It’s not an embedded Linux distribution - it creates a custom one for you.

Tuning Embedded Linux
When Less is More

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Agenda

- Objectives, Motivation, and Target

- Current image type summary reports

- Require concepts and tools

- Iterate over configurations
  - Analyze the kernel and root fs for bloat
  - Identify configuration changes
  - Rebuild and compare reports

- Summary

- Next steps
Objectives

- Reduce raw image size
- Reduce static memory use
- Reduce dynamic memory use
- Minimize boot time
Motivation

• System-on-chip
  • On-die memory is expensive in terms of real-estate and power usage

• Mass market
  • Saving pennies on a smaller flash chip translates to real money

• Performance
  • Smaller images translate to more efficient cache use

• Power usage
  • Less memory means less power

• Smaller images reduce processing due to IO overhead
  • Fewer background services means longer idle states

• Boot time
  • Smaller images translate to less IO and decompression time

• Reduced development overhead
  • Smaller images contain less unnecessary code to build and validate
Real-World Examples

- Digital camera
  - 10 MB memory
  - Critical boot time
- Medical devices
  - 8 MB flash
  - 4 MB memory
- Network boot RAM FS
  - No flash on device
  - Entire FS in RAM
- Small headless systems
  - 8 MB SPI flash
  - MMC/SD for additional storage
- Partitioned flash
  - Smaller parallel NAND
  - Larger MMC/SD

Thank you to the individuals who shared their experiences on the Yocto mailing list to generate these examples.
Target

- Generate a Kernel + RootFS in under 4MB
- Boot in under 8MB
  - (4MB would be better)
- Boot to shell in under 2 seconds
- Maintain ipv4 functionality
- Avoid an initial RAM disk
  - (No cheating by building everything as modules)
- We'll use qemux86 for the purposes of this exercise
Sato: Size Report

• Contents
  • Linux kernel
  • Eglibc
  • Udev
  • Login
  • X Server
  • Sato Desktop and Applications

• Size Report
  • BzImage:  4.0 MB
  • RootFS:  118.0 MB
  • Modules:  35.0 MB
  • Total:  122.0 MB

• Memory Report
  • RAM:  128 MB
  • Early boot:  9.8 MB
  • Login:  82.3 MB
  • Kernel Freed:  444 KB

• Boot Time
  • Kernel*:  4.26s
  • Sato Desktop:  21.9s

* At “Freeing unused kernel memory”
Minimal: Size Report

• Contents
  • Linux kernel
  • Eglibc
  • Udev
  • Login

• Size Report
  • BzImage: 4.0 MB
  • RootFS: 11.0 MB (-107.0 MB)
  • Modules: 35.0 MB
  • Total: 15.0 MB

• Memory Report
  • RAM: 32 MB
  • Early boot: 8.6 MB
  • Login: 15.8 MB
  • Kernel Freed: 444 KB

• Memory Report
  • RAM: 32 MB
  • Early boot: 8.6 MB
  • Login: 15.8 MB
  • Kernel Freed: 444 KB

• Boot Time
  • Kernel: 3.84s
  • Login: 9.5s
Components

- Root filesystem
  - Packages
    - Boot
    - Libraries
    - Applications
  - Package configuration
  - Filesystem

- Linux kernel
  - Policy
  - Subsystems
  - Architecture
  - Drivers
Guiding Principles

• Prepare a budget
  • Linux Kernel: 1 MB
  • Root FS: 3 MB

• Don't sweat the small stuff (90% rule)

• Avoid difficult to maintain hacks
  • At first anyway...

• Leverage device specific options

• Develop in a separate layer
Concepts: Storage

- **ELF Sections**
  - text: the code itself
  - data: initialized data
  - bss: uninitialized data

- **Image Size**
  - Includes text and data sections only, not bss.

- **Measure size in blocks with df (not in bytes with du)**

```
$ df mnt-stage1/
Filesystem   1K-blocks  Used  Available  Use%  Mounted on
/dev/loop1   8059  5407    2243   71%   mnt-stage1
```
Concepts: Memory

- **Static Memory**
  - The text, data, and bss sections.

