

GNU Mes – Reduced Binary Seed bootstrap

janneke@gnu.org

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Outline

- 1 Reduced Binary Seed bootstrap: Introduction.
- 2 Reduced Binary Seed bootstrap: Why?
- 3 Reduced Binary Seed bootstrap: How?
- 4 Reduced Binary Seed bootstrap: Future.
- 5 Thanks
- 6 Legalese
- 7 Extra: Maxwell Equations of Software
- 8 Extra: History
- 9 Extra: Timeline
- 10 Extra: Metrics

Reduced Binary Seed bootstrap: GNU Mes

GNU Mes

- A Scheme interpreter written in ~5,000LOC of simple C.
- A C compiler written in Scheme.
- Built on eval/apply, the Maxwell Equations of Software.



What is a Compiler?

A compiler takes source code and produces executable object code

```
$ gcc hello.c -o hello  
$ ./hello => "Hello, Mes!"  
$ gcc hello.c -S -o hello.s
```

hello.c

```
void  
main ()  
{  
    puts ("Hello, Mes!");  
}
```

hello.s

```
main: push    %ebp  
      mov     %esp,%ebp  
      push    _string_0  
      call    puts  
      add    $4,%esp  
      leave  
      ret  
  
_string_0: .string "Hello, Mes!"
```

What is a Compiler?

A compiler takes source code and produces executable object code

```
$ gcc -c hello.s -o hello.o  
$ gcc hello.o -o hello  
$ ./hello => "Hello, Mes!"
```

hello.o object code

```
5589e5689b020001e8dc00000083c404c9c3
```

hello executable code

```
7f454c460101...5589e5689b020001e8dc00000083c404c9c3
```

What is a Binary Seed?

- ① A binary (program) that was not build from source.
- ② A binary (program) that was injected from a previous generation.
 - Think: Binutils, GCC, Glibc, Go, Haskell, Java, Perl, Rust, ...

What is a Bootstrap Seed?

In Guix 0.16 ~250MB

- "bootstrap-binaries": bash, binutils, bzip2, coreutils, gawk, gcc, glibc, grep, gzip, patch, sed, tar, and xz.



In Debian ~ 450MB

- "debootstrap" + "build-essential": adduser, apt, base-files, base-passwd, bash, binutils, bsdutils, bzip2, coreutils, cpp, cpp-6, dash, debconf, debian-archive-keyring, debianutils, diffutils, dpkg, dpkg-dev, e2fslibs, e2fsprogs, findutils, g++, g++-6, gcc, gcc-6, gcc-6-base, gpgv, grep, gzip...



What is a Bootstrap?

Impossible task: pull yourself up on your boot straps



Software: to create your first: kernel, shell, C compiler, ...



source + ?? =  binary

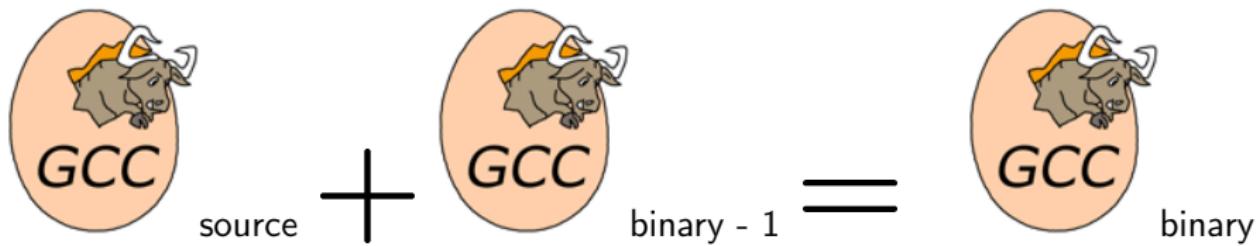
How to Bootstrap: An Old Recipe...



