Debugging Usually Slightly Broken Devices and Drivers

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Agenda

- USB basics
- Plug & Play
- Plug & do what I want
- Plug & tell me more
- Summary
- Q & A

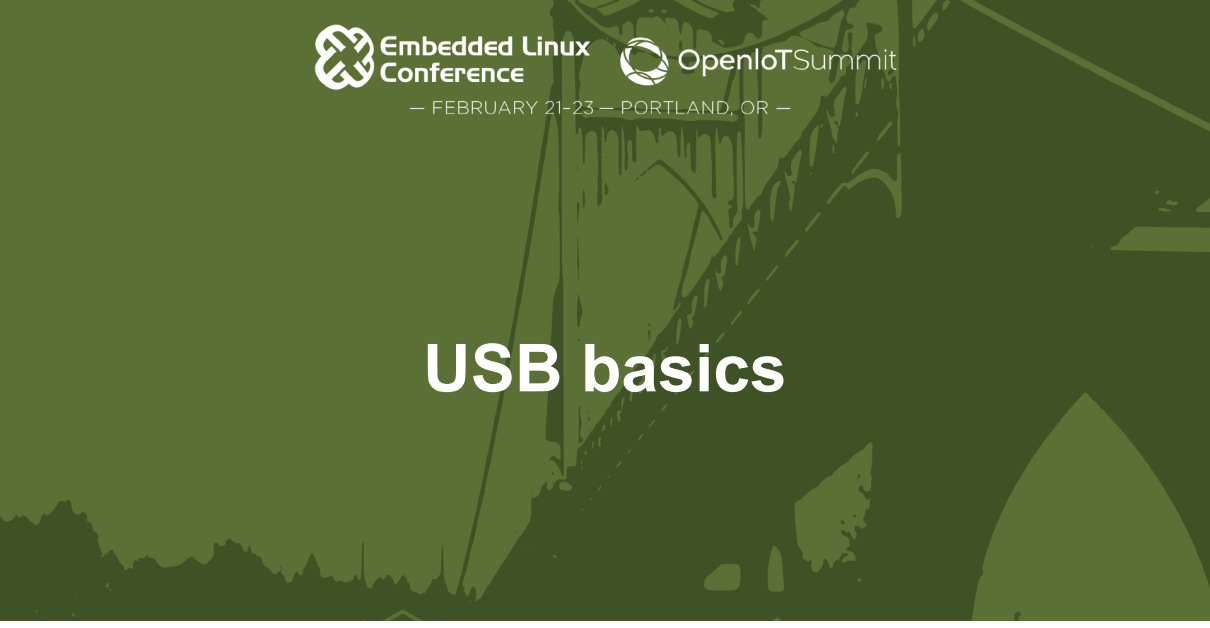
This presentation…

is about:

- **USB**
- **USB devices management**
- **USB drivers policy modification**
- **USB traffic sniffing**

is **NOT** about:

- **Kernel code debugging**
- **Using kgdb**
- **Using tracepoints**
- **Using JTAG**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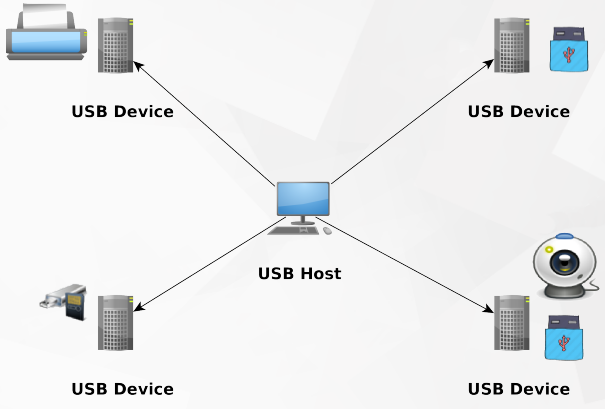
USB basics

What USB is about?

It's about providing services!