- **Dynamic Memory**
  - Memory allocated at runtime
  - Stacks
  - Hashtables
  - Allocators
  - Page Cache
  - Reservations

- **Temporary Memory**
  - Decompression
  - `__init__`
Tools

• Identify, quantify, and record your changes
  • ksize.py
  • dirsize.py
  • merge_config.sh
  $ bitbake -u depexp -g core-image-*

• Scripts available here until merged upstream
  • http://dvhart.com/darren/yocto/tiny/
Minimal: Root FS

$ cat dirsize-100k.log

9850251 ./
3878968 ./lib
1457504 ./lib/libc-2.13.so
173908 ./lib/libm-2.13.so
158617 ./lib/libacl.so.1.1.0
127228 ./lib/ld-2.13.so
...
696977 ./lib/modules/3.0.4-yocto-standard+/kernel/drivers/video
645004 ./lib/udev
2907574 ./usr
2516900 ./usr/lib
1047940 ./usr/lib/libgio-2.0.so.0.2800.8
1036944 ./usr/lib/libglib-2.0.so.0.2800.8
249756 ./usr/lib/libgobject-2.0.so.0.2800.8
299502 ./usr/share
170680 ./usr/share/pci.ids.gz
124206 ./usr/share/usb.ids.gz
1263456 ./sbin
691588 ./sbin/ldconfig
137012 ./sbin/udevadm
133132 ./sbin/udevd
115932 ./sbin/v86d
1138391 ./etc
1044480 ./etc/dev.tar
659740 ./bin
602752 ./bin/busybox

Displayed 7968656/9850251 bytes (80.90%)
Glib?

$ bitbake -u depexp -g core-image-minimal
**Minimal → Stage 1**

- Reduce size with minimal impact on features

- We can get by with devtmpfs and mdev

- We don't **need** a VGA display, we have serial

- Drop udev and v86d

```bash
$ cat conf/local.conf | head -n 7
################# MINIMAL STAGE 1 Mods #################
# Drop udev (and glib) and use mdev
# Save 4MB from minimal image rootfs!
VIRTUAL-RUNTIME_dev_manager = ""
# Drop v86d from qemux86 required packages
MACHINE_ESSENTIAL_EXTRA_RDEPENDS_qemux86 = ""
```
Filesystem Options

- Minimal builds ext3 by default

- ext3 requires a 1k block journal
  - 1 MB with 1024 byte blocks (instead of 4096)

- If we don't need the journal, we can save 1 MB by using ext2
  - 5.3 MB ext3
  - 4.0 MB ext2

- For a small image, you are most likely going to use JFFS2 or UBIFS anyway
## Stage 1: Size Report

**Contents**
- Linux kernel
- Eglibc
- Login

**Size Report**
- `bzImage`: 4.0 MB (minimal)
- `rootfs`: 4.0 MB (-7.0 MB)
- `modules`: 35.0 MB
- **Total**: 8.0 MB (-7.0 MB)

**Memory Report**
- RAM: 32 MB
- Early boot: 8.6 MB
- Login: 15.7 MB
- Kernel Freed: 444 KB

**Boot Time**
- Kernel: 3.54s
- Login: 7.19s
Stage 1: Root FS

$ cat dirsize-30k.log
  3878774 .
  2242550 ./lib
  1457504 ./lib/libc-2.13.so
  173908 ./lib/libm-2.13.so
  127228 ./lib/ld-2.13.so
  96624 ./lib/libpthread-2.13.so
  91956 ./lib/libnsl-2.13.so
  79620 ./lib/libresolv-2.13.so
  46672 ./lib/libnss_files-2.13.so
  35956 ./lib/libcrypt-2.13.so
  34588 ./lib/libnss_compat-2.13.so
  30624 ./lib/librt-2.13.so
  807168 ./sbin
  691588 ./sbin/ldconfig
  34300 ./sbin/init.sysvinit
  659740 ./bin
  602752 ./bin/busybox
  50308 ./bin/tinylogin
  87565 ./usr
  50168 ./usr/bin
  80786 ./etc
  34406 ./etc/init.d

Displayed 3553628/3878774 bytes (91.62%)
**Stage 1: Kernel**

```
$ ls -s bzImage
4064 bzImage-qemux86.bin

$ cat ksize.log
Linux Kernel

<table>
<thead>
<tr>
<th>total</th>
<th>text</th>
<th>data</th>
<th>bss</th>
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<tr>
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<td>133508</td>
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<td>1137786</td>
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<td>kernel/built-in.o</td>
<td>1033129</td>
<td>723329</td>
<td>45832</td>
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<td>fs/built-in.o</td>
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</table>
```
Stage 1 → Stage 2

- 91.62% of the Root FS is composed of:
  - Eglibc
  - Busybox

- 66.53% of the Kernel image is composed of:
  - Drivers
  - Networking
  - Core kernel
  - Filesystems
  - Sound

- Bound to be more fluff in the kernel image
## Drivers

<table>
<thead>
<tr>
<th>drivers</th>
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<th>data</th>
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### Networking