Recipe for yoghurt: Add yoghurt to milk – Anonymous

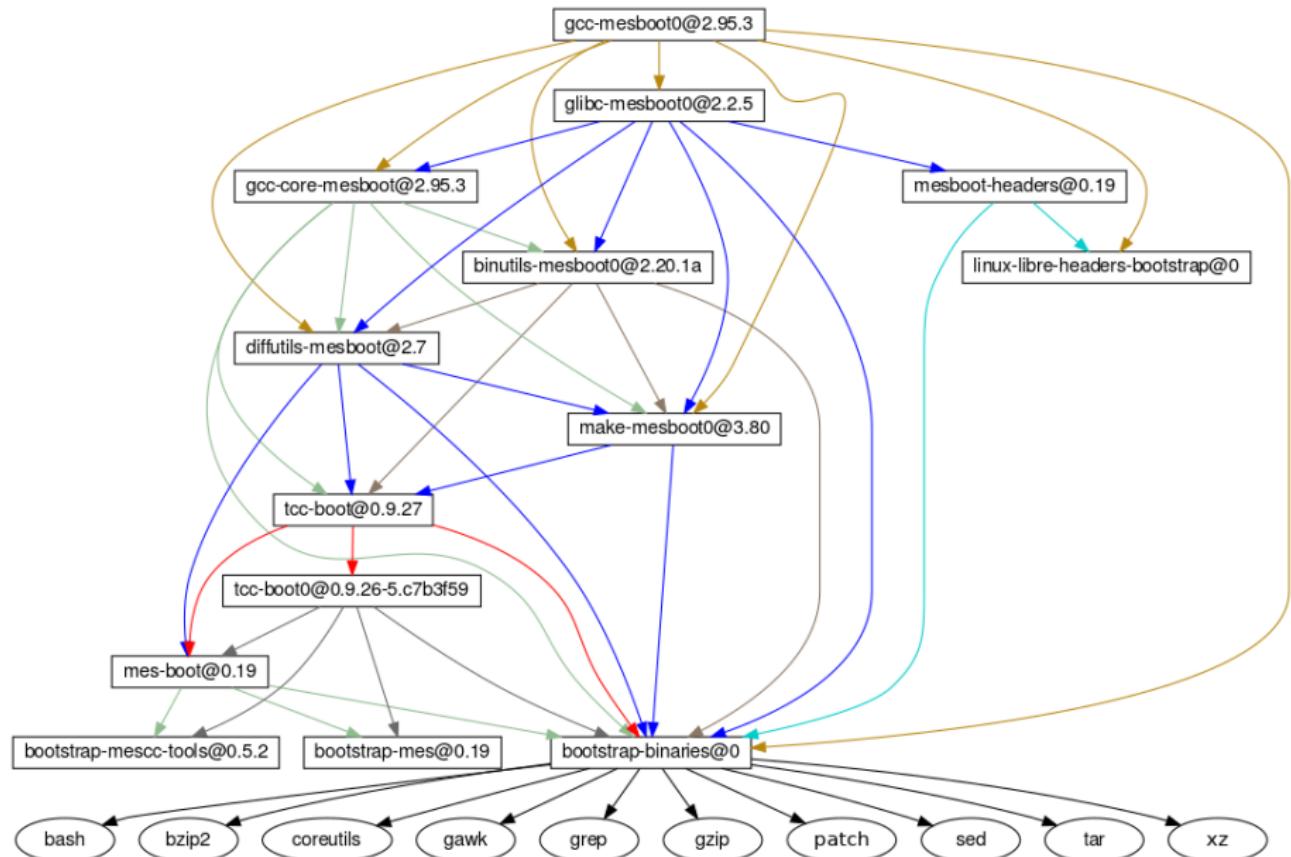
How to Bootstrap: Create your first GCC

Traditional recipe: like yoghurt



... and done!

Reduced Binary Seed: Remove Binutils, GCC, and GLIBC



GNU Mes: Reduced Binary Seed bootstrap

GNU Mes v0.19 (dec 2018)

- mes.c: small Scheme interpreter written in a simple C subset
 - 5000LOC
 - mostly Guile-compatible
- mescc.scm: A C compiler written in mes-compatible Guile Scheme
 - Nyacc C99 parser
- Mes C Library
 - libc.c: small C library for mes.c (25 functions, 1000LOC)
 - libc+tcc.c (80 functions, 3000LOC)
 - libc+gnu.c: bootstrap support libraries (160 functions, 6000LOC)

Reduced Binary Seed bootstrap (unreleased: @core-updates)

- Bootstrap GNU without binutils, GCC, or C Library
- Halves the size of the trusted set of binaries
 - Debian: 450MB, Guix: 250MB, RBSb-Guix: 130MB

Reduced Binary Seed bootstrap: Why?

Safety/Security

- Ken Thompson's "Reflections on trusting trust" attack.

Moral duty

- James Comey: ought to take responsibility for safety and security.

We like source

- Everything in Guix is built from source, except the bootstrap binaries.

Tradition

- This is how we used to do it.

Pragmatism

- Support new hardware architecture

Reduced Binary Seed bootstrap: Why?

Legality

- Is it even legal to distribute a GCC binary in DisneyWorld?

Inspiration

- Stage0's hex0 Monitor/Assembler.

Bruce Schneier: "Trusting trust" attack gotten easier

It's interesting: the "trusting trust" attack has actually gotten easier over time, because compilers have gotten increasingly complex, giving attackers more places to hide their attacks.

Here's how you can use a simpler compiler – that you can trust more – to act as a watchdog on the more sophisticated and more complex compiler. – Bruce Schneier, 2006

Peter Herdman: "Trusting trust" more fitting today

Reflecting on 'Reflections on Trusting Trust'

Enterprises appear to be overlooking or bypassing robust software assurance processes and procedures

Thompsons essay is probably more fitting today than it was when it was written.

The moral of this article is that you still cannot trust any software. – Peter Herdman, 2014

David A. Wheeler: Address subverted bootstrap code

Bootstrappable builds focuses on minimizing the amount of bootstrap binaries. They're not just interested in the direct "bootstrap" code to boot a computer, but also what is necessary to generate the direct bootstrap code.

The problem bootstrappable builds is trying to address is a real one, namely, they are worried about subverted bootstrap code. – David A. Wheeler, 2016

James Comey: Ought to take responsibility

I put a piece of tape [...] over the camera [of my personal laptop [...] so that people who don't have authority don't look at you. I think that's a good thing. I think people ought to take responsibility for their own safety and security. – US FBI director James Comey, 2016

That probably also applies to dowloading binaries from the internet and running them; paraphrasing

The FBI thinks that we ought to bootstrap our computers from source.

Ludovic Courtès: Reduce seeds to bare minimum

These big chunks of binary code are practically non-auditable which breaks the source to binary transparency that we get in the rest of the package dependency graph.

Every unauditible binary leaves us vulnerable to compiler backdoors as described by Ken Thompson in the 1984 paper [Reflections on Trusting Trust](#).

Thus, our goal is to reduce the set of bootstrap binaries to the bare minimum. – Ludovic Courtès (GNU Guix documentation, December 2017)

Is it legal to distribute a GCC binary in DisneyWorld?