- **Storage**
- **Printing**
- **Ethernet**
- **Camera**
- **Any other**



Endpoints…

- **Device may have up to 31 endpoints (including ep0)**
- **Each of them gets a unique endpoint address**
- **Endpoint 0 may transfer data in both directions**
- **All other endpoints may transfer data in one direction:**

IN Transfer data from device to host
OUT Transfer data from host to device

Endpoint types

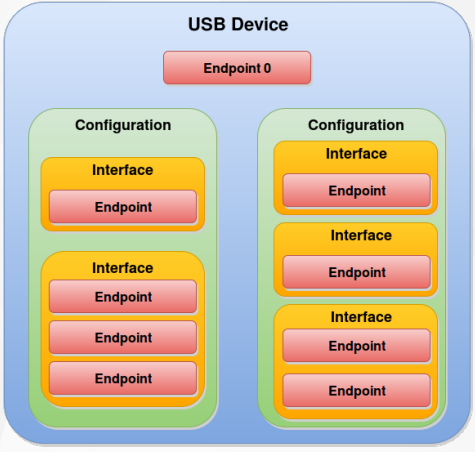
- **Control**
  - Bi-directional endpoint
  - Used for enumeration
  - Can be used for application
- **Bulk**
  - Used for large data transfers
  - Used for large, time-insensitive data (Network packets, Mass Storage, etc).
  - Does not reserve bandwidth on bus, uses whatever time is left over

Endpoint types

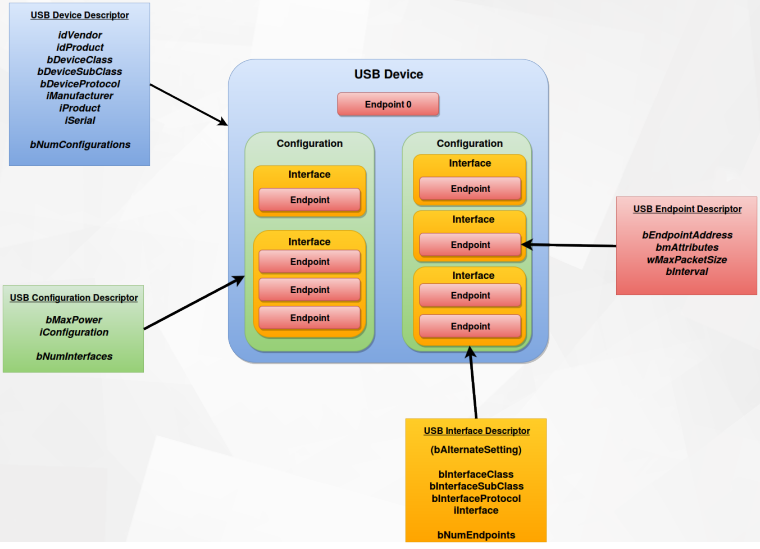
- **Interrupt**
  - Transfers a small amount of low-latency data
  - Reserves bandwidth on the bus
  - Used for time-sensitive data (HID)

- **Isochronous**
  - Transfers a large amount of time-sensitive data
  - Delivery is not guaranteed (no ACKs are sent)
  - Used for Audio and Video streams
  - Late data is as good as no data
  - Better to drop a frame than to delay and force a re-transmission

