16	0	0	0	0	0	0	0	0	0	0							i
17																	c
18	Exactly as above																
19											66	68	ChkSum		0	0	3
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21																	
22																	S
23																	o
24																	n
25																	i
26																	c
27																	
28																	3
29																	
30																	&
31																	
32																	K

NOTE: ALL NUMBERS ARE DECIMAL !!!

Azure Lake times
Balloon Park times
Desert Palace times
Chrome Gadget times
Endless mine times

Time Attacks stuff

Notice the stage sequence. 2 copies of same stuff are used to prevent possible data corruption (?)

Time format:
Byte Description
0 - Completed flag (0/128)
1 - Minutes (0...9)
2 - Seconds (0...59)
3 - Hundreths (0...99)

Char format
0 - Place 1
1 - Place 2
2 - Place 3
3 - Unused (0)

Characters
0 - Sonic
1 - Tails
2 - Knuckles

Save slot format

Save slots stuff

Byte Description
0 - Use flag (128 unused / 0 used, same as ↑)
1 - Unknown (always(?) 0)
2 - Character (0-S&T, 1-Sonic, 2-Tails)
3 - Current zone (0...5)
4 - Special stage count (0...don't remember)
5 - Emerald count (0...6)
6 - Collected emeralds (1 BIT = 1 emerald)
7 - Special stages played (each BIT means 1 specific special stage ring. If BIT is set, it means that ring has been entered)

I have no idea how the checksums are calculated It is not like ones on ROMs as no WORD/LWORD access is possible. It is not read byte, add byte type checksum either.

S3&K SRAM will be added here soon (if people want of course).

E-mail: tmeeco@gmail.com
Homepage: www.hot.ee/tmeeco

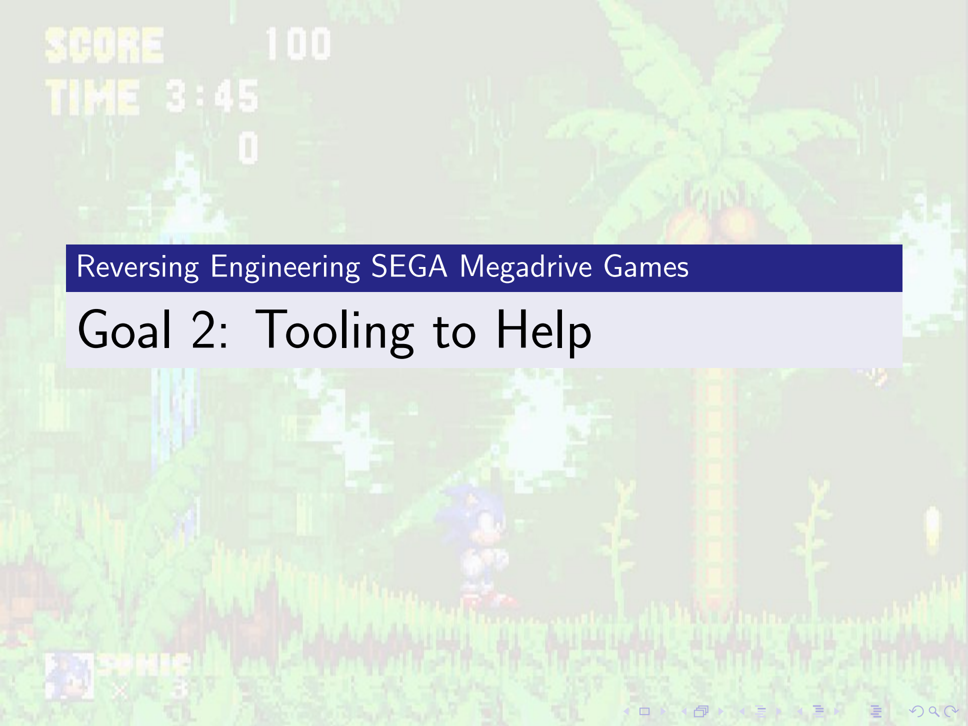
dgm_s3ramgen

- Mex and I reimplemented the checksum in C.
- Wrote a tool to generate custom save RAMs for Sonic 3.

```
Usage:  dgm_s3ramgen [options] outputfile

Options:
  -c num        Character select (0=ST, 1=S, 2=T)
  -e num        Emeralds (8-bitfield)
  -h            Show help
  -M            Make a MEGA-RAM (fully complete RAM)
  -p            Pad (word-align) RAM
  -s num        Choose slot to change
  -x num        Debug level (0-3)
  -z num        Choose zone (0-6)
```