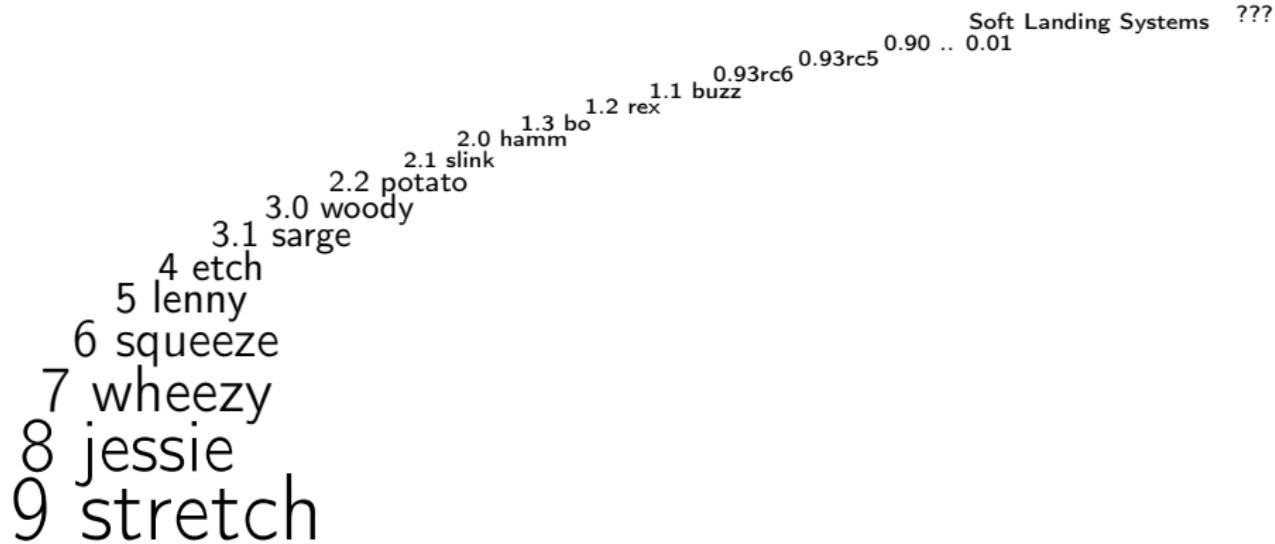
Only if you distribute, or give access to the 'Corresponding Source'

The "Corresponding Source" for a work in object code form means all the source code needed to generate, install, and (for an executable work) run the object code and to modify the work, including scripts to control those activities. However, it does not include the work's System Libraries, or general-purpose tools or generally available free programs which are used unmodified in performing those activities but which are not part of the work. –
GNU GPL version 3

Let's assume GCC was built using GCC-1

- Is GCC-1 a 'System Library'? or
- Is GCC-1 a 'general-purpose tool'? or
- Was GCC-1 a 'generally available free program'?

Journey to the source?



As time goes on we will expire the binary packages for old releases. Currently we have binaries for squeeze, lenny, etch, sarge, woody, potato, slink, hamm and bo available, and only source code for the other releases. –

www.debian.org/distrib/archive

Inspiration: Stage0's 500 byte hex0 Monitor

```
## ELF Header
7F 45 4C 46      ## e_ident[EI_MAG0-3] ELF's magic number
02                ## e_ident[EI_CLASS] Indicating 64 bit
01                ## e_ident[EI_DATA] Indicating little endian
...
## ascii other
48 c7 c0 ff ff ff # mov $0xfffffffffffffff,%rax
c3                # retq

## start
49 c7 c7 ff ff ff # mov $0xfffffffffffffff,%r15
49 c7 c6 00 00 00 00 # mov $0x0,%r14

## Loop
48 c7 c2 01 00 00 00 # mov $0x1,%rdx
48 c7 c6 99 01 60 00 # mov $0x600199,%rsi
```

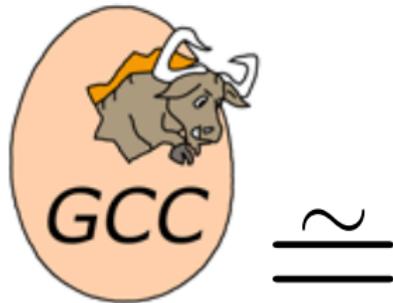
How: Remove Yoghurt-software!



How: Remove Yoghurt-software!



Is GNU GCC Yoghurt-software?



=
=



?

From boot-strap to boot-strip



Is TCC Yoghurt-software?



\equiv



?

Is Mes+MesCC Yoghurt-software?



=?



?

MesCC: Compile to M1

```
mescc -S scaffold/hello.c -o hello.M1
mescc scaffold/hello.c      -o a.out
```

hello.c

```
void
main ()
{
    puts ("Hello, Mes!");
}
```

hello.M1

```
:main
    push__%ebp
    mov__%esp,%ebp
    sub__$i32,%esp %0x1054
    push__$i32 &_string_0
    call32 %puts
    add__$i8,%esp !0x4
    leave
    ret
```

MesCC [M1-macro]: Assemble to hex2

```
mescc -c scaffold/hello.c -o hello.hex2
```

hello.hex2

```
:main
55
89E5
83EC 40
68 &string_0
E8 %eputs
83C4 04
85C0
B8 2A000000
C9
C3
```