USB device



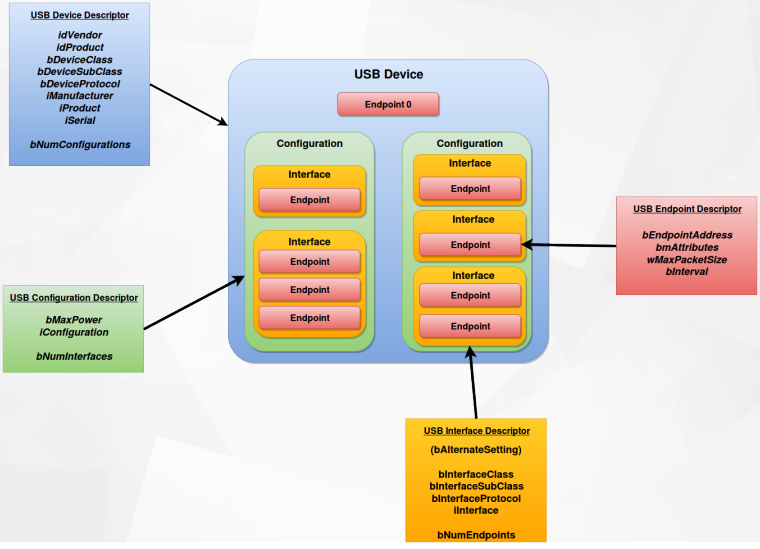
USB descriptors

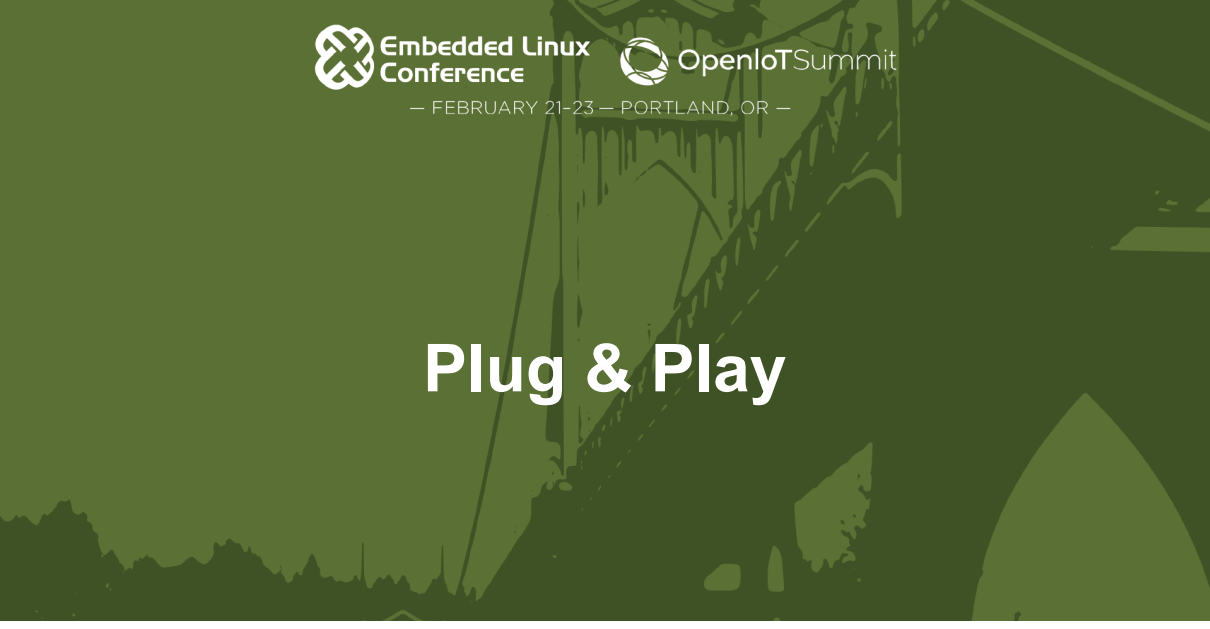


USB classes

00h	Device	Use class information in the Interface Descriptors
01h	Interface	Audio
02h	Both	Communications and CDC Control
03h	Interface	HID (Human Interface Device)
05h	Interface	Physical
06h	Interface	Image
07h	Interface	Printer
08h	Interface	Mass Storage
09h	Device	Hub
0Ah	Interface	CDC-Data
0Bh	Interface	Smart Card
0Dh	Interface	Content Security
0Eh	Interface	Video
0Fh	Interface	Personal Healthcare
10h	Interface	Audio/Video Devices
11h	Device	Billboard Device Class
DCh	Both	Diagnostic Device
E0h	Interface	Wireless Controller
EFh	Both	Miscellaneous
FEh	Interface	Application Specific
FFh	Both	Vendor Specific

USB descriptors

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Plug & Play

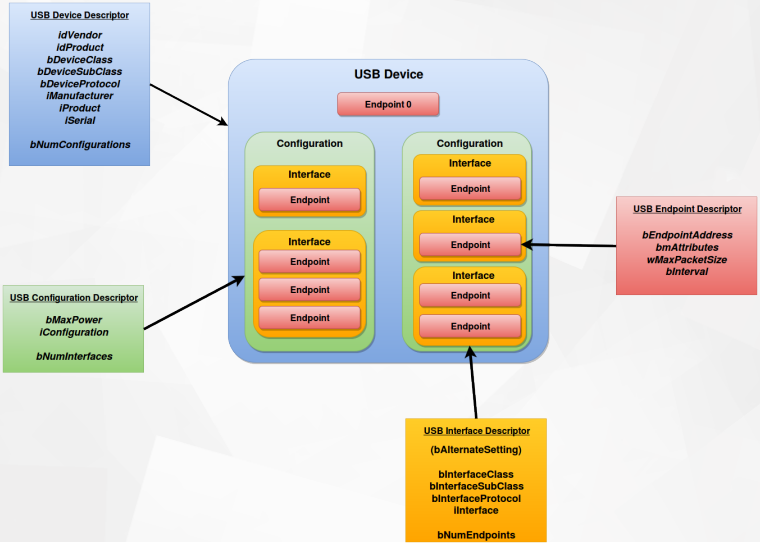
Step by step

- Plug in device
- Detect Connection
- Set address
- Get device info
- Choose configuration
- Choose drivers for interfaces
- Use it ;)

Set address

- On plug-in device uses default address 0x00
- Only one device is being enumerated at once
- Hosts assigns unique address for new device
- Usually it's just the next one (dev.addr = addr++)

USB Device Details



Which configuration is the most suitable?