Eg. RAM with save slot 1 with S+T on zone 4 with 2 emeralds:

`dgm_s3ramgen -s1 -c0 -z3 -e3 -p myramfile`



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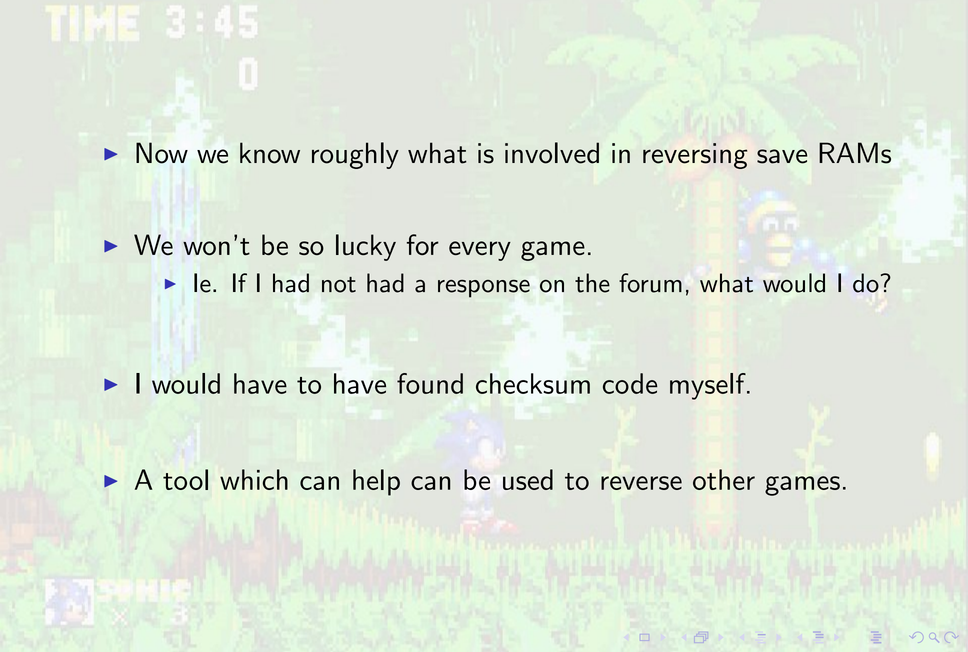
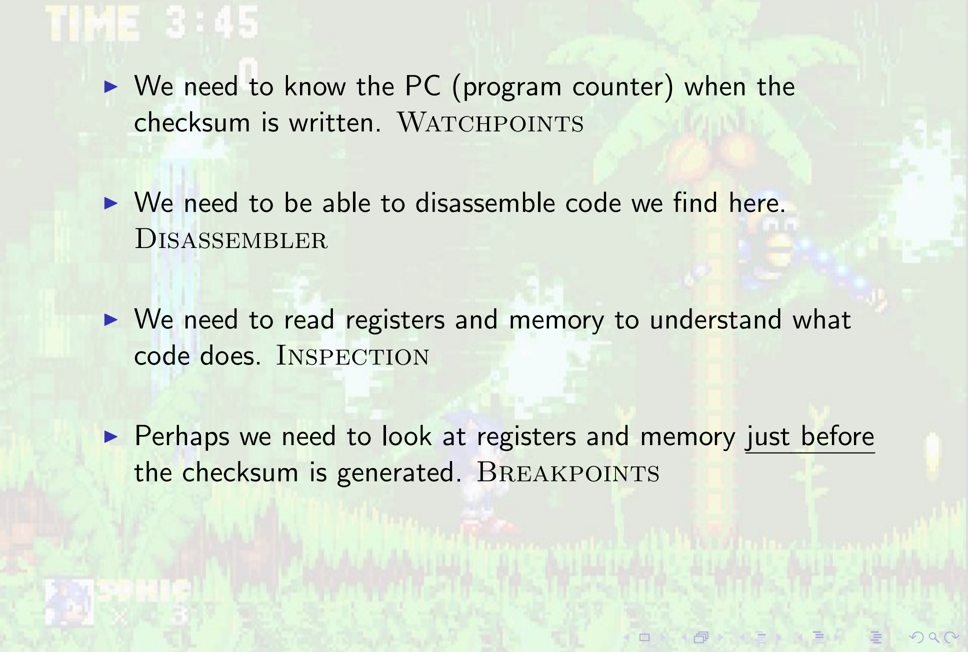
Goal 2: Tooling to Help

We Won’t Always be So Lucky



- Now we know roughly what is involved in reversing save RAMs
- We won’t be so lucky for every game.
  - Ie. If I had not had a response on the forum, what would I do?
- I would have to have found checksum code myself.
- A tool which can help can be used to reverse other games.

