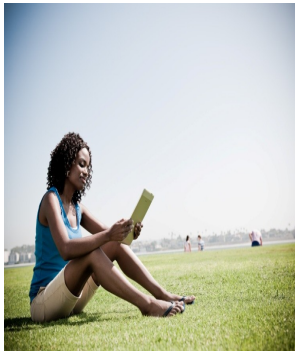
Open *Source* | Open *Possibilities*



Compiling Linux with LLVM

Presented by: Mark Charlebois

Presentation Date: 06/07/2012

QuIC
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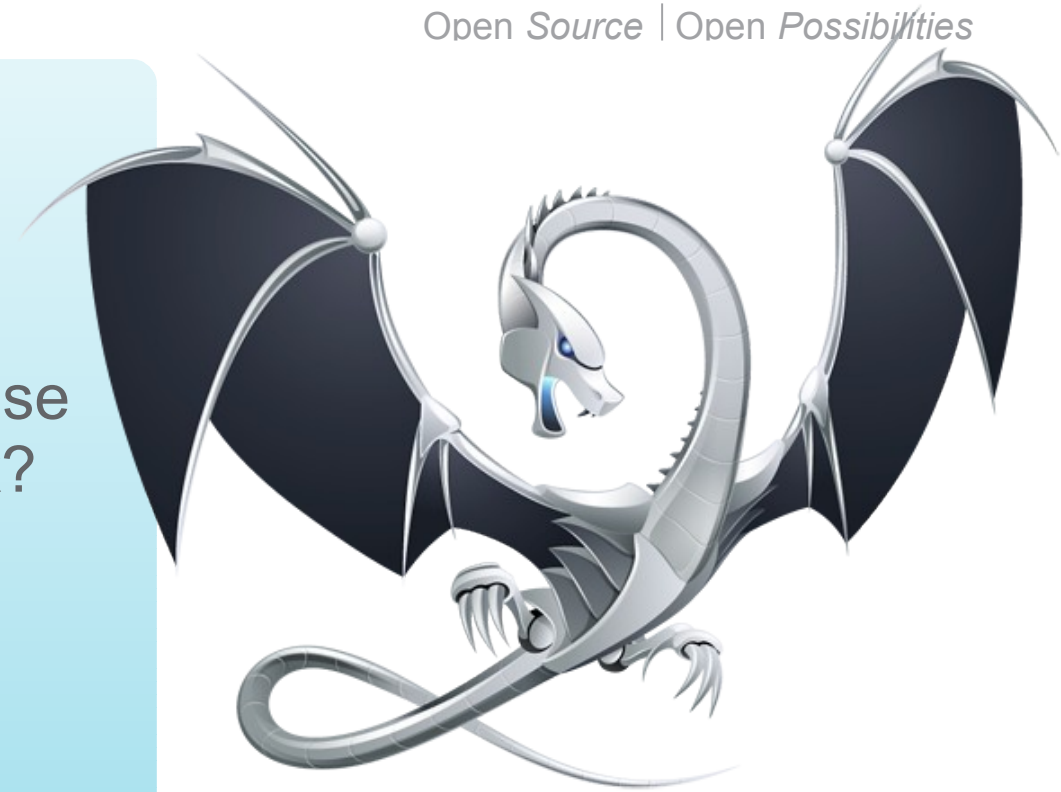
Agenda

Why would I want to use Clang to compile Linux?
Status updates:

- cross compiling for ARM with Clang
- building Linux kernel with Clang
- running Linux compiled with Clang

To do list

Why Would I Want to Use Clang to Compile Linux?



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Better Diagnostics

```
$ gcc-4.2 -fsyntax-only t.c
t.c:7: error: invalid operands to binary + (have 'int' and 'struct A')

$ clang -fsyntax-only t.c
t.c:7:39: error: invalid operands to binary expression ('int' and 'struct A')
return y + func(y ? ((SomeA.X + 40) + SomeA) / 42 + SomeA.X : SomeA.X);
                    ~~~~~~~~~~~~~~~ ^ ~~~~~
```

See http://clang.llvm.org/diagnostics.html for more examples

GCC extensions: all extensions are explicitly recognized as such and marked with extension diagnostics, which can be mapped to warnings, errors, or just ignored.