- **Do we have enough power for it (bMaxPower)?**
- **Does it have at least one interface?**
- **If the device has only one config**
  - The first one!
- **If the device has multiple configs**
  - The first one which first interface class is **different** than **Vendor Specific**
- **All interfaces of chosen configuration become available so let's use them**

What USB driver really is?

- **Piece of kernel code (often a module)**
- *struct usb_driver*
- **Usually it provides something to userspace (network interface, block device, tty, etc.)**
- **Implementation of some communication protocol**
- **…so it's a little bit equivalent of web browser, ssh client etc.**

How driver is chosen?

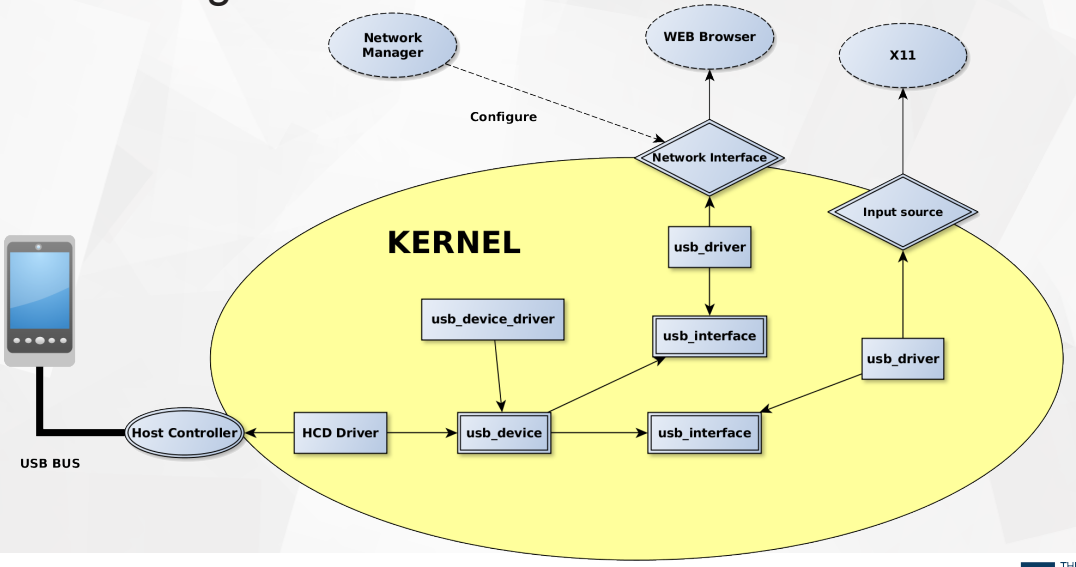
- **Kernel has a list of registered drivers**
- **Each driver has an array of acceptable device IDs**
- **Kernel goes through the list and if some id matches calls driver's** *probe()*
- **If driver is not there udev may load it's module based on alias**
- **Module aliases are generated based on acceptable device IDs**