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## Core Kernel

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### Filesystems

<table>
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<tr>
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<th>Text</th>
<th>Data</th>
<th>BSS</th>
</tr>
</thead>
<tbody>
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<td>fs/nfs/built-in.o</td>
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<td>fs/quotah/built-in.o</td>
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<td>fs/notify/built-in.o</td>
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</tr>
<tr>
<td>sum</td>
<td>952864</td>
<td>930552</td>
<td>18776</td>
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<td>delta</td>
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<td>-3871</td>
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## Sound

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<th>bss</th>
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<tr>
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<td>5320</td>
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<td>sound/core/built-in.o</td>
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<td>205834</td>
<td>2596</td>
<td>4452</td>
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<td>sound/*.o</td>
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<td>8620</td>
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<td>192</td>
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<td>delta</td>
<td>-4781</td>
<td>-4325</td>
<td>-388</td>
<td>-68</td>
</tr>
</tbody>
</table>
Linux Kernel Config Fragments

• Entire defconfigs make it difficult to quantify cost of individual options

• Better to assemble config fragments

• Avoid modules and the initial RAM disk

• Start with allnoconfig

• Merge fragments with merge_config.pl
  • Generates a .config
  • Warns on overrides
  • Warns on missing CONFIG_ options
    (possibly due to missing dependencies)
Minimal Linux Kernel Config

- Start with the bare minimal for an x86-32 machine:
  - `defconfig (x86_32_allnoconfig)`
  - `core.cfg`
  - `smp.cfg`
  - `rtc-pc.cfg`

- Some basic policy:
  - `serial.cfg`
  - `devtmpfs.cfg`
  - `sysfs.cfg`
  - `ext2.cfg`
  - `ext3.cfg`
  - `net.cfg`
  - `vt.cfg`
  - `fb.cfg`
  - `debug.cfg`

- QEMU “hardware” support:
  - `ata.cfg`
  - `e1000.cfg`
  - `floppy.cfg`
  - `usb.cfg`
  - `vga.cfg`
  - `intel-hda.cfg`
## Stage 2: Size Report

### Contents
- Linux kernel
- Eglibc
- Login

### Size Report
- **BzImage:** 1.8 MB (-2.2 MB)
- **RootFS:** 4.0 MB (stage 1)
- **Total:** 5.8 MB (-2.2 MB)

### Memory Report
- **RAM:** 32 MB
- **Early boot:** 4.49 MB
- **Login:** 9.37 MB
- **Kernel Freed:** 240 KB

### Boot Time
- **Kernel:** 0.90s
- **Login:** 3.38s
### Stage 2: Kernel

#### $ ls -s bzImage
4064  bzImage-qemux86.bin

#### $ cat ksize.log

<table>
<thead>
<tr>
<th>Linux Kernel</th>
<th>total</th>
<th>text</th>
<th>data</th>
<th>bss</th>
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</thead>
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<tr>
<td>vmlinux</td>
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</tr>
<tr>
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<td>548606</td>
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<tr>
<td>kernel/built-in.o</td>
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<td>77555</td>
<td>138952</td>
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<td>net/built-in.o</td>
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<td>17507</td>
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<td>1976</td>
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<td>ipc/built-in.o</td>
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<td>init/built-in.o</td>
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<td>security/built-in.o</td>
<td>3738</td>
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<td>8</td>
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<td>sum</td>
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<tr>
<td>delta</td>
<td>1227658</td>
<td>70637</td>
<td>22882</td>
<td>1134139</td>
</tr>
</tbody>
</table>
Stage 2 → Stage 3

- 91.62% of the Root FS is composed of:
  - eglibc
  - busybox

- 44.13% of the Kernel image is composed of:
  - drivers
  - sound
  - Filesystems

- Let's see what we can shave off from each
Kernel: Only the Essentials

- Drop everything but the essentials for boot, serial console, and networking

- Drop from policy
  - vt.cfg
  - ext3.cfg
  - fb.cfg

- Drop from QemuX86 “Hardware” support
  - floppy.cfg
  - usb.cfg
  - vga.cfg
  - intel-hda.cfg
Root FS: Busybox

- Drop all the vt services from busybox, this needs a simple patch to avoid opening tty devices
- Drop ipv6 and all the Linux module utilities
- Use a busybox bbappend recipe and a new defconfig
Root FS: eglibc

- Dropping 'who' and tools like 'grep' and 'sed' allow the removal of libc-posix-regexp, libc-utmp, and libc-getlogin, but start to limit functionality.
Root FS: System Services