MesCC [hex2-linker]: Link to ELF

M1-Macros

```
DEFINE push__%ebp      55  
DEFINE mov__%esp,%ebp  89e5  
DEFINE sub__$i32,%esp  81ec  
DEFINE push__$i32       68
```

... continued

```
DEFINE call32          e8  
DEFINE sub__$i32,%esp   81ec  
DEFINE leave            c9  
DEFINE ret              c3
```

a.out

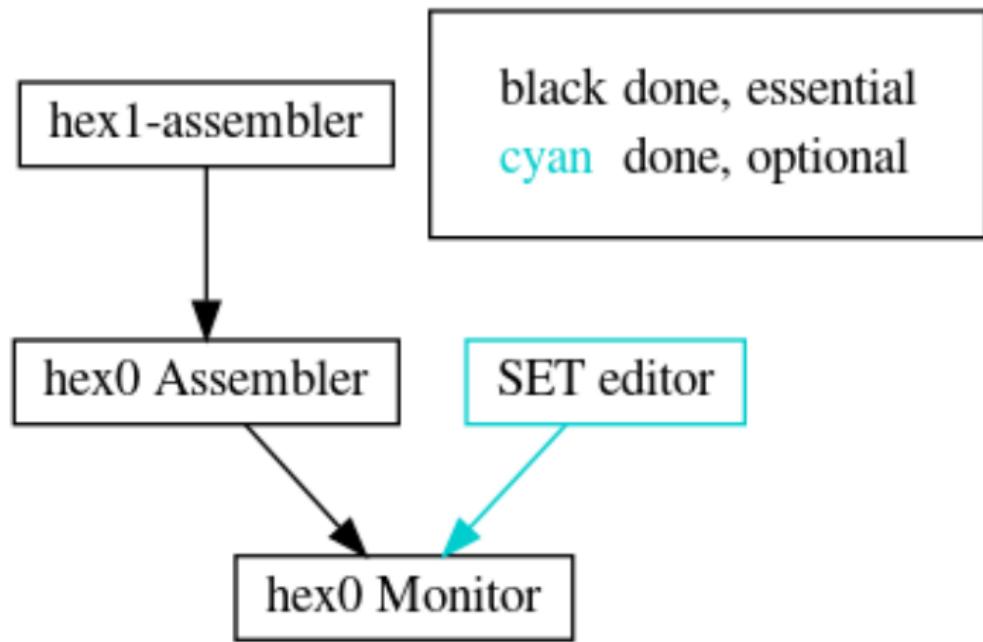
0100026d <main>:

100026d: 55	push %ebp
100026e: 89 e5	mov %esp,%ebp
1000270: 81 ec 54 10 00 00	sub \$0x1054,%esp
1000276: 68 9b 02 00 01	push \$0x100029b
100027b: e8 dc 00 00 00	call 100035c <puts>
1000280: 83 c4 04	add \$0x4,%esp
1000283: c9	leave
1000284: c3	ret

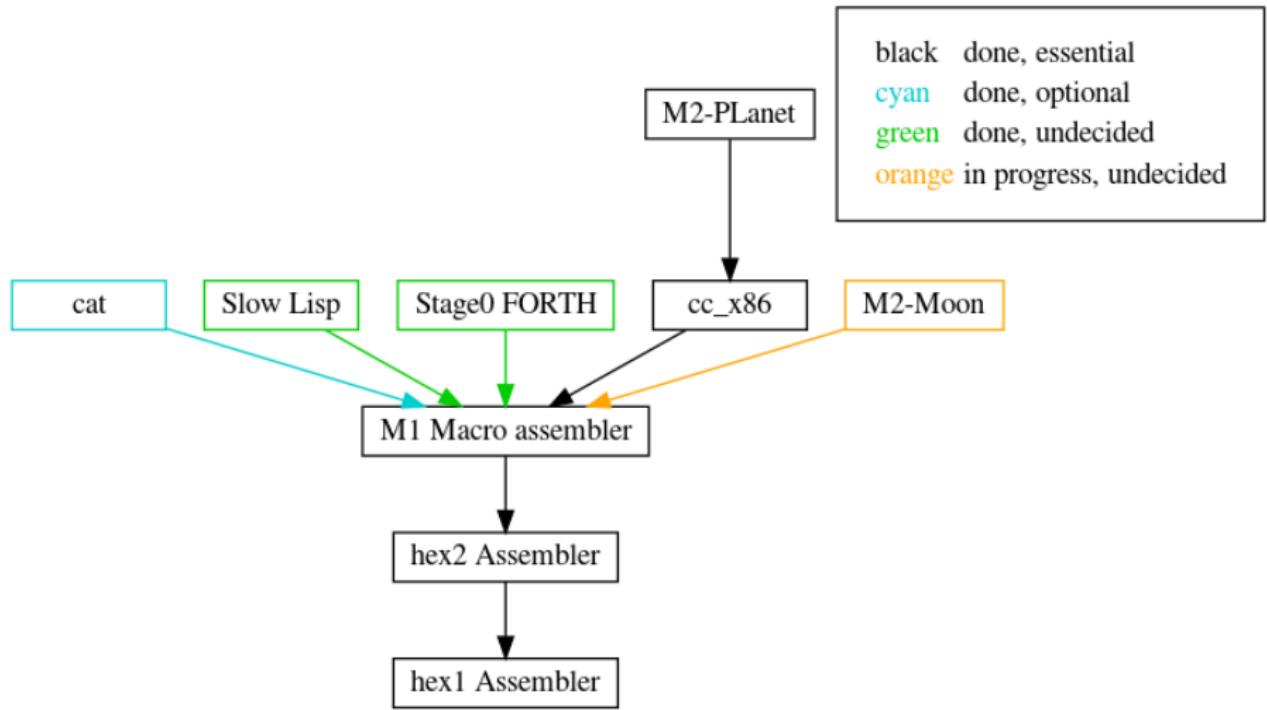
Future: Aim for the Stars: Full Source Bootstrap