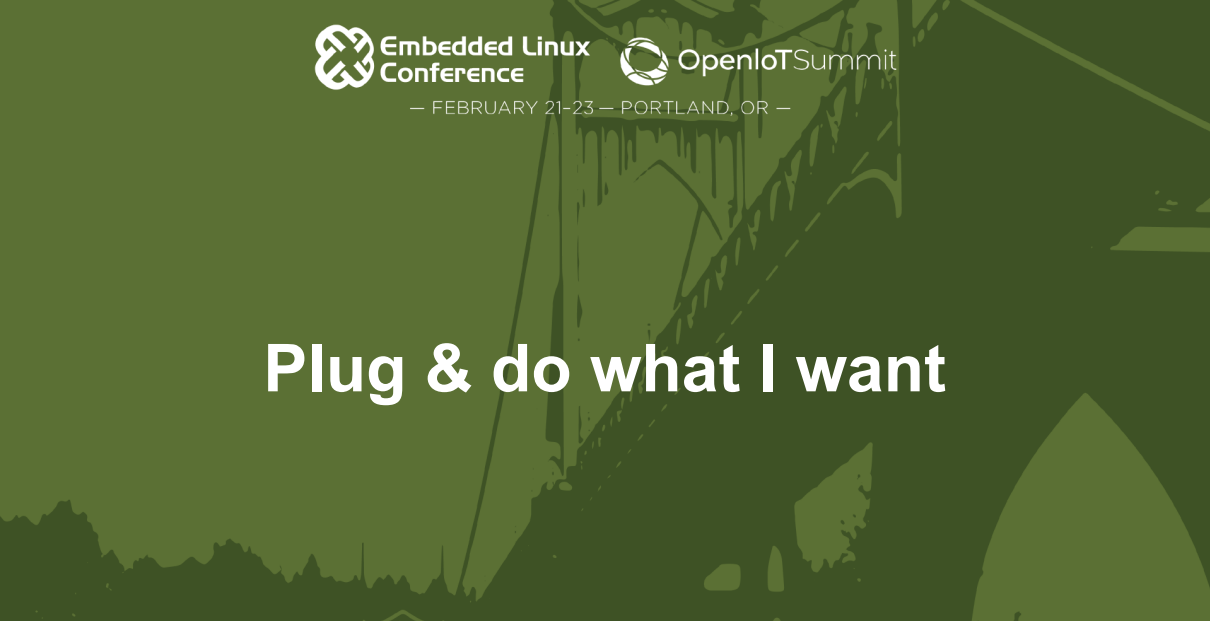
USB device identity

```
struct usb_device_id {
    /* which fields to match against? */
    __u16 match_flags;

    /* Used for product specific matches */
    __u16 idVendor;
    __u16 idProduct;
    __u16 bcdDevice_lo;
    __u16 bcdDevice_hi;

    /* Used for device class matches */
    __u8 bDeviceClass;
    __u8 bDeviceSubClass;
    __u8 bDeviceProtocol;

    /* Used for interface class matches */
    __u8 bInterfaceClass;
    __u8 bInterfaceSubClass;
    __u8 bInterfaceProtocol;

    /*
     * Used for vendor-specific
     * interface matches
     */
    __u8 bInterfaceNumber;

    /* not matched against */
    kernel_ulong_t driver_info;
};
```

```
#define USB_DEVICE_ID_MATCH_VENDOR 0x0001
#define USB_DEVICE_ID_MATCH_PRODUCT 0x0002
#define USB_DEVICE_ID_MATCH_DEV_LO 0x0004
#define USB_DEVICE_ID_MATCH_DEV_HI 0x0008
#define USB_DEVICE_ID_MATCH_DEV_CLASS 0x0010
#define USB_DEVICE_ID_MATCH_DEV_SUBCLASS 0x0020
#define USB_DEVICE_ID_MATCH_DEV_PROTOCOL 0x0040
#define USB_DEVICE_ID_MATCH_INT_CLASS 0x0080
#define USB_DEVICE_ID_MATCH_INT_SUBCLASS 0x0100
#define USB_DEVICE_ID_MATCH_INT_PROTOCOL 0x0200
#define USB_DEVICE_ID_MATCH_INT_NUMBER 0x0400
```

USB Host Big Picture

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Plug & do what I want

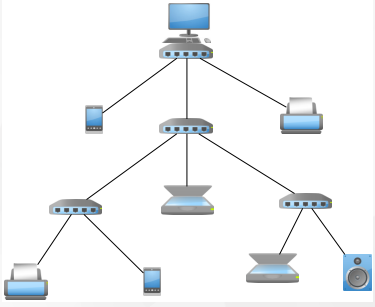
Automation is good…

…but not always:

- **Too many devices allowed**
- **Only part of device functionality is needed**
- **Wrong config chosen**
- **No matching driver found**
- **Wrong driver bound**

/sys/bus/usb/devices/ demystified

- `usbX`
  - X **ID of host controller on your machine**
- `X-A.B.C`
  - X **HCD ID (as above)**
  - A.B.C **Physical path to port where your USB device is connected**
- `X-A.B.C:Y.Z`
  - X-A.B.C **Device path (as above)**
  - Y **Active configuration**
  - Z **bInterfaceNumber**



Limit number of allowed devices

Let's use USB Device Authorization!

