USB设备驱动开发

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今天的内容

- 1.USB及驱动框架简介
- 1.1 USB协议
- 1.2 USB驱动的体系结构
- 2.主机端驱动
- 2.1 主机控制器驱动
- 2.2 设备驱动
- 3.设备端驱动
- 3.1 设备控制器驱动
- 3.2 gadget驱动
- 4. USB OTG

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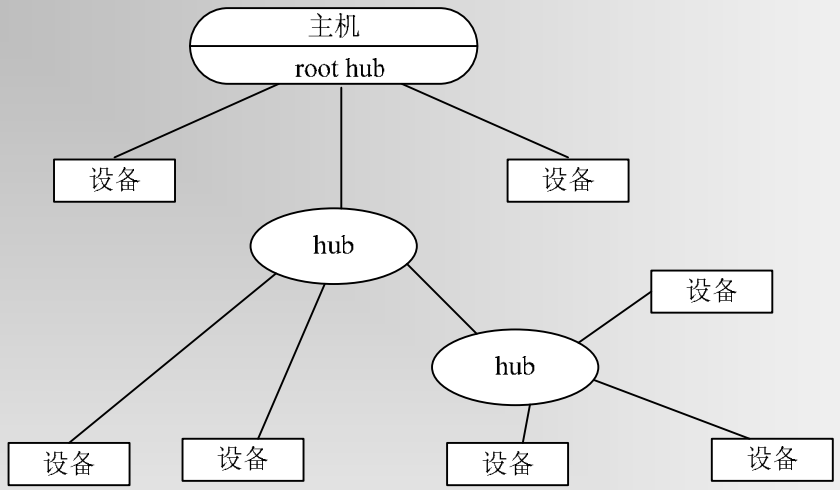
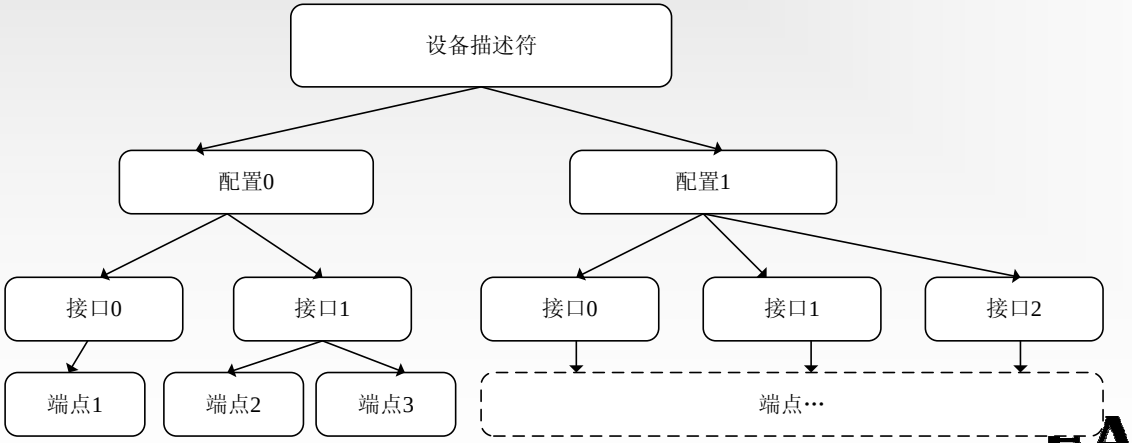
华清远见

USB协议(1)