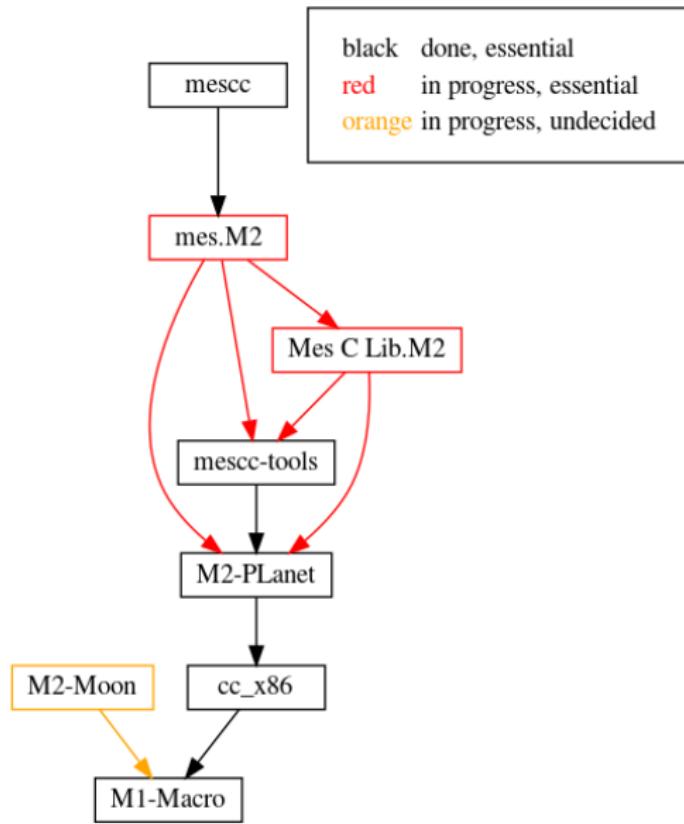
Aim for the Stars: Stage 0



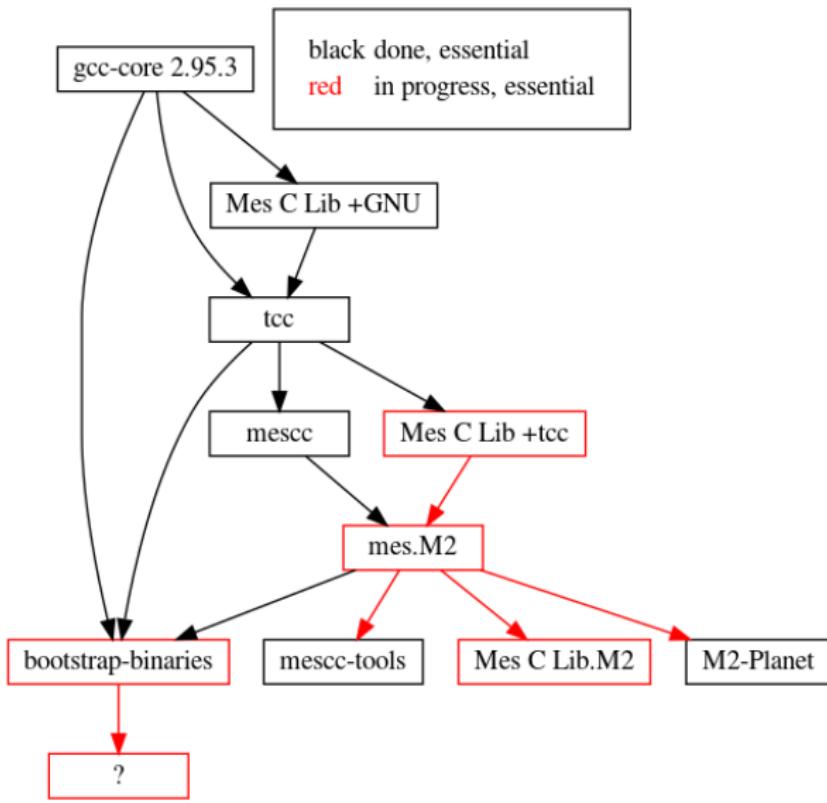
Aim for the Stars: Stage 1



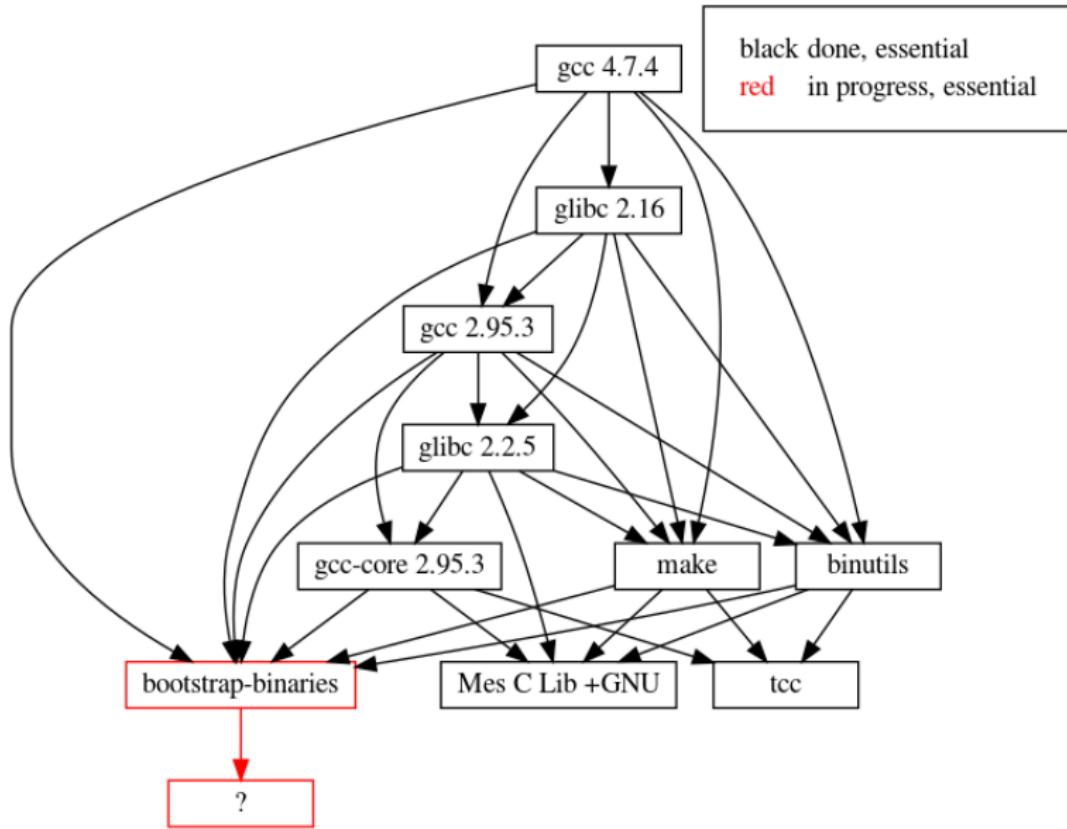
Aim for the Stars: Stage 2



Aim for the Stars: Stage mes



Aim for the Stars: Stage mesboot



Aim for the Stars: Further reductions

In progress

- Gash: Scheme-only Bootstrap (Guix @wip-bootstrap)
 - Bootstrap Guix from only `mescc-tools`, `mes`, `gash`, `guile`.
- Mes v0.20: Mes C Lib support for awk, bash, sed, tar.
- Bootstrap Mes.M2 using M2-Planet.
- A Reduced Binary Seed bootstrap for Nix.
- Skip gcc-2.95.3 stage, build gcc-4.x directly?

Later

- Inspire the GCC developers to write their own bootstrap story.
- Remove `bootstrap-mescc-tools`, `bootstrap-mes`.
- Fully replace `bootstrap-guile` with `bootstrap-mes`.
- Other Architectures (ARM).
- Non-functional distributions (Debian, a *BSD?).

Aim for the Stars: Gash

Recent merger between historical Gash and Geesh

- Gash: experimental PEG parser for Bash
 - focus on converting shell to Guile
 - shelly Guile scripting and interactive use
- Geesh: LALR parser for POSIX sh
 - focus on sh compliance and bootstrap

Current focus

- Scheme-only bootstrap
- 0.1 release

Features

- Bootstraps Bash 4.4: configure script, make shell snippets
- awk lexer parser basename cat chmod cmp compress cp cut diff dirname expr find grep ln ls mkdir mv printf reboot rm rmdir sed reader sleep sort tar test testb touch tr uname uniq wc which

Thanks

Thanks