- **Each USB device has *authorized* attribute**
- **Each HCD (`usbX`) has *authorized_default* attribute**
- **If *authorized* == *0*, device is left unconfigured**
- **When authorized, drivers probed automatically**
- **Automated by *usbguard***

```
# Choose USB bus
$ cd /sys/bus/usb/devices/usb$X

# Stop authorizing devices by default
$ echo 0 > authorized_default

# Connect new device, do other stuff

# Authorize device of your choice
$ cd /sys/bus/usb/devices/$DEV_DIR
$ echo 1 > authorized
```

Use only subset of functionality

Let's use USB Interface Authorization! (v4.4+)

- **Each USB interface has *authorized* attribute**
- **Each HCD (`usbX`) has *interface_authorized_default* attribute**
- **If *authorized* == *0*, drivers are not allow to bind**
- **Driver probing has to be triggered manually**

```
# Choose USB bus
$ cd /sys/bus/usb/devices/usb$X

# Stop authorizing interfaces by default
$ echo 0 > interface_authorized_default

# Authorize interface of your choice
$ cd /sys/bus/usb/devices/$INTERFACE_DIR
$ echo 1 > authorized

# Trigger driver search
$ echo -n $INTERFACE_DIR \
                > /sys/bus/usb/drivers_probe
```

Change configuration

- **Each USB device has *bConfigurationValue* attribute**
- **Read it to get current configuration**
- **Write to it to choose another one**

```
$ cd $DEV_DIR

# Check current config
$ cat bConfigurationValue
1

# Set new one
$ echo $NEW_CONFIG > bConfigurationValue
```

Add Device ID to driver

- Many drivers are bound based on VID:PID pair…
- But "cost effective vendors" sometimes changes them:(
- or maintainer removes your VID:PID pair from the driver
- or you have device which is compatible with another one
- but has different VID:PID
- So you need to somehow modify driver's device ID table

Dynamic IDs - formats

- **VID+PID:**

```
$ echo $VID $PID
```

- **VID+PID+Intf Class:**

```
$ echo $VID $PID $IntfClass
```

- **VID+PID+Intf Class+dev_info:**

```
$ echo $VID $PID $IntfClass $RefVID $RefPID
```

Dynamic IDs - formats

- **VID+PID:**

```
$ echo $VID $PID
```

- **VID+PID+Intf Class:**

```
$ echo $VID $PID $IntfClass
```

- **VID+PID+Intf Class+dev_info:**

```
$ echo $VID $PID $IntfClass $RefVID $RefPID
```

- **All numbers are interpreted as HEX!**

Dynamic IDs - handling

- **Add new device ID**

```
$ echo $VID $PID > \
        /sys/bus/usb/drivers/$DRV_NAME/new_id
```

- **Show the list of dynamic IDs**

```
$ cat /sys/bus/usb/drivers/$DRV_NAME/new_id
```

- **Remove previously added device ID**

```
$ echo $VID $PID > \
        /sys/bus/usb/drivers/$DRV_NAME/remove_id
```

Bind/Unbind particular interface

- **Check which driver is bound**

```
$ readlink \
    /sys/bus/usb/devices/$INTERFACE_DIR/driver
```

- **Unbind driver**

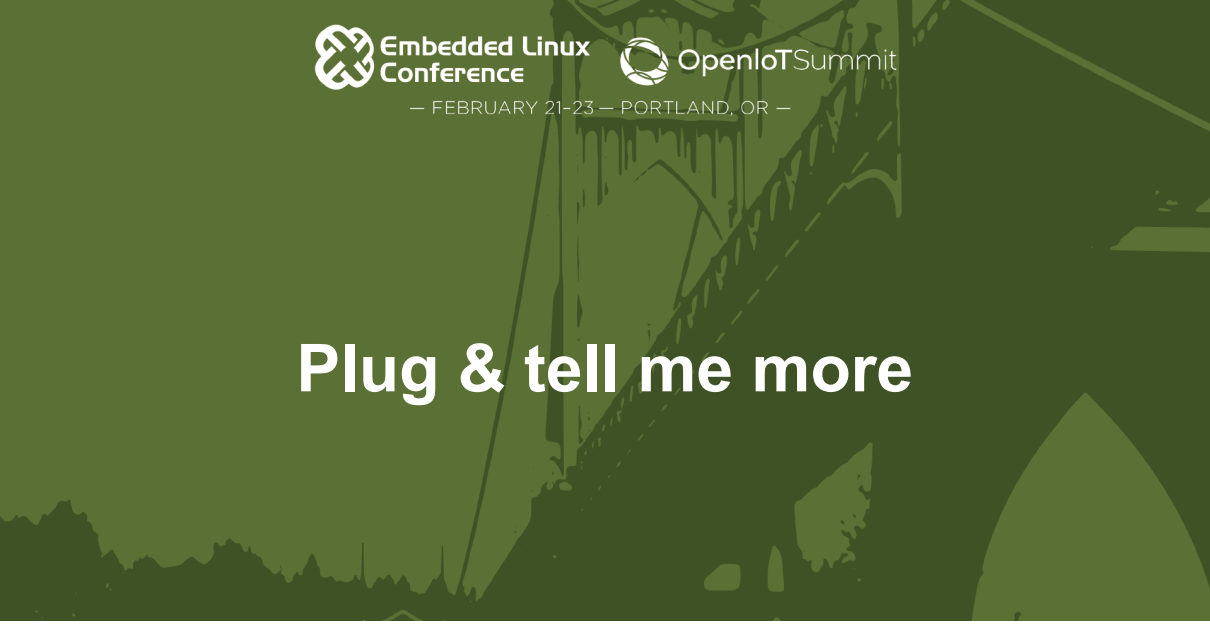
```
$ echo -n  $INTERFACE_DIR > \
    /sys/bus/usb/drivers/$DRV_NAME/unbind
```