- 拓扑结构



- 设备、配置、接口和端点



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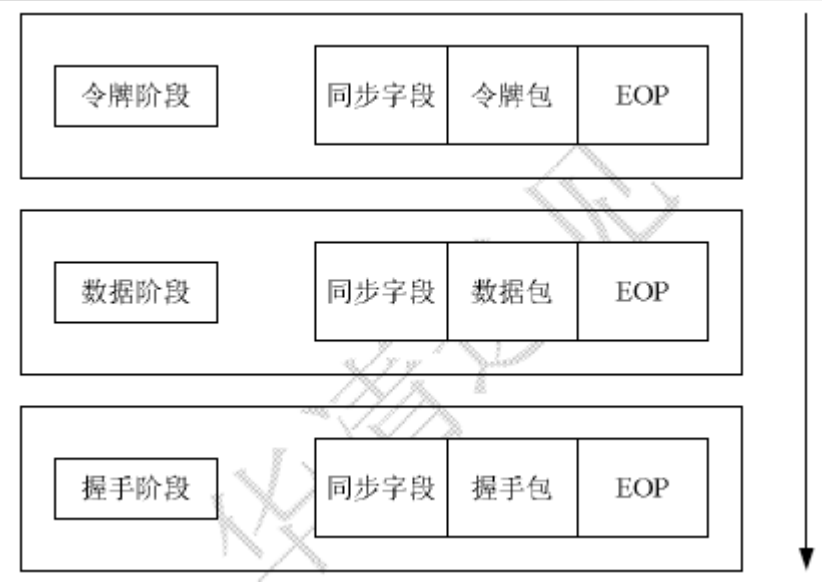
USB协议(2)

- 传输方式
  - *控制（Control）传输方式*
  - *同步（Synchronization）传输方式*
  - *中断（Interrupt）传输方式*
  - *批量（Bulk）传输方式*
- 事务处理



华清远见

USB协议(3)

➢包格式

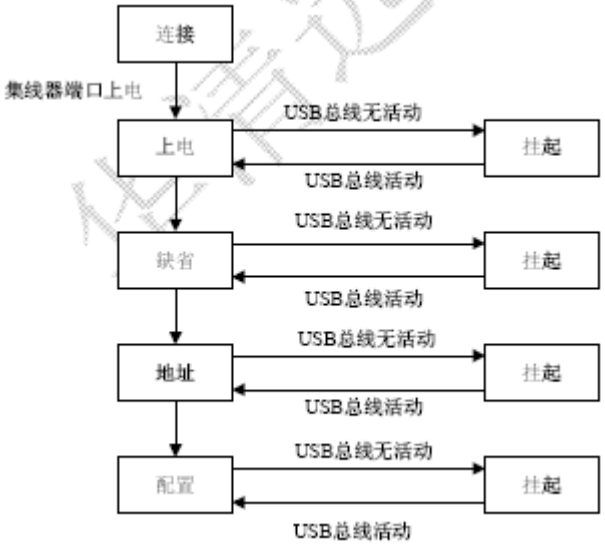
IN令牌包字段	PID	ADDR	ENDP	CRC
位数	8	7	4	5

SOF令牌包字段	PID	帧号字段	CRC
位数	8	11	5

数据包字段	PID	数据字段	CRC
位数	8	0~1024*8	16

握手包字段	PID
位数	8

➢设备状态



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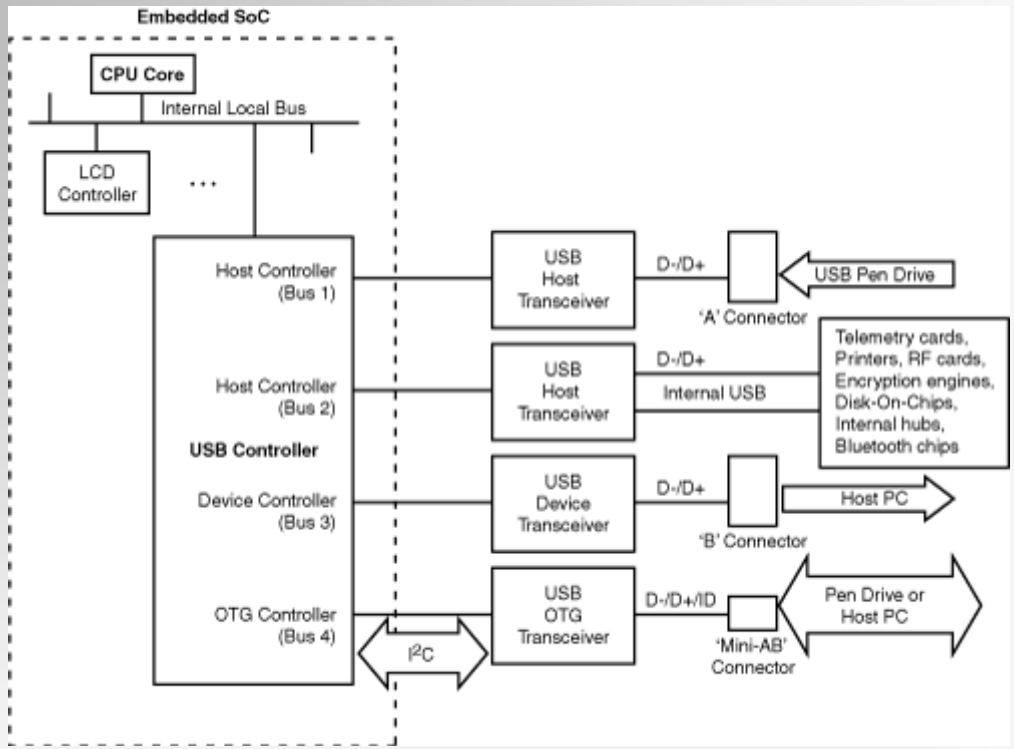
USB控制器