- John McCarthy
- Eelco Dolstra
- Ludovic Courtès
- Matt Wette
- Jeremiah Orians
- Rutger van Beusekom

Thanks everyone else

- LISP-1.5
- GNU/Linux
- Nix
- Debian
- Reproducible builds
- Guix

Connect

- irc freenode.net #bootstrappable #guix
- mail guix-devel@gnu.org, bug-mes@gnu.org
- git <https://git.savannah.gnu.org/git/mes.git>
- web bootstrappable.org

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LISP as the Maxwell's Equations of Software

That was the big revelation to me when I [...] finally understood that the half page of code on the bottom of page 13 of the Lisp 1.5 manual was Lisp in itself. These were “Maxwell’s Equations of Software!” – Alan Kay

LISP-1.5 John McCarthy: page 13

```
apply[fn;x;a] =  
  {atom[fn] -> [eq[fn;CAR] -> caar[x];  
                 eq[fn;CDR] -> cdar[x];  
                 eq[fn;CONS] -> cons[car[x];cadr[x]];  
                 eq[fn;ATOM] -> atom[car[x]];  
                 eq[fn;EQ] -> eq[car[x];cadr[x]];  
                 T -> apply[eval[fn;a];x;a]]};  
  eq[car[fn];LAMBDA] -> eval[caddr[fn];pairlis[cadr[fn];x;a]];  
  eq[car[fn];LABEL] -> apply[caddr[fn];x;cons[cons[cadr[fn];  
                                                 caddr[fn]];a]]]  
  
eval[e;a] = [atom[e] -> cdr[assoc[e;a]];  
            atom[car[e]] ->  
              [eq[car[e],QUOTE] -> cadr[e];  
               eq[car[e];COND] -> evcon[cdr[e];a];  
               T -> apply[car[e];evlis[cdr[e];a];a]]];  
            T -> apply[car[e];evlis[cdr[e];a];a]]]
```