Google builds their products also with Clang just for the better debug output

Rich diagnostic output enables auto-generation of patches

Fix-it Hints

"Fix-it" hints provide advice for fixing small, localized problems in source code.

```
$ clang t.c
t.c:5:28: warning: use of GNU old-style field designator extension struct point
origin = { x: 0.0, y: 0.0 };
           ~~ ^
           .x =

t.c:5:36: warning: use of GNU old-style field designator extension struct point
origin = { x: 0.0, y: 0.0 };
                   ~~ ^
                   .y =
```

Macro Expansion

```
$ gcc-4.2 -fsyntax-only t.c
t.c: In function 'test':
t.c:80: error: invalid operands to binary < (have 'struct mystruct' and
'float')

$ clang -fsyntax-only t.c
t.c:80:3: error: invalid operands to binary expression ('typeof(P)' (aka
'struct mystruct') and 'typeof(F)' (aka 'float'))
 X = MYMAX(P, F);
     ^~~~~~~~~~~
t.c:76:94: note: instantiated from:
#define MYMAX(A,B) __extension__ ({ __typeof__(A) __a = (A); __typeof__(B) __b
= (B); __a < __b ? __b : __a; })
     ~~~ ^ ~~~
```

Static Analyzer

http://littlechina.org/~vcgomes/bluez-static-analysis/2012-02-10-1/report-n7KJtW.html#EndPath

```
2919
2920        for_each_opt(opt, lecup_options, NULL) {
2921                if (optarg && strncasecmp("0x", optarg, 2) == 0)
```

1 Taking false branch

```
2922                        base = 16;
2923                else
2924                        base = 10;
2925
2926                switch (opt) {
```

2 Control jumps to 'case 116:' at line 2939

```
2927                case 'H':
2928                        handle = strtoul(optarg, NULL, base);
2929                        break;
2930                case 'm':
2931                        min = strtoul(optarg, NULL, base);
2932                        break;
2933                case 'M':
2934                        max = strtoul(optarg, NULL, base);
2935                        break;
2936                case 'l':
2937                        latency = strtoul(optarg, NULL, base);
2938                        break;
2939                case 't':
2940                        timeout = strtoul(optarg, NULL, base);
```

3 Null pointer passed as an argument to a 'nonnull' parameter

```
2941                        break;
```

Clang/LLVM use in Open Source OSes

Minix moved to Clang as default compiler
    http://wiki.minix3.org/en/MinixReleases

FreeBSD is working on ClangBSD
    Using LLVM and KLEE for automatic test generation

    http://wiki.freebsd.org/BuildingFreeBSDWithClang

LLVM is the basis of the Renderscript compiler in Android
    Supported on ARM, MIPS and x86

LLVM a hard dependancy for Gallium3D
    llvm-pipe driver

    Clover – OpenCL state tracker

    May be used for GLSL shader optimizer

Clang and Debian

Building Debian with Clang:

> "…most of the issues are either difference in C standard supported, difference of interpretation or corner cases."
>
> "My personal opinion is that clang is now stable and good enough to rebuild most of the packages in the Debian archive, even if many of them will need minor tweaks to compile properly."
>
> "In the next few years, coupled with better static analysis tools, clang might replace gcc/g++ as the C/C++ compiler used by default in Linux and BSD distributions."
>
> "The clang developers are progressing very fast: 14.5% of the packages were failing with version 2.9 against 8.8% with version 3.0."