- 主机、设备、OTG控制器



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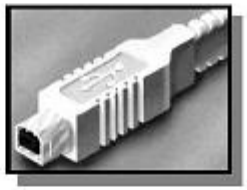
华清远见

USB接口

➢A、B

Series "A" Connectors	Series "B" Connectors
♦ Series "A" plugs are always oriented **upstream** towards the *Host System*	♦ Series "B" plugs are always oriented **downstream** towards the *USB Device*
 **"A" Plugs** (*From the USB Device*)	 **"B" Plugs** (*From the Host System*)
"A" Receptacles (*Downstream Output from the USB Host or Hub*) 	**"B" Receptacles** (*Upstream Input to the USB Device or Hub*) 

➢mini、micro

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直观的例子—U盘描述符

- *lsusb*

bDeviceSubClass 0
bDeviceProtocol 0
bMaxPacketSize0 64
idVendor 0x0781 SanDisk Corp.
idProduct 0x5151
bcdDevice 0.10
iManufacturer 1 SanDisk Corporation
iProduct 2 Cruzer Micro
iSerial 3 20060877500A1BE1FDE1
bNumConfigurations 1
Configuration Descriptor:
bLength 9
bDescriptorType 2
wTotalLength 32
bNumInterfaces 1
bConfigurationValue 1
iConfiguration 0
bmAttributes 0x80
MaxPower 200mA

Interface Descriptor:
bLength 9
bDescriptorType 4
bInterfaceNumber 0
bAlternateSetting 0
bNumEndpoints 2
bInterfaceClass 8 Mass Storage
bInterfaceSubClass 6 SCSI
bInterfaceProtocol 80 Bulk (Zip)
iInterface 0
Endpoint Descriptor:
bLength 7
bDescriptorType 5
bEndpointAddress 0x81 EP 1 IN
bmAttributes 2
Transfer Type Bulk
Synch Type none
wMaxPacketSize 512
bInterval 0
Endpoint Descriptor:
bLength 7
bDescriptorType 5
bEndpointAddress 0x01 EP 1 OUT
bmAttributes 2
Transfer Type Bulk
Synch Type none
wMaxPacketSize 512
bInterval 1
Language IDs: (length=4)
0409 English(US)