LISP-1.5 in Guile Scheme: APPLY

```
(define (apply fn x a)
  (cond
    ((atom fn)
     (cond
       ((eq fn CAR) (caar x))
       ((eq fn CDR) (cdar x))
       ((eq fn CONS) (cons (car x) (cadr x)))
       ((eq fn ATOM) (atom (car x)))
       ((eq fn EQ) (eq (car x) (cadr x)))
       (#t (apply (eval fn a) x a))))
    ((eq (car fn) LAMBDA)
     (eval (caddr fn) (pairlis (cadr fn) x a)))
    ((eq (car fn) LABEL)
     (apply (caddr fn) x (cons (cons (cadr fn)
                                       (caddr fn))
                                a))))))
```

LISP-1.5 in Guile Scheme: EVAL

```
(define (eval e a)
  (cond
    ((atom e) (cdr (assoc e a)))
    ((atom (car e))
     (cond ((eq (car e) QUOTE) (cadr e))
           ((eq (car e) COND) (evcon (cdr e) a))
           (#t (apply (car e)
                      (evlis (cdr e) a) a))))
    (#t (apply (car e) (evlis (cdr e) a) a))))
```

LISP-1.5 in Scheme: ASSOC, PAIRLIS, EVCON, EVLIS

```
(define (assoc x a)
  (cond ((eq (caar a) x) (car a))
        (#t (assoc x (cdr a)))))

(define (pairlis x y a)
  (cond ((null x) a)
        (#t (cons (cons (car x) (car y))
                  (pairlis (cdr x) (cdr y) a)))))

(define (evcon c a)
  (cond ((eval (caar c) a) (eval (cadar c) a))
        (#t (evcon (cdr c) a)))))

(define (evlis m a)
  (cond ((null m) NIL)
        (#t (cons (eval (car m) a) (evlis (cdr m) a)))))
```

History – 1984 Four Software Freedoms: GNU GPL

1984 Four Software Freedoms: GNU GPL

- The freedom to
 - 0 run the program as you wish, for any purpose
 - 1 study how the program works, and change it if you wish
 - 2 redistribute copies so you can help your neighbor
 - 3 share copies of your modified versions with others

– *Richard M. Stallman*

History – 1990s Reproducible GNU Tools @Cygnus

- 1984 Four Software Freedoms: GNU GPL

1990s Reproducible GNU Tools @Cygnus

We made the GNU tools that we were shipping and supporting – and all of our test cases compiled by them – reproducible. That includes gcc, gdb, gas, binutils, gnu make, and a few other things. – John Gilmore

History – 2006 Nix: Purely Functional Software Deployment

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus

2006 Nix: Purely Functional Software Deployment

- functional package management
- isolated builds
- Nix (and GNU Guix) are designed for reproducibility

Installation of a component can lead to the failure of previously installed components; a component might require other components that are not present; and it is difficult to undo deployment actions.

This thesis describes a better approach based on a purely functional deployment model, implemented in a deployment system called Nix. – Eelco Dolstra

History – 2007 debian-devel: Reproducibility

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
- 2006 Nix: Functional package management

2007 debian-devel: Reproducibility

I think it would be really cool if the Debian policy required that packages could be rebuilt bit-identical from source.

At the moment, it is impossible to independently verify the integrity of binary packages. – Martin Uecker

History – 2012 GNU Guix: user autonomy and safety

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
- 2006 Nix: Functional package management
- 2007 debian-devel: Reproducibility

2012 GNU Guix: user autonomy and safety

- Reproducible builds: a means to an end
- User autonomy and safety

We view “reproducible builds” as a technical means to an end: that of guaranteeing user autonomy and safety. – Ludovic Courtès

History – 2013 DebConf13: reproducible-builds.org

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
- 2006 Nix: Functional package management
- 2007 debian-devel: Reproducibility
- 2012 GNU Guix: user autonomy and safety

2013 DebConf13: reproducible-builds.org

- Lunar organizes reproducible-builds.org

A build is reproducible if given the same source code, build environment and build instructions, any party can recreate bit-by-bit identical copies of all specified artifacts. – reproducible-builds.org

History – 2016 R-B Summit II: bootstrappable.org

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
- 2006 Nix: Functional package management
- 2007 debian-devel: Reproducibility
- 2012 GNU Guix: user autonomy and safety
- 2013 DebConf13: reproducible-builds.org

2016 R-B Summit II: bootstrappable.org

- reproducible builds summit II
- session: Writing a statement about what it means to do bootstrappable compilers II
- host: Ludovic Courtès
- result: Following up on the first session focusing on this effort, the group drafted a first version of the bootstrappable.org website.

History – 2016 Initial release of Stage0 and Mes

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
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2016 Initial release of Stage0 and Mes

Release of Stage0 and Mes

History – 2018 Reduced Binary Seed bootstrap

- 1984 Four Software Freedoms: GNU GPL
- 1990s Reproducible GNU Tools @Cygnus
- 2006 Nix: Functional package management
- 2007 debian-devel: Reproducibility
- 2012 GNU Guix: user autonomy and safety
- 2013 DebConf13: reproducible-builds.org
- 2016 R-B Summit II: bootstrappable.org
- 2016 Initial release of Stage0 and Mes

2018 Reduced Binary Seed bootstrap

This talk!