- **Bind driver (device id must match)**

```
$ echo -n  $INTERFACE_DIR > \
    /sys/bus/usb/drivers/$DRV_NAME/unbind
```

Let's try this

DEMO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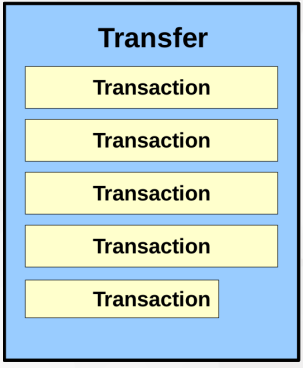
Plug & tell me more

USB bus

- **USB is a Host-controlled bus**
- **Nothing on the bus happens without the host first initiating it.**
- **Devices cannot initiate any communication.**
- **The USB is a Polled Bus.**
- **The Host polls each device, requesting data or sending data.**

USB transfer vs transaction

- **Transaction**
  - Delivery of data to endpoint
  - Limited by wMaxPacketSize
- **Transfer**
  - One or more transactions
  - May be large or small
  - Completion conditions



USB Request Block

- **Kernel provides hardware independent API for drivers**
- **URB is a kind of envelope for data**
- **This API is asynchronous**
  - *usb_alloc_urb()*
  - *usb_free_urb()*
  - *usb_submit_urb()*
  - *usb_unlink_urb()*
  - *usb_kill_urb()*

```
struct urb {
    struct list_head urb_list;

    struct usb_device *dev;
    unsigned int pipe;

    int status;
    unsigned int transfer_flags;
    void *transfer_buffer;
    u32 transfer_buffer_length;
    u32 actual_length;

    unsigned char *setup_packet;

    void *context;
    usb_complete_t complete;
};
```

Typical USB driver

Where?	What?
probe()	check device + allocate resources
disconnect()	release resources
complete()	check status, get data, resubmit
related to other subsystem	depends on susbsys

Typical bugs?

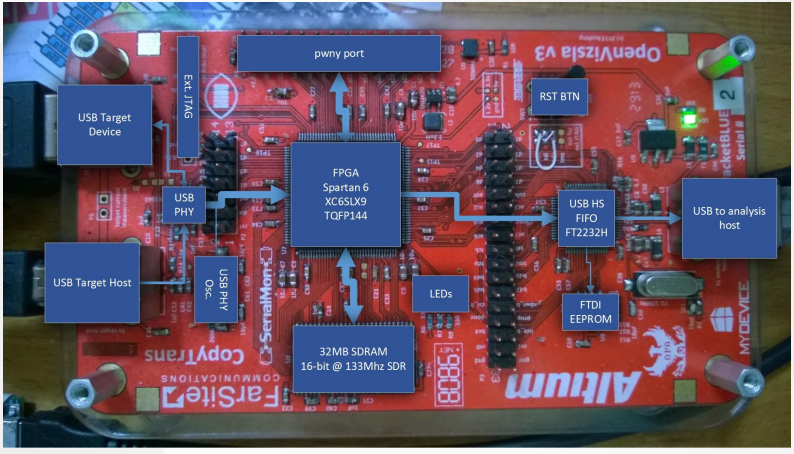
- **Missing descriptors**
- **No error path on missing entities**
- **No correct error handling in complete()**
- **Malformed packets**