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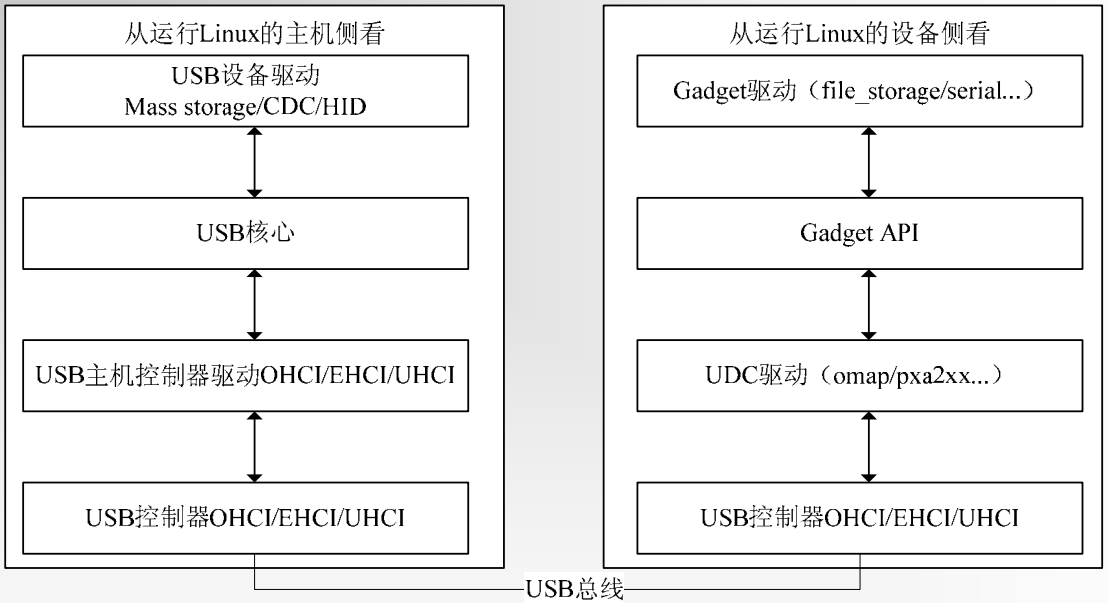
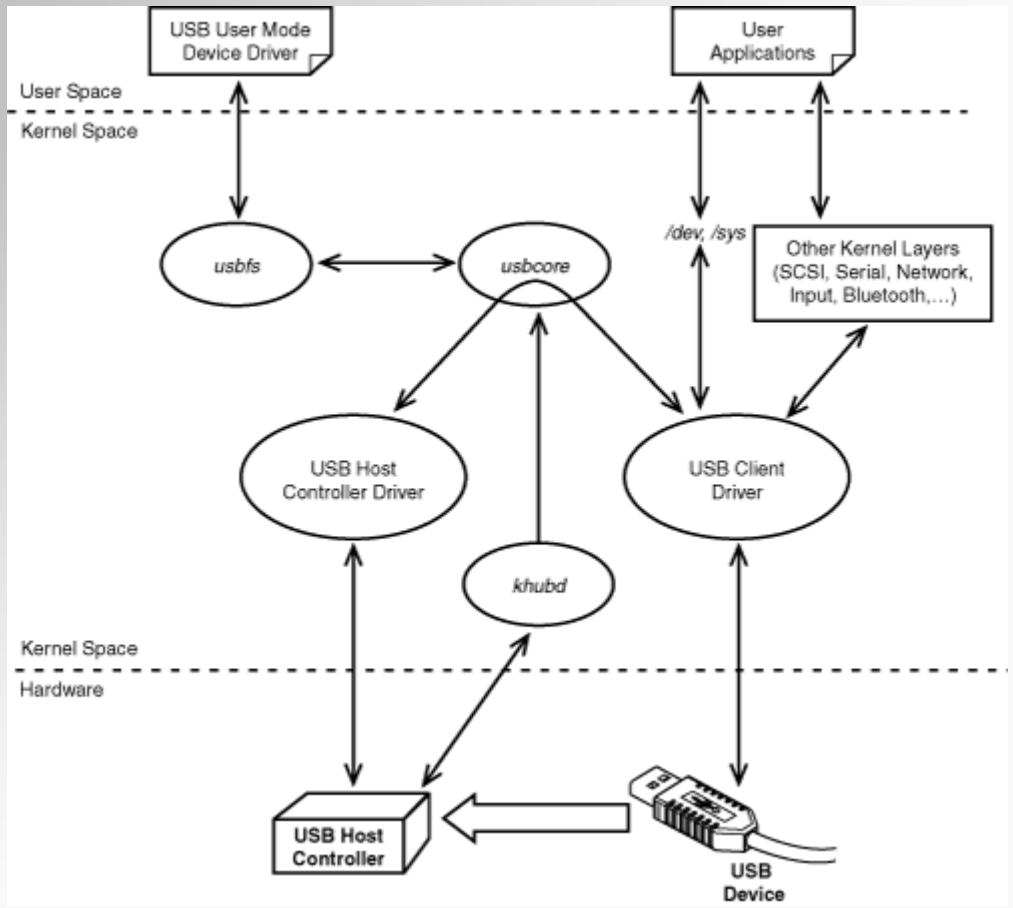
USB驱动体系结构