Timeline 2016

October 23: 0.1 [not announced]

- let-syntax, match
- compile main.c in 2s (was 1'20")
- add REPL

November 21: 0.2 [not announced]

- psyntax integration, syntax-case, load

December 12: on bootstrapping: first Mes 0.3 released

- Garbage Collector/Jam Scraper

December 25: Mes 0.4 released

- run Nyacc, PEG, reduced core

Timeline 2017

April 27: Mes 0.5 released

- mutual self-hosting
 - mes.c runs mescc.scm
 - mescc.scm compiles mes.c

May 14: Mes 0.6 released

- MesCC runs on unpatched Nyacc
- MesCC compiles 33/55 of tinycc/tests/test2

June 3: Mes 0.7 released

- Mes C Library headers and stubs support working on compiling tcc.c

June 25: Mes 0.8 released

- MesCC compiles to stage0's hex2 format

Timeline 2017-2

July 26: Mes 0.9 released

- MesCC compiles mes-tcc, to a mostly segfaulting executable

September 10: Mes 0.10 released

- mes-tcc can compile a working trivial C program "int main () {return 42;}"

November 18: Mes 0.11 released

- MesCC: test suite with 69 tests
- less-heavily patched mes-tcc passes 41/69 MesCC C tests

Timeline 2018

April 8: Mes 0.12 released

- performance work: MesCC compiles mes-tcc in ~2h30' (was: ~1day)

April 28: Mes 0.13 released

- MesCC builds functional mes-tcc
- Patches offered to tcc community, rejected

May 24: Mes 0.14 released

- MesCC builds functional, only slightly patched mes-tcc

June 12: Mes 0.15 released

- Experimental Guix integration
- Mes C Library supports building binutils-2.14, gcc-2.95.3, glibc-2.2.5.

Timeline 2018-2

June 26: Mes 0.16 released

- Fix ELF header bug: all Mes binaries segfault on Linux 4.17
- Guix integration: build gcc-4.1.0

August 10: GNU Mes 0.17 released

- Mes is an official GNU package
- Guix integration: build gcc-4.7.4

Ocotber 7: GNU Mes 0.18 released

- Guix integration: Reduced Binary Seed bootstrap (cheat using Guile)
- Introduce embarrassing bug: MesCC only runs on Guile

December 16: GNU Mes 0.19 released

- Compile mes-tcc in ~8' (was: ~1h30).
- Guix integration: Remove MesCC-on-Guile shortcut

Metrics: Mes since Fosdem'17

- 14 releases: 0.5..0.19
- 1174 commits

Metrics: simplifying-tcc patches

135 0001-bootstrappable-Outline-elf-unions.patch
41 0002-bootstrappable-Outline-CValue_str.patch
44 0003-bootstrappable-Outline-enum-TCCState_pflag.patch
162 0005-bootstrappable-Heterogeneous-initializer-list.patch
51 0006-bootstrappable-Simple-initializer-lists.patch
496 0007-bootstrappable-Heterogeneous-switch-case.patch
26 0008-bootstrappable-(foo--)>bar.baz.patch
47 0010-bootstrappable-foo (bar (), baz ()).patch
176 0011-bootstrappable-foo ()>bar.patch
39 0012-bootstrappable-char foo[] [].patch
94 0013-bootstrappable-Multi-line-strings.patch
187 0014-bootstrappable-sizeof-type.patch
36 0015-bootstrappable-str-r-chr-str-0.patch
30 0016-bootstrappable-uint16_t-in-struct-on-heap.patch
64 0017-bootstrappable-constant-pointer-arithmetic.patch
1704 total

Metrics: remaining tcc patches

35	0001-bootstrappable-Work-around-Nyacc-0.80.42-bug.patch
47	0002-bootstrappable-HAVE_LONG_LONG.patch
47	0003-bootstrappable-HAVE_BITFIELD.patch
94	0004-bootstrappable-HAVE_FLOAT.patch
27	0005-bootstrappable-Skip-tidy_section_headers.patch
26	0006-bootstrappable-Handle-libtcc1.a.patch
30	0007-bootstrappable-uint16_t-in-struct-on-heap.patch
193	0008-bootstrappable-add-tcc.h-include-guards-to-include-l.p
33	0009-bootstrappable-Work-around-MesCC-bug.patch
26	0010-bootstrappable-Force-static-link.patch
558	total

Metrics: GNU patches

```
26 tcc-boot-0.9.27.patch
157 binutils-boot-2.20.1a.patch
137 gcc-boot-2.95.3.patch
251 glibc-boot-2.2.5.patch
  68 gcc-boot-4.7.4.patch
352 glibc-boot-2.16.0.patch
991 total
```

Metrics: GNU Guix patches

gnu: Use i686-linux bootstrap binaries on x86_64-linux.
bootstrap: Merge mes-minimal into mes-minimal-stripped.
doc: Update mesboot graph without bootstrap-guile.
bootstrap: Do not fake, use Mes instead of Guile.
bootstrap: bootstrap-mes: Update.
bootstrap: mes-minimal-stripped: Do not strip bin.
bootstrap: Switch to official bootstrap urls.
bootstrap: mes-boot: Use mes-boot0 version.
doc: Update for bootstrap-mescc-tools change.
bootstrap: Force i686-linux for bootstrap-tarballs.
bootstrap: Update %bootstrap-tarballs.
bootstrap: Replace %mescc-tools-seed with %bootstrap-mescc-tools.
bootstrap: Update %bootstrap-mes.
bootstrap: Add %bootstrap-mescc-tools.
bootstrap: Add %mes-minimal.
bootstrap: Add mescc-tools-static, mescc-tools-static-tarball.