Herd Your Boards, Become a Farmer
Embedded Linux Conference Europe 2016

Geert Uytterhoeven
geert@linux-m68k.org

Glider bvba

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About Me

Introduction

Building Blocks
  Power Control
  Console
  Network
  Interaction
  Management Host

Power Supply

Software

Final Words
# About Me (and Linux)

## Hobbyist

<table>
<thead>
<tr>
<th>Year</th>
<th>Platform</th>
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<tbody>
<tr>
<td>1994</td>
<td>Linux/m68k on Amiga</td>
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<tr>
<td>1997</td>
<td>Linux/PPC on CHRP</td>
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<tr>
<td>1997</td>
<td>FBDev</td>
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## Sony

<table>
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<th>Platform</th>
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<tbody>
<tr>
<td>2006</td>
<td>Linux on PS3/Cell</td>
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## Glider bvba

<table>
<thead>
<tr>
<th>Year</th>
<th>Platform</th>
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<tbody>
<tr>
<td>2013</td>
<td>Renesas ARM-based SoCs</td>
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</table>
Why a Board Farm?
Board on Your Desk

Advantages

✓ Easy to setup
✓ Easy to interact with

Disadvantages

X One too many boards (*boards are cheap*), outgrowing your desk
X Too much noise
X Home Office: Significant other, family members

How many boards on your desk?
Why a Board Farm?
Organizing Development Boards in a Board Farm

Advantages

✓ Less clutter on your desk
✓ Centralization
✓ Automation
✓ (Worldwide) Remote access
✓ Board sharing

Disadvantages/Challenges

X (More) Complex setup
X How to interact with your board?
Board Farm Requirements

Basic
- Power & Serial Console

Intermediate
- Reset (≠ powercycle ≠ software reboot)
- Wake-Up
- Soft Power-On
- Input buttons
- Measure Power Consumption

Advanced
- Video in & out
- ... (add yours) ...
Board Farm Building Blocks
Single Development Board

Power Control

Console
- Boot Loader
- Kernel
- Userspace

Interaction

Network
- TFTP
- DHCP
- NFS

Board image source: http://elinux.org/
Board Farm Building Blocks

Board Farm

Console

Power Control

Interaction

Network

Boot Loader
Kernel
Userspace

TFTP
DHCP
NFS

Board image source: http://elinux.org/
Power Control

Power Outlet Control

- Classical solution
- Multiple interface options (Ethernet/serial)
- Metering
- Fine for your freezer or washing machine
- Overkill for many low-power embedded boards

Image source: http://www.apc.com/
Power Control
Relay Board

- Multiple interface options (GPIO, I2C, USB, Ethernet)
  - Beware multiple boards with identical MAC addresses!
- Overkill for many low-power embedded boards

Image source: http://www.yourduino.com/
Cape for BeagleBone Black

OR ... connect to anything that has an I2C bus

Up to 8 channels (max. 2 capes)

Image source: http://baylibre.com/
Power Control
BayLibre ACME

- Power Control and Voltage/Current Monitoring:
  - Jack Power Probe (2.1/5.5mm Center-pos, up to 20V/6A)
  - USB Power Probe (Mini-B, up to 1A)
  - Not good enough for the z890 😞

- Measurement only:
  - HE10 Power Probe (up to 150mA/1.5A/10A)
  - Temperature Probe

Image source: http://baylibre.com/
Power Measurement

Power Consumption $P = U \times I$

- Measure Voltage $U$
- Calculate Current $I$:
  - Measure Voltage $U$ across a small Measurement Resistor $R$
  - Ohm’s law:
    $$U = R \times I \Leftrightarrow I = \frac{U}{R}$$
- Whole board / Subsystem power rails / Component

Serial consoles

- Legacy DB9/DB25 serial → USB-serial adapter
- 1.8V/3.3V/5V UART → USB-serial adapter
- On-board USB-serial chip
- 96Boards UART

USB hub with many ports (may need power)

Use `udev` rules to pin names to your serial ports

```
/etc/udev/rules.d/99-usb-serial.rules
```

```
SUBSYSTEM=="tty", ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6001", \  ATTRS{serial}=="A900YDVW", SYMLINK="tty-ape6evm"
SUBSYSTEM=="tty", DRIVERS=="mos7840", ATTRS{port_number}=="0", \  SYMLINK="tty-aten0"
```

Beware USB-serial chips with identical serial numbers!
Fortunately USB devices can be addressed by topology

```
/dev/serial/by-path/...
```
Network

- Ethernet Switch
  - Beware multiple boards with identical MAC addresses!
- Wireless Access Point
- Similar to networking *normal* Linux machines
Interaction

- Mostly input and control
- Output: complicated beyond console
- May require creative and custom solutions
Interaction

Switches and Buttons

- System Reset
- System Wake-Up
- Soft Power-On
- Generic input (e.g. keypad)
- ...
Interaction

Signal Inputs

- 2.54mm Female/Male Header
- 2 mm Female/Male Header

Interaction
Signal Inputs

- Unpopulated Header → Solder header

- Test Point → Test Clip or Hook

Image source: http://www.robotroom.com/
Interaction

Signal Inputs

- High-Density Connector Breakout: Buy ...