- Drop tinylogin, modutils-initscripts, and netbase
- Define a new image type, core-image-tiny which is built using a new task-core-tiny task

```
RDEPENDS_task-core-tiny = "base-files base-passwd \\
                         busybox initscripts"

# task-core-tiny RDEPENDS on a subset of what task-core-boot does:
#RDEPENDS_task-core-boot = "base-files base-passwd \\
#                          busybox initscripts \\
#                          modutils-initscripts netbase \\
#                          ${@base_contains("MACHINE_FEATURES", "keyboard", "keymaps", ",", d)} \ 
#                          ${VIRTUAL-RUNTIME_login_manager} \\
#                          ${VIRTUAL-RUNTIME_init_manager} \\
#                          ${VIRTUAL-RUNTIME_dev_manager} \\
#                          ${VIRTUAL-RUNTIME_update-alternatives} \\
#                          ${MACHINE_ESSENTIAL_EXTRA_RDEPENDS}"
```
## Stage 3: Size Report

### Contents
- Linux kernel
- Eglibc
- Busybox shell

### Size Report
- BzImage: 1.2 MB (-0.6 MB)
- RootFS: 3.2 MB (-0.8 MB)
- **Total:** 4.4 MB (-1.4 MB)

### Memory Report
- RAM: 32 MB
- Early boot: 3.42 MB
- Login: 6.66 MB
- Kernel Freed: 220 KB

### Boot Time
- Kernel: 0.60s
- Shell: 2.13s
Now What?

- Kernel
  - networking
  - SMP
  - ACPI
  - SysV IPC, Futexes
  - Printk

- Eglibc
  - networking
  - regular expressions

- To get below 4.0 MB, we should look at uclibc
Stage 3 → Stage 4

- Switch to uclibc

```bash
DISTRO_FEATURES_NET = "ipv4 nfs"
DISTRO_FEATURES = "${DISTRO_FEATURES_TINY} \n    ${DISTRO_FEATURES_NET} \n    ${DISTRO_FEATURES_LIBC}"
TCLIBC = "uclibc"
```
Stage 4: Size Report

- Contents
  - Linux kernel
  - Uclibc
  - Busybox shell

- Size Report
  - BzImage: 1.2 MB (stage 3)
  - RootFS: 1.5 MB (-1.7 MB)
  - Total: 2.7 MB (-1.7 MB)

- Memory Report
  - RAM: 32 MB
  - Early boot: 3.42 MB
  - Login: 5.84 MB
  - Kernel Freed: 220 KB

- Boot Time
  - Kernel: 0.61s
  - Shell: 2.07s
Stupid Small

• You can go further still if you want
  • Drop networking support (uclibc and kernel)
  • Cripple Busybox (grep, network tools, etc)
  • Cripple Linux kernel (acpi, smp, ipc, futex, printk)

• Size Report
  • bzImage: 585K (-0.7 MB)
  • rootfs: 1.1MB (-0.4 MB)
  • Total: 1.6 MB (-1.1 MB)

• Memory Report
  • We removed printk and proc!

• Boot Time
  • Shell: 1.28s

• You have lost a lot of functionality to get here
Memory Usage Summary

Memory Usage

<table>
<thead>
<tr>
<th>Stage</th>
<th>Login</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Stage1</td>
<td>7</td>
<td>8</td>
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<tr>
<td>Stage2</td>
<td>4</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Stage4</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Boot Time Summary

Boot Time

- Minimal
- Stage1
- Stage2
- Stage3
- Stage4
- Stage5

Seconds:
- Kernel
- Login
Next Steps

• Bitbake config fragments
  • Incorporate config fragment management from the Yocto Project kernel tools into the Bitbake recipe

• Distribution package feature mechanism
  • Prepare a distro package feature configuration mechanism for fine tuning recipe configs, such as bitbake and linux-yocto.
  • Eglibc and uclibc have similar mechanisms, but may need to be modified for a consistent implementation across recipes.

• Define one or more poky-tiny distributions and images
  • Your input is needed here
  • Do we define a no-network image?
  • Do we define a smaller graphical image?
    • Perhaps something with directfb instead of X
Resources

- Yocto Project and Meta-Tiny
  - http://www.yoctoproject.org
  - http://git.yoctoproject.org/cgit.cgi/user-contrib/dvhart/meta-tiny

- ELCE 2010 Videos
  - The Right Approach to Minimal Boot Time by Andrew Murray
  - http://free-electrons.com/blog/elce-2010-videos/

- Andi Kleen's Memory Usage Papers
  - http://halobates.de/memorywaste.pdf
  - http://halobates.de/memory.pdf

- Phil Blundell's meta-micro layer
  - http://cgit.openembedded.org/meta-micro/
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