Sylvestre Ledru: http://sylvestre.ledru.info/blog/sylvestre/2012/02/29/rebuild_of_the_debian_archive_with_clang

Status of Cross Compiling for ARM with Clang

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Clang Parameters for Building ARM Linux User Space

Getting much simpler now:

```
export COMPILER_PATH=/opt/arm-2011.03
CC=clang -ccc-host-triple arm-none-linux-gnueabi \
    -ccc-gcc-name arm-none-linux-gnueabi-gcc \
    --sysroot=${COMPILER_PATH}/arm-none-linux-gnueabi/libc \
    -march=armv7-a -mfpu=neon
```

The default for arm-none-linux-gnueabi is armv4t

Using triple armv7-none-linux-gnueabi will not find the codesourcery compiler and default to the native assembler: /usr/bin/as

Universal Driver - http://clang.llvm.org/UniversalDriver.html

User specifies just a “configuration”:

clang --config=arm-cortex-a9-baremetal foo.c

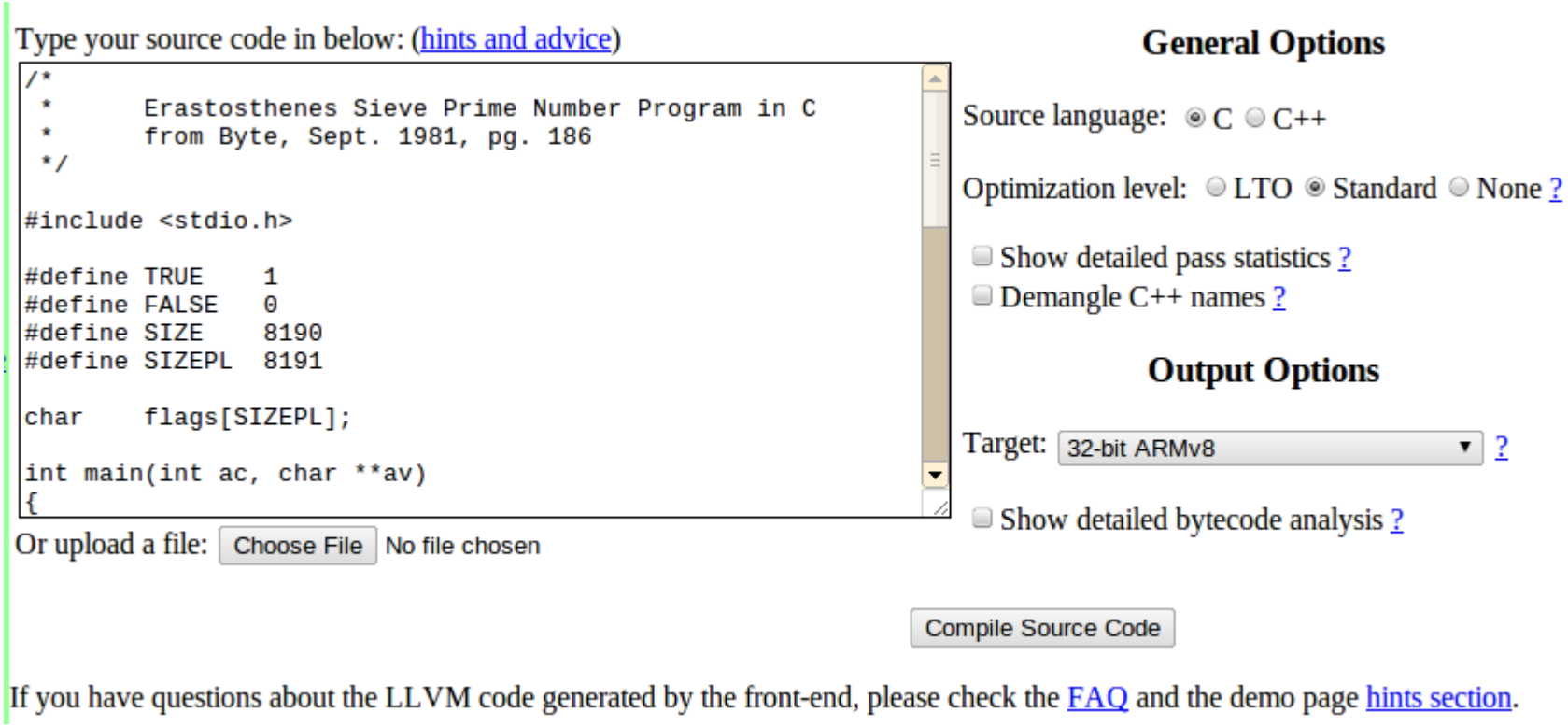
clang --config=cortex-m4-my-toaster morning-food.c

Under the hood this entry point (the universal driver) would have access to all the information that the driver, compiler, and other tools need to build applications for that target.