- 从运行Linux的主机侧
- 从运行Linux的设备侧



华清远见

USB主机端驱动体系结构



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USB主机控制器驱动

数据结构：

- struct usb_hcd
- struct hc_driver

```
static const struct hc_driver xxx_hc_driver = {
        .description =          xxx_hcd_name,
        .product_desc =         "xxx OTG Controller",
        .hcd_priv_size =        sizeof(xxx_hcd_t),
        .irq =                  xxx_hcd_irq,
        .flags =                HCD_MEMORY | HCD_USB2,
        .start =                xxx_hcd_start,
        .stop =                 xxx_hcd_stop,
        .urb_enqueue =          xxx_hcd_urb_enqueue,
        .urb_dequeue =          xxx_hcd_urb_dequeue,
        .endpoint_disable =     xxx_hcd_endpoint_disable,
        .get_frame_number =     xxx_hcd_get_frame_number,
        .hub_status_data =      xxx_hcd_hub_status_data,
        .hub_control =          xxx_hcd_hub_control,
};
```

MS1

API：

```
struct usb_hcd *usb_create_hcd (const struct hc_driver *driver, struct device *dev, char *bus_name);
```

MS1 Starts processing a USB transfer request specified by a USB Request Block (URB). mem_flags indicates the type of memory allocation to use while processing this URB.

MC SYSTEM, 2008-12-12

华清远见

USB设备驱动体系结构

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USB设备驱动数据结构和API

➢struct usb_driver

```
static struct usb_driver skel_driver =
{
                .name =         "skeleton",
                .probe =        skel_probe,
                .disconnect =   skel_disconnect,
                .id_table =     skel_table,
};
```

➢struct usb_device_id

```
static struct usb_device_id skel_table [] = {
   { USB_DEVICE(USB_SKEL_VENDOR_ID,
    USB_SKEL_PRODUCT_ID) },
   { }
};
MODULE_DEVICE_TABLE (usb, skel_table);
```

➢USB字符设备

```
int usb_register_dev(struct usb_interface *intf,
                                    struct usb_class_driver *class_driver);
void usb_deregister_dev(struct usb_interface *intf,
                                    struct usb_class_driver *class_driver);
struct usb_class_driver
{
 char *name;  /*sysfs中用来描述设备名*/
 struct file_operations *fops;/*文件操作结构体指针*/
 int minor_base; /*开始次设备号*/
};
```

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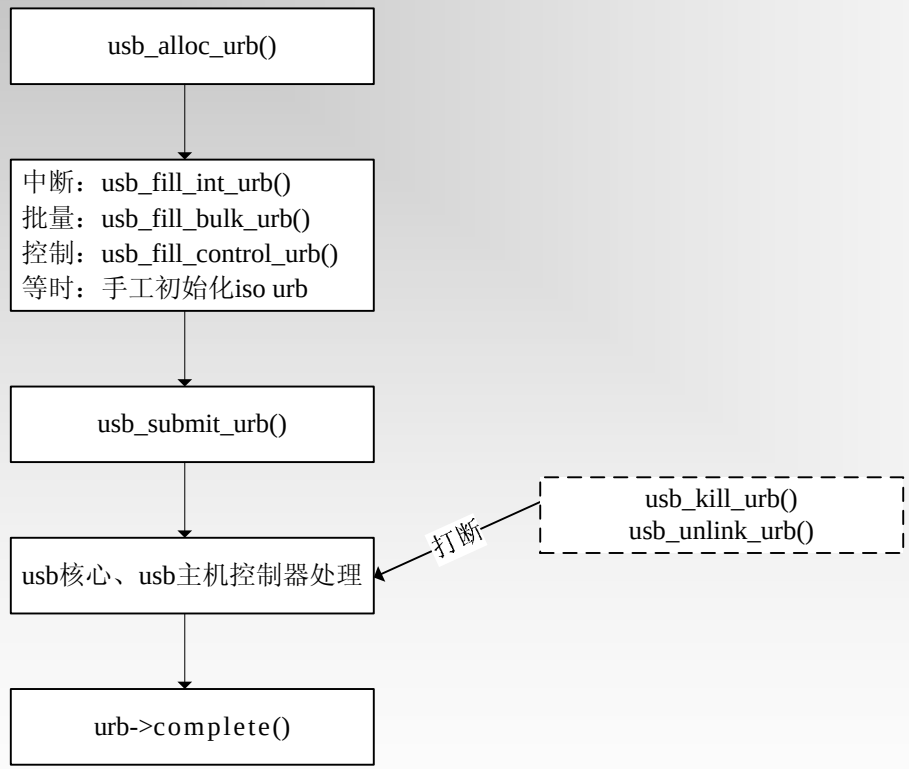
USB设备驱动--URB