How to Find the Checksum Code in Sonic 3?



- We need to know the PC (program counter) when the checksum is written. Watchpoints

- We need to be able to disassemble code we find here. Disassembler

- We need to read registers and memory to understand what code does. Inspection

- Perhaps we need to look at registers and memory just before the checksum is generated. Breakpoints

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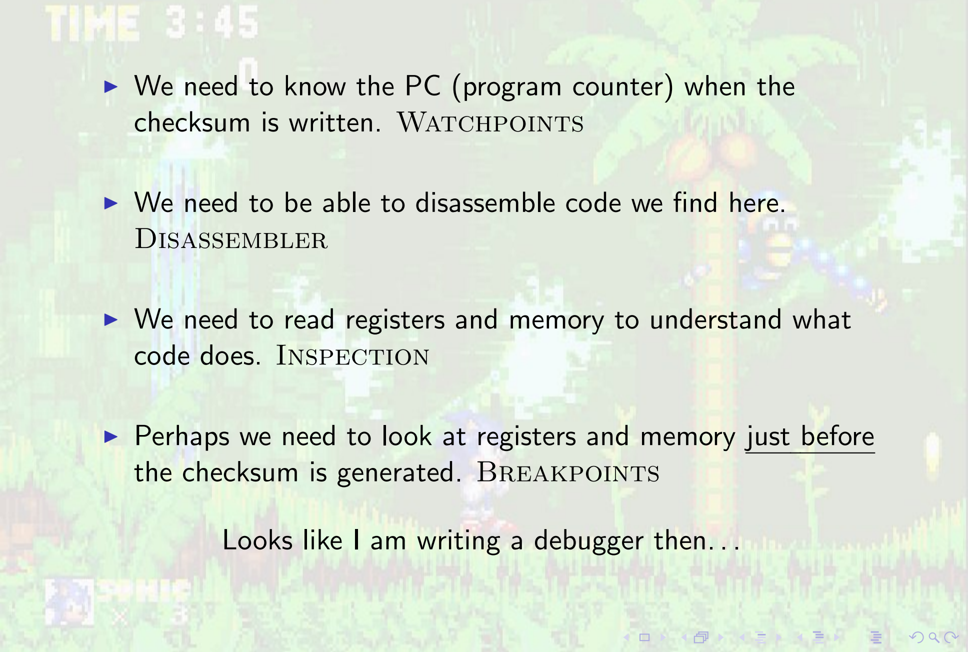

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Looks like I am writing a debugger then. . .

Implementing a Debugger

- Take existing emulator and modify.
- I chose Dgen/SDL

Dgen/SDL

- Pretty good (fast) emulator
- Open-source
- Mature – 1999-2012 – Dgen originally designed for DOS.
- Cross platform – well . . . UNIX + windows
- Original developers MIA – Currently maintained by zamaz
- Written in C++

“Dgen runs well on a P2-233” :P

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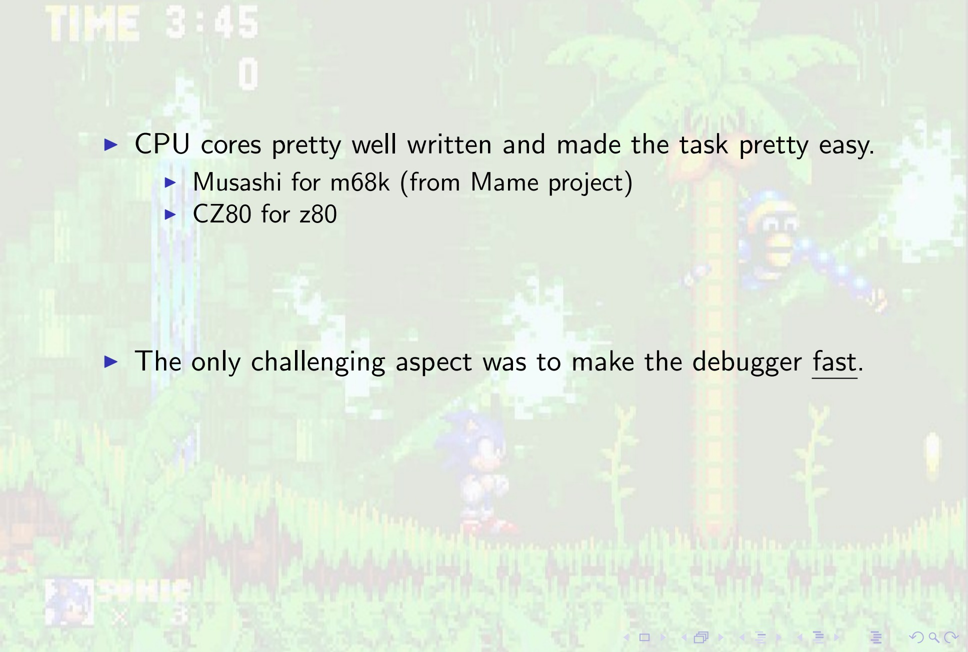
Implementing a Debugger