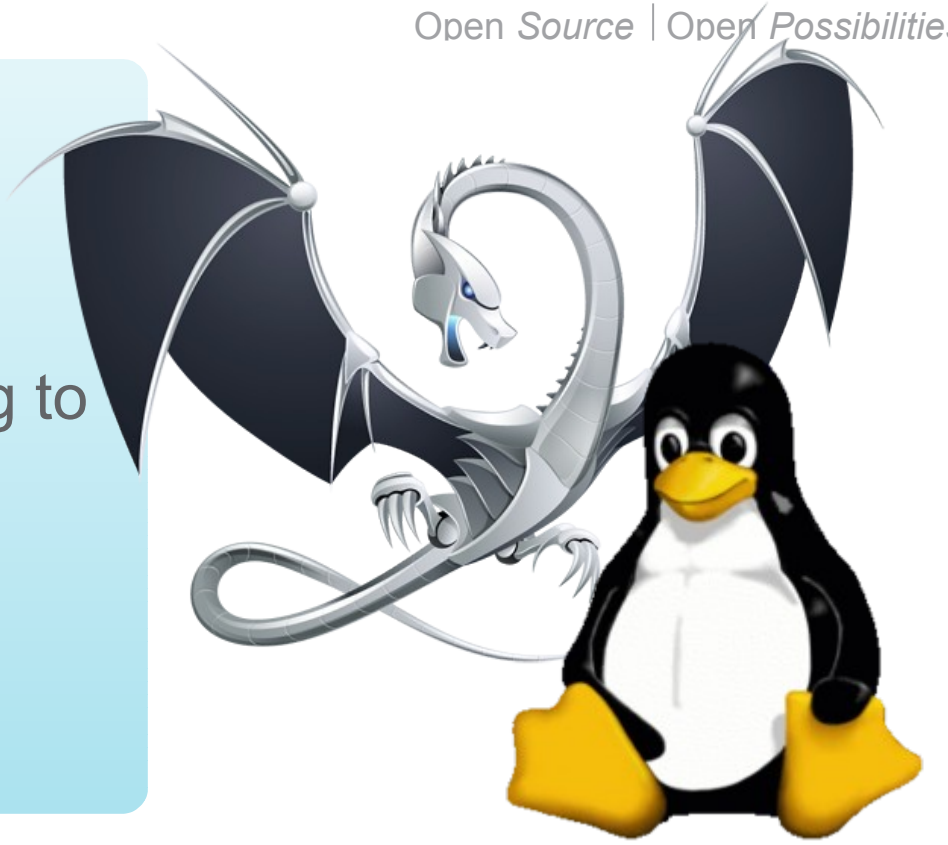
Status?

ELLCC - http://ellcc.org/

The primary emphasis of the ELLCC project is to create an easy to use multi-target cross compilation environment for embedded systems [based on Clang and LLVM]. Multi-target support: ARM, i386, Microblaze, Mips, Nios2[2], PowerPC, PowerPC64, Sparc[1] and X86_64



Challenges Using Clang to Build Linux Kernel



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Challenges Using Clang for Cross Compilation

Cross compilation with Clang
- Not a supported configuration
- Dependence on GNU cross toolchain for assembly and linking
  - Configuring GNU toolchain dependencies
- Finding the right triplet

Lots of warnings
- Must set –Wno-unused-value (otherwise slows compilation)