Interaction

Signal Inputs

- High-Density Connector Breakout: ... or Build

- Extreme Wiring on the Prototyping Board
  http://elm-chan.org/docs/wire/wiring_e.html
- Solder to switch, or other component
- JTAG has reset
- Wake-Up needs an IRQ, or GPIO with interrupt capability
- Add any GPIO on expansion connector to gpio-keys in DT, to avoid having to solder a wire to a switch

Caveats:
- Signals are usually asserted by grounding
- Sometimes asserted by pulling high (to which voltage?)
- Positive voltage supply may be missing on connector 😞
keyboard {
  compatible = "gpio-keys";
  pinctrl-names = "default";
  pinctrl-0 = <&keyboard_pins>;
  key-wakeup {
    gpios = <&gpio2 1 GPIO_ACTIVE_LOW>;
    label = "EXIO-D-50";
    linux,code = <KEY_WAKEUP>;
  };
};

&pfc {
  keyboard_pins: keyboard {
    pins = "GP_2_1";
    bias-pull-up;
  }
};
Interaction
How to Control All Those Signals?

- GPIOs with/without driving Transistors/MOSFETs
  - X No isolation

- Relays
  - Electromagnetically Controlled Switch

✓ Isolation
✓ Relay Boards readily available
X Noisy
X Overkill for most input signals

Image source: http://www.wikipedia.org/
Interaction
How to Control All Those Signals?

- Opto-Isolators
  - Light Controlled Switch

- Isolation
- Can switch +1.8V, +3.3V, +5V, ...
- Add a relay if needed
- Polarity!

Image source: http://www.wikipedia.org/
Interaction
Eight Opto-Isolators Driven by I2C GPIO Expander
Management Host

- Control and monitor all blocks
- Provide services
- Old PC, embedded x86
- Embedded Development Boards becoming more powerful
  - E.g. BeagleBone Black, Raspberry Pi, ...
Beagle Bone Black Console Bed
Power Supplies

- Each board comes with its own power supply
- Wall wart rats nest

- Can we improve upon?
Board Power Needs

- Most boards take either 5V or 12V
- Different connectors types, voltages, and polarities
  - 2.1/5.5mm or 2.5/5.5mm jack
    - 5V, 7.5V, 9V, 12V, . . . , up to 9A
    - Most (not all!) are Center-positive
  - EIAJ connector, Center-positive, 2A
- #1 0–3.15V 2.35/0.7mm
- #2 3.15–6.3V 4.0/1.7mm
- #3 6.3–10.5V 4.75/1.7mm ← 96Boards 8–18V
- #4 10.5–13.5V 5.5/3.4/1.0mm
- #5 13.5–18V 6.5/4.4/1.4mm
- USB mini/micro-B
- Need for conversion when used with ACME

Image source: https://www.sparkfun.com/
Identical and Low Power Needs

- Powered USB hub for e.g. Beowulf of Raspberry Pis
- Barrel jack splitters (2-way, 4-way)

- Usually limited to 2A, maximum current is seldom advertized

Image source: https://solarbotics.com/
Single Power Supply

- **My needs:**
  - 8 Boards + Management Host & Control Hardware
  - 13A @ 5V $\rightarrow$ 65W
  - 28A @ 12V $\rightarrow$ 336W
  - Absolute maximum ratings!

- Lab power supply
- PC power supply
### Multiple Output Voltages

- **+5V** For development boards
- **+12V** For development boards
  - Single or Dual Rail!
- **+3.3V** For an MSP430 LaunchPad?
- **-12V** Not so useful without real RS232

### Management Host Features

- **+5Vsb** +2A is ample
- **PS_ON** Remote control
Minimum Load?

Older supplies may need some load to work
- Look for *Haswell C6/C7 Zero Load Support*
- Use e.g. Ethernet switch as load, or load resistors

Voltage Stability / Power Rail Cross Impact

- Not so much of an issue anymore
  - Single rail 12V with DC/DC converters for 3.3V and 5V
  - SoCs run at low voltages, board has own PMIC
  - Boards that need stable +5V signals typically run from 12V
  - Any boards that still need stable +12V signals?
- Power Supply needs some time to stabilize!
  - Turn power supply on first, individual boards last
  - Turn individual boards off first, power supply last
  - *PWR_OK* signal
Watch out for high currents!