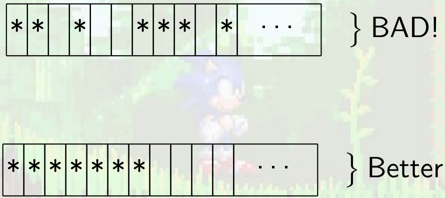
- CPU cores pretty well written and made the task pretty easy.
  - Musashi for m68k (from Mame project)
  - CZ80 for z80

- The only challenging aspect was to make the debugger fast.

Eg. Making Breakpoints Fast

```
#define MAX_BREAKPOINTS                      64
struct dgen_bp debug_bp_m68k[MAX_BREAKPOINTS];
```

- After each instr, we have to check if any of these BPs will fire
- Checking 64 BPs if only 1 is used is wasteful (and slow)
- Do as little work as possible by storing BPs cleverly.



} BAD!

} Better

Eg. Making Breakpoints Fast Again

Another optimisation:

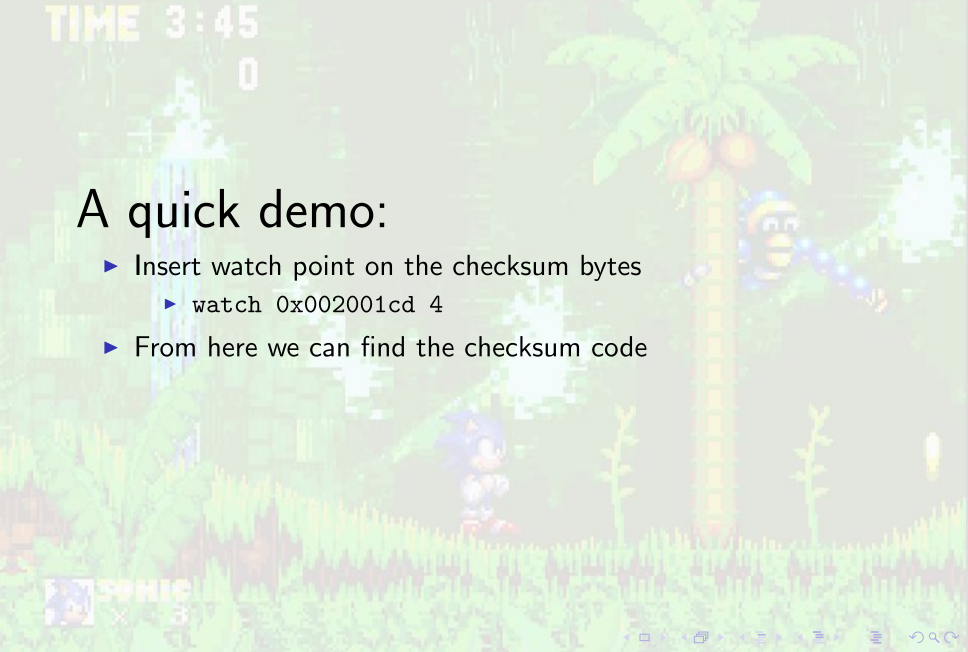
Too Slow

1. Execute single instruction
2. Check if breakpoint fires
3. Draw screen
4. Goto 1

Faster

1. Register CPU step handler in Musashi core.
2. Execute as many instructions as possible (up to frame limit)
   - CPU calls a handler after each instruction (last slide)
   - End current burst of instruction if we need to break.
3. Draw screen
4. Goto 1