Clang/LLVM Bugs

GCC Dependencies:
- Clang C99 vs GCC GNU89
- Kernel expects some undocumented GCC behavior
- Unsupported GCC flags, builtin function behavior differences

Unsupported GCC Behavior Expected by Linux Kernel

scripts/Kbuild.include are gcc specific

cc-option tests fail for gcc, pass erroneously for clang

Clang warning is for unused, not unsupported

No way to check supported options in Clang

http://clang.llvm.org/docs/DriverInternals.html#int_unused_warnings

```
cc-option = $(call try-run,\
    $(CC) $(KBUILD_CPPFLAGS) $(KBUILD_CFLAGS) $(1) -c -xc /dev/null -o "$$TMP",$(1),$(2))
```

GCC returns false for unsupported flag and issues warning:

cc1: error: unrecognized command line option "-fno-delete-pointer-checks“

Clang returns true for unused flag and issues warning:

clang: warning: argument unused during compilation: '-fno-delete-pointer-checks'

See LLVM/Clang bug 9701 – only helps with warnings, not flags

Unsupported GCC Flags

-fconserve-stack

Attempt to minimize stack usage. The compiler will attempt to use less stack space, even if that makes the program slower. This option implies setting the large-stack-frame parameter to 100 and the large-stack-frame-growth parameter to 400.

-fdelete-null-pointer-checks (Bug 9251)

Assume that programs cannot safely dereference null pointers, and that no code or data element resides there. This enables simple constant folding optimizations at all optimization levels. In addition, other optimization passes in GCC use this flag to control global dataflow analyses that eliminate useless checks for null pointers; these assume that if a pointer is checked after it has already been dereferenced, it cannot be null.

-fno-inline-functions-called-once

Suppresses inlining of subprograms local to the unit and called once from within it, which is enabled if -O1 is used.

http://gcc.gnu.org/onlinedocs/gnat_ugn_unw/Switches-for-gcc.html

Unsupported GCC C Language Extensions

Variable length arrays in structs (VLAIS)

A declaration like:

```
void f (int i) {
     struct foo_t {
         char a[i];
     } foo;
 }
```

cannot be compiled in Clang, though declarations like:

```
void f (int i) {
     char foo[i];
 }
```

are perfectly acceptable.

Used in the iptables code, the kernel hashing (HMAC) routines, gadget driver, and possibly some other drivers

Unsupported GCC C Language Extensions

Explicit register variables not supported

register unsigned long current_sp asm ("sp");

Nested functions

Only used in a thinkpad driver

Use of 'aligned' attribute in cast (Bug 11071)

Crypto/shash.c

Return len + (mask & ~(__alignof__(u8 __attribute__ ((aligned))) - 1));

^~~~~~~

GCC allows EXPORT_SYMBOL of inlined functions

Linux kernel bugs

Patches submitted upstream by Greg KH

Incompatibilities with GCC

Warnings for unused return values
- Thousands of instances in kernel, must use –Wno-unused-value
  - Re-enabled with W=1

Segment references
- More __refdata, __initdata, __exitdata attributes required
  - Investigate differences in linking and segments

Inline syntax handling
- GNU89

__builtin_constant_p() fails for Clang (Bug 4898)
- Include/linux/rcupdate.h

ARM Specific Clang/LLVM Bugs or Missing Features

-mabi-linux not properly supported on ARM (Bug 11326)
- Causes incorrect structure member offsets

64 bit type parameter passing (Bug 11753)
- Must use register pairs
- Hack used at Linux Foundation site, no upstream fix

ARM paired register GNU inline assembly syntax
- Hack used at Linux Foundation site, no upstream fix

Clang Integrated Assembler (IA) not enabled for ARM (incomplete)

ARM Specific Clang Configuration Issues

Using triple arm-none-eabi, or triple arm-none-linux-gnueabi generates undefined reference to __aeabi_*

Must define __aeabi_memset, and __aeabi_memcpy

Note: be careful with args for __aeabi_memset!!!