- Typical 650W PC Power Supply
  - 52A @ 12V
  - 22A @ 5V
  - Low voltage, but high current, needs thick wires
  - My induction stove needs only 32A (@ 230V, though)

- Do not feed everything from one wire!
  - 4A per wire
  - Modular Power Supply can still be handy

- Fuses for individual boards
  - The PS should be designed to survive a short circuit
  - Your Raspberry Pi may not (@ 20A)
Use Ethernet switch with 12V input (some need e.g. 7.5V)
Most USB hubs need 5V
+12V rail is the major rail on modern supplies
+5V limited to 20–25A, independent of total wattage
Many boards that need 5V? → add a DC/DC converter
PC Power Supply
Before 3D Printing, There Existed LEGO

Beau Barrier Strips — Fuses — Eurostyle Barrier Strips
PC Power Supply

Before 3D Printing, There Existed LEGO

Beau Barrier Strips — Fuses — Eurostyle Barrier Strips
Software Side
GPIO Control

- Add PFC8574 GPIO expander at I2C address 0x24:

```bash
if i2cget -y 1 0x24 >& /dev/null; then
echo pcf8574 0x24 > /
    /sys/class/i2c-adapter/i2c-1/new_device
for i in $(seq 480 487); do
echo $i > /sys/class/gpio/export
    done
fi
```

- Toggle reset line at gpio 480 using sysfs:

```bash
echo out > /sys/class/gpio/gpio480/direction
sleep 0.2
echo in > /sys/class/gpio/gpio480/direction
```

- Should try new GPIO chardev interface . . .
Software Side
ACME

- Sigrok integration
- PulseView GUI
- Command line

```
# sigrok-cli --driver=baylibre-acme --samples=1
FRAME-BEGIN
P1_ENRG_PWR: 1.225000 W
P1_ENRG_CURR: 0.246000 A
P1_ENRG_VOL: 5.019000 V
...
FRAME-END
```

- sysfs GPIO for board power control, or `sigrok-cli`
- ACME powers on all boards during boot up 🌛

→ Edit `/etc/init.d/S95acme-init`:

```
- echo 1 > /sys/class/gpio/gpio$GPIO/value
+ echo 0 > /sys/class/gpio/gpio$GPIO/value
```
Big collection of scripts:

- `main-power-{on,off,status}`
- `<board>-power-{on,off,status}`
- `<board>-acc-{on,off,status}`
- `<board>-{reset,wakeup}`
- `...`

<table>
<thead>
<tr>
<th>Device</th>
<th>Power (W)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ape6evm</td>
<td>4.850000</td>
<td>0.406000</td>
<td>11.928000</td>
</tr>
<tr>
<td>armadillo</td>
<td>3.025000</td>
<td>0.620000</td>
<td>4.893000</td>
</tr>
<tr>
<td>h3-salvator-x</td>
<td>9.625000</td>
<td>0.812000</td>
<td>11.851000</td>
</tr>
<tr>
<td>kzm9g</td>
<td>1.800000</td>
<td>0.364000</td>
<td>4.938000</td>
</tr>
<tr>
<td>rbtx4927</td>
<td>2.425000</td>
<td>0.490000</td>
<td>4.901000</td>
</tr>
<tr>
<td>rpi</td>
<td>1.225000</td>
<td>0.250000</td>
<td>4.879000</td>
</tr>
</tbody>
</table>

Total: 22.95 W

Total at 5V: 8.475 W, 1.724 A

Total at 12V: 14.475 W, 1.218 A
Software Side

- Booting (TFTP / DHCP / NFS root): cfr. board on your desk
- TODO: Automated boot
  - Boot testing
  - Auto-bisecting regressions
  - Join kernelci.org?

Q How can I participate in the boot test phase?
A The best way to participate is to send us your boards

Source: https://kernelci.org/faq
My Board Farm fulfills my requirements.

You may want:

- JTAG
- VNC for display output
- Board sharing
- Virtualization to isolate multiple users
- ...
Final Words

What have I learned?

- Improved soldering skills
- Modern PC power supplies work with zero load
- It takes a while to get the details right

What can I improve?

- More automation
- Better UI for controlling boards
- Create my own PCB for the Opto-Isolator Board
- Get a real case for the power distribution parts
- Better furniture for the whole farm
Thanks & Acknowledgements

- **Renesas Electronics Corporation**, for contracting me for Linux kernel work, and supplying me with development boards,
- The **Linux Foundation**, for organizing this conference and giving me the opportunity to present here,
- **BayLibre**, for creating ACME,
- The **Renesas Linux Kernel Team**, for insights and discussions,
- The **Linux Kernel Community**, for having so much fun working together towards a common goal.