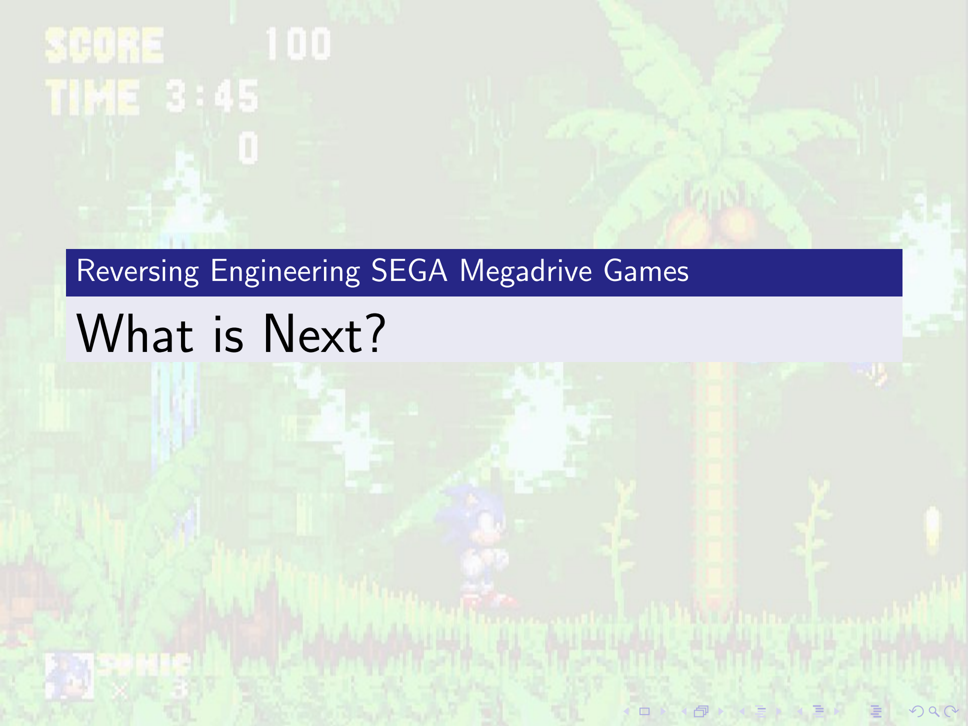
Demo



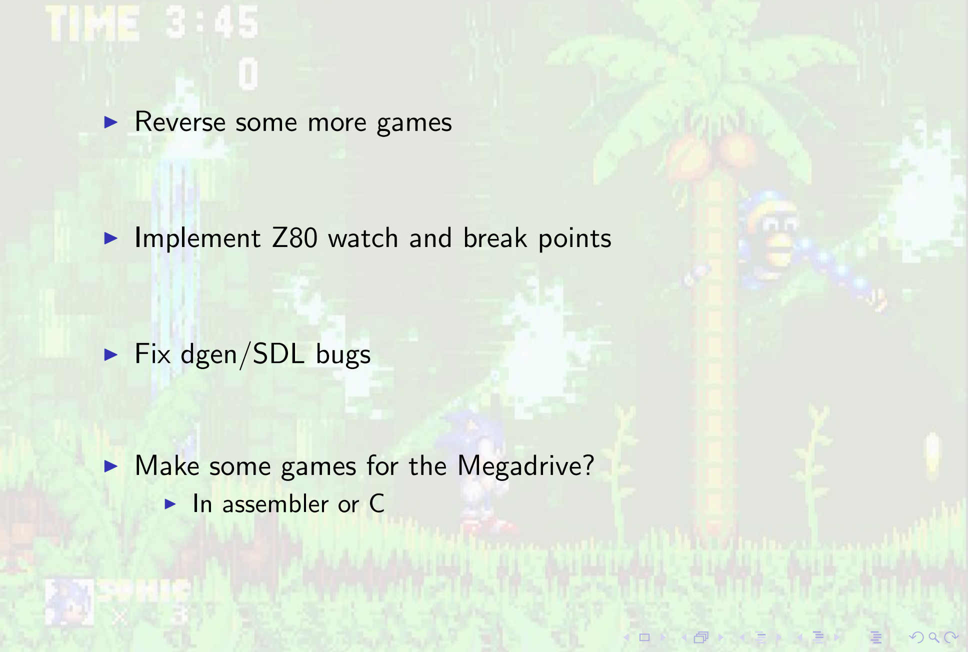
A quick demo:

- Insert watch point on the checksum bytes
  - `watch 0x002001cd 4`
- From here we can find the checksum code

What is Next?



Future Distractions



- Reverse some more games
- Implement Z80 watch and break points
- Fix dgen/SDL bugs
- Make some games for the Megadrive?
  - In assembler or C