Compiler-rt will not cross compile for ARM

Using triple “arm” or “armv7” will build kernel, but:
arch/arm/kernel/unwind.c:

warning: Your compiler does not have EABI support.

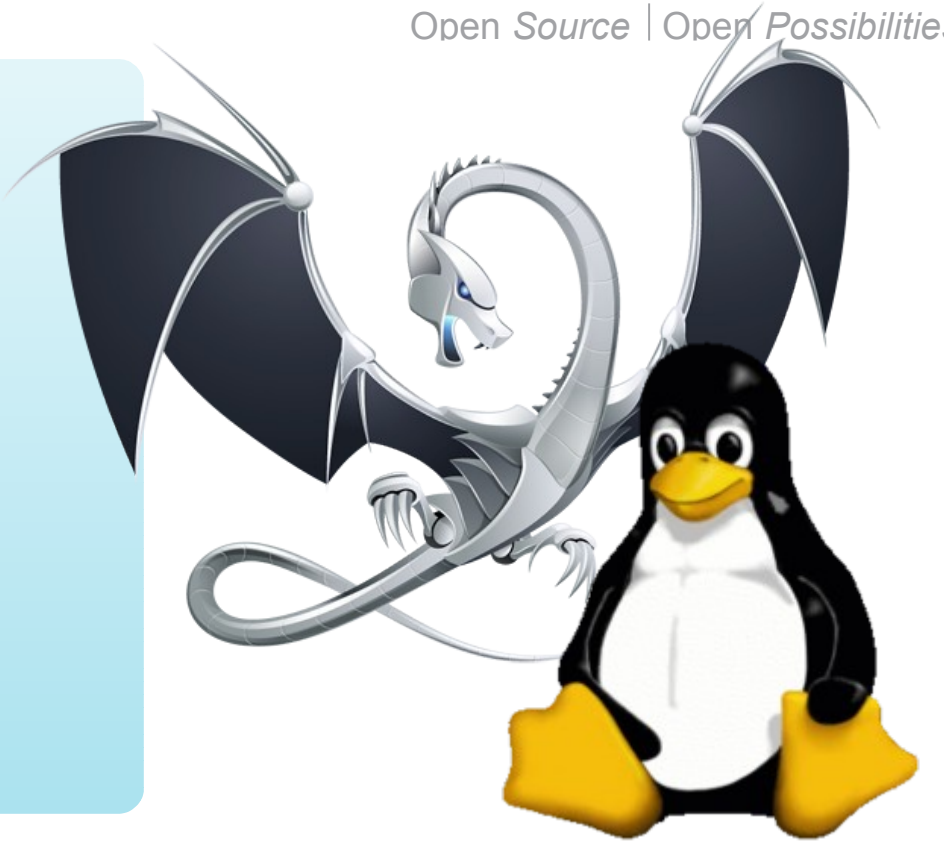
warning: ARM unwind is known to compile only with EABI compilers.

warning: Change compiler or disable ARM_UNWIND option.

Non-EABI kernel hangs at boot

__kernel_size_t vs size_t and posix functions

Status of Building Linux Kernel With Clang



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Wiki and git Repository at llvm.linuxfoundation.org

Links to known LLVM bugs, organized by architecture, place to aggregate information about building Linux with Clang

Automated Build Framework

Documented in Wiki

Git repository

Current support for:

- ARM Cortex A9 (Versatile Express)
- Qualcomm MSM

Easy to add new arch/platforms

Anyone welcome to participate, would especially like to see x86 and MIPS support

Patches organized by common, arch, subarch/board

Easy to add new architectures and platforms

Automated Build Framework

Automated build to simplify fetching and building Clang, QEmu, and initrd

- Automates fetching, patching and building the Linux kernel

Git repository of build scripts and patches

- http://git.linuxfoundation.org/llvm-setup.git
- Proper build dependencies for Clang, kernel, QEMU and initramfs
- Patches organized as:
  - General
  - Arch specific
  - SoC family or board specific
- Tracks which patches apply and which do not
- Python tools for managing and maintaining patches