- USB请求块（USB request block，urb）



USB设备驱动实例分析

- USB骨架程序
- USB串口驱动

```
1  static int __init usb_serial_init(void)
2  {
...
6    /* 分配tty_driver */
7    usb_serial_tty_driver = alloc_tty_driver(SERIAL_TTY_MINORS);
...
39   /* 注册tty_driver */
40   result = tty_register_driver(usb_serial_tty_driver);
...
47   /* 注册USB驱动 */
48   result = usb_register(&usb_serial_driver);
49   if (result < 0)
50   {
51     err("%s - usb_register failed", __FUNCTION__);
52     goto exit_tty;
53   }
...
72 }
```

- USB键盘驱动

USB设备控制器驱动

数据结构

struct usb_ep_ops

```
static struct usb_ep_ops xxx_ep_ops = {
        .enable         = xxx_ep_enable,
        .disable        = xxx_ep_disable,
        .alloc_request  = xxx_alloc_request,
        .free_request   = xxx_free_request,
        .alloc_buffer   = xxx_alloc_buffer,
        .free_buffer    = xxx_free_buffer,
        .queue          = xxx_ep_queue,
        .dequeue        = xxx_ep_dequeue,
        .set_halt       = xxx_ep_set_halt,
};
```

struct usb_gadget_ops

```
static const struct usb_gadget_ops xxx_udc_ops =
{
        .get_frame          = xxx_udc_get_frame,
        .wakeup             = xxx_udc_wakeup,
};
```

struct usb_gadget

```
struct usb_gadget {
        const struct usb_gadget_ops *ops; //设备的操作集
        struct usb_ep   *ep0; //ep0, 处理setup()请求
        struct list_head  ep_list; //设备支持的ep的list
        enum usb_device_speed  speed; //当前连接到host的速度
        unsigned   is_dualspeed:1; //支持full/high speed
        unsigned   is_otg:1; //用到mini-AB接口，所以gadget driver必须提供USB OTG descriptor
        ...
};
```

struct xxx_udc

```
struct xxx_udc
{
        struct usb_gadget gadget;
        struct usb_gadget_driver *driver;
        ...
};
```

USB Gadget驱动--组成(1)

- struct usb_gadget_driver

```
static struct usb_gadget_driver zero_driver = {
#ifdef CONFIG_USB_GADGET_DUALSPEED
        .speed          = USB_SPEED_HIGH,
#else
        .speed          = USB_SPEED_FULL,
#endif
        .function       = (char *) longname,
        .bind           = zero_bind,
        .unbind         = __exit_p(zero_unbind),

        .setup          = zero_setup,
        .disconnect     = zero_disconnect,

        .suspend        = zero_suspend,
        .resume         = zero_resume,

        .driver         = {
                .name           = (char *) shortname,
                .owner          = THIS_MODULE,
        },
};
```

USB Gadget驱动--组成(2)