HW USB sniffers - Commercial

2850$

1400$

HW USB sniffers - Open Hardware



about 100$

USBMon

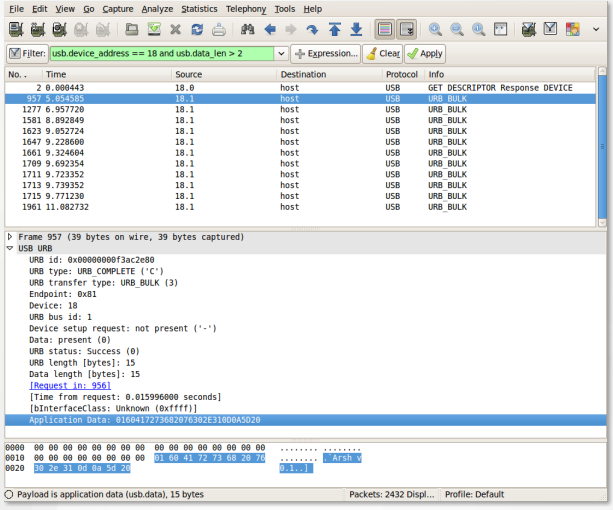
- **Kind of logger for URB related events:**
  - submit()
  - complete()
  - submit_error()
- **So it's not going to show you low level USB tokens!**
- **Text interface**
- **Binary Interface**
- **One instance for each USB bus**

Data validity

- **Data in URB buffer may is not always valid**
- **Validity depends on transfer results**
- **And on endpoint direction:**

	IN	OUT
submit()	NO	YES
complete()	YES	NO

Good old friend Wireshark



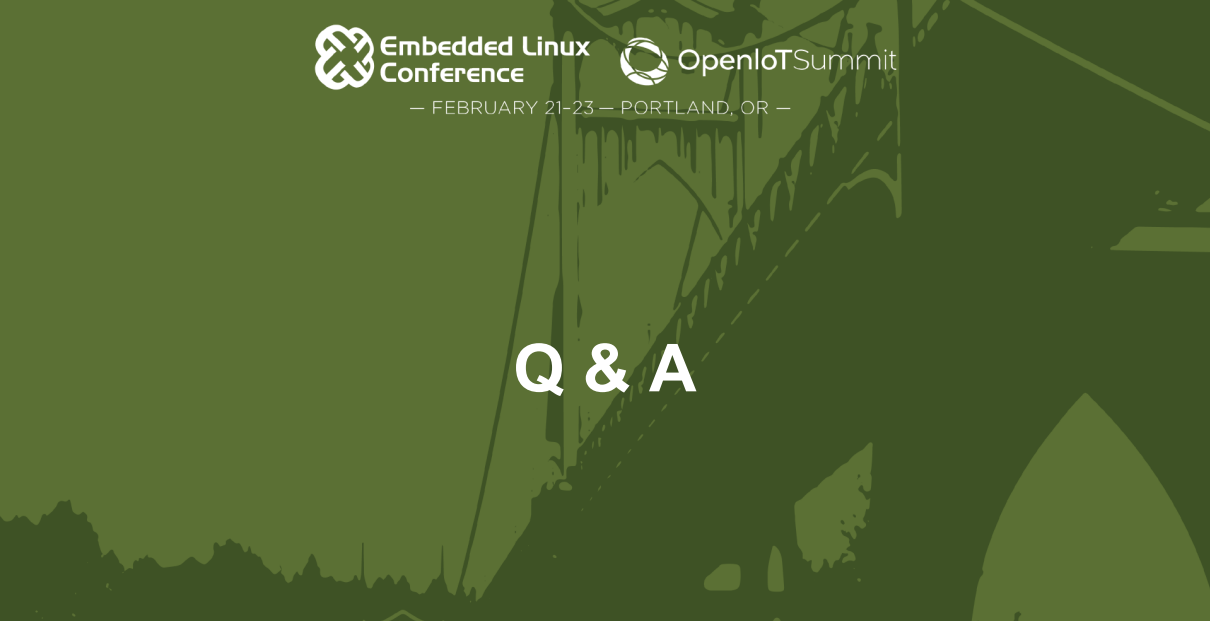
Let's catch sth

DEMO

Summary

Summary

- **USB descriptors are like passports**
- **You can get them using *lsusb***
- **Each driver declares list of compatible devices**
- **USB devices are manageable via SysFS:**
  - Change active config
  - Add new device to driver
  - Bind/Unbind driver
  - Device/Interface authorization
- **Drivers communicate using URBs**
- **You don't need money to sniff your USB traffic**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Q & A

Thank you!

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