All build targets can be listed

- Make list-targets

Common/Arch Independent Status

Only 2 required Clang/LLVM patches
- Required for missing ARM functionality

One optional patch:
- Error on unsupported warnings (GCC compatibility)

Linux Kernel patches for
- Explicit register variables
- VLAIS (not for IP tables yet)
- Segment linkage differences
  - Additional __refdata needed for some drivers
- return_address and extern inline in ftrace.h
- __builtin_constant_p() workaround
- GCC specific use of aligned attribute in cast

IP Tables use of VLAIS

net/ipv4/netfilter/ip_tables.c
net/ipv4/netfilter/../../netfilter/xt_repldata.h

```
#define xt_alloc_initial_table(type, typ2) ({ \
        unsigned int hook_mask = info->valid_hooks; \
        unsigned int nhooks = hweight32(hook_mask); \
        unsigned int bytes = 0, hooknum = 0, i = 0; \
        struct { \
                struct type##_replace repl; \
                struct type##_standard entries[nhooks]; \
                struct type##_error term; \
        } *tbl = kzalloc(sizeof(*tbl), GFP_KERNEL); \

/* Today's hack: quantum tunneling in structs
 'entries' and 'term' are never anywhere referenced by word in code. In fact, they
serve as the hanging-off data accessed through repl.data[]. */
```

Status of Building the ARM Linux Kernel With Clang

ARM Versatile Express

- Compiles (3.4 kernel)
- Supports crypto, ext4, SD card, initramfs
- Boots and runs multiple initramfs images, or SD card image under QEMU
- Builtbot status at http://88.198.35.80:8765/waterfall

Qualcomm MSM

- Compiles with Clang/LLVM patches
- More __refdata fixes
- Have not yet tested on HW

Clang IA not yet enabled for ARM by default

Tracing is not yet enabled

Specific ARM Issues

Unsupported flags

-mlittle-endian

Everything assumes little-endian byte order

-mno-thumb-interwork

-mshort-load-bytes

Broken flags

-mabi=aapcs-linux

Creates struct member offset issues

Replace

```
register unsigned long current_sp asm ("sp");

asm ("mov %0, r13" : "=r" (current_sp));
```

Unsupported ARM Flags

-mno-thumb-interwork

Generate code that supports calling between the ARM and Thumb instruction sets. Without this option, on pre-v5 architectures, the two instruction sets cannot be reliably used inside one program. The default is -mno-thumb-interwork, since slightly larger code is generated when -mthumb-interwork is specified. In AAPCS configurations this option is meaningless.

-mlittle-endian

Generate code for a processor running in little-endian mode. This is the default for all standard configurations

-mshort-load-bytes

deprecated alias for -malignment-traps.

-malignment-traps

This option is ignored when compiling for ARM architecture 4 or later, since these processors have instructions to directly access half-word objects in memory.

http://gcc.gnu.org/onlinedocs/gcc/ARM-Options.html

TODO

Check status of other issues reported by Bryce Lelbach

- -mregparm
- -fcall-saved-reg
- -pg and mcount
- -fno-optimize-sibling-calls

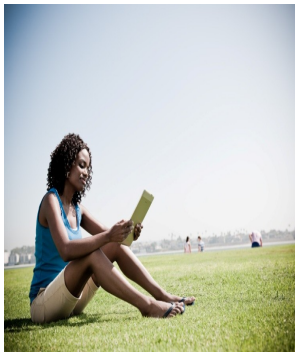
Status of Clang IA (Integrated Assembler)
Test gadget driver and crypto VLAIS patches
Segment linkage differences
Inline differences
Try building LTP with LLVM and create virtual SD card FS
Fix cc-option issues and other GCC specific dependencies

Call for Participation

Others are welcome to participate at the LLVM work at Linux Foundation Wishlist:

- Integrating the patches from lll-linux tree for x86/x86_64
- X86 QEMU test target
- MIPS support and QEMU test target
- LTP integration
- Unit tests for known LLVM Linux bugs

Thank You



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