- 设备、配置、接口、端点描述符

```
static struct usb_device_descriptor
device_desc = {
        ...
};

static struct usb_config_descriptor
source_sink_config = {
        ...
};

static struct usb_config_descriptor
source_sink_config = {
        ...
};
static struct usb_endpoint_descriptor
fs_source_desc = {
        ...
};
static struct usb_endpoint_descriptor
fs_sink_desc = {
        ...,
};
....
```

```
static const struct usb_descriptor_header *fs_source_sink_function [] = {
        (struct usb_descriptor_header *) &otg_descriptor,
        (struct usb_descriptor_header *) &source_sink_intf,
        (struct usb_descriptor_header *) &fs_sink_desc,
        (struct usb_descriptor_header *) &fs_source_desc,
        NULL,
};

int usb_gadget_config_buf(
        const struct usb_config_descriptor      *config,
        void                                    *buf,
        unsigned                                length,
        const struct usb_descriptor_header      **desc
                )
{
                ...
        /* then interface/endpoint/class/vendor/... */
        len = usb_descriptor_fillbuf(USB_DT_CONFIG_SIZE + (u8*)buf,
                length - USB_DT_CONFIG_SIZE, desc);
                ...
}
```

USB Gadget驱动--组成(3)

- setup

```
static int
zero_setup (struct usb_gadget *gadget, const struct usb_ctrlrequest *ctrl)
{
        struct zero_dev         *dev = get_gadget_data (gadget);
        struct usb_request      *req = dev->req;
...
        switch (ctrl->bRequest) {
        case USB_REQ_GET_DESCRIPTOR:
...
        case USB_REQ_SET_CONFIGURATION:
...
        case USB_REQ_GET_CONFIGURATION:
...
        case USB_REQ_SET_INTERFACE:
...
        case USB_REQ_GET_INTERFACE:
...
        /* respond with data transfer before status phase? */
        if (value >= 0) {
                req->length = value;
                req->zero = value < w_length;
                value = usb_ep_queue (gadget->ep0, req, GFP_ATOMIC);
                if (value < 0) {
                        DBG (dev, "ep_queue --> %d\n", value);
                        req->status = 0;
                        zero_setup_complete (gadget->ep0, req);
                }
        }
        /* device either stalls (value < 0) or reports success */
        return value;
}
```

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USB Gadget驱动--usb request

- struct usb_request MS6

```
struct usb_request {
        void                *buf;
        unsigned            length;
        dma_addr_t          dma;
        unsigned            no_interrupt:1;
        unsigned            zero:1;
        unsigned            short_not_ok:1;
        void                (*complete)(struct usb_ep *ep,
                                struct usb_request *req);
        void                *context;
        struct list_head    list;
        int                 status;
        unsigned            actual;
};
```

- API

```
static inline struct usb_request * usb_ep_alloc_request (struct usb_ep *ep, gfp_t gfp_flags); MS5
static inline void usb_ep_free_request (struct usb_ep *ep, struct usb_request *req);  MS4
static inline int usb_ep_queue (struct usb_ep *ep, struct usb_request *req, gfp_t gfp_flags); MS3
static inline int usb_ep_dequeue (struct usb_ep *ep, struct usb_request *req); MS2
```

MS2

```
338/**
339 * usb_ep_dequeue - dequeues (cancels, unlinks) an I/O request from an endpoint
340 * @ep:the endpoint associated with the request
341 * @req:the request being canceled
342 *
343 * if the request is still active on the endpoint, it is dequeued and its
344 * completion routine is called (with status -ECONNRESET); else a negative
345 * error code is returned.
346 *
347 * note that some hardware can't clear out write fifos (to unlink the request
348 * at the head of the queue) except as part of disconnecting from usb.  such
349 * restrictions prevent drivers from supporting configuration changes,
350 * even to configuration zero (a "chapter 9" requirement).
351 */
```

MC SYSTEM, 2008-12-13

MS3

```
278/**
279 * usb_ep_queue - queues (submits) an I/O request to an endpoint.
280 * @ep:the endpoint associated with the request
281 * @req:the request being submitted
282 * @gfp_flags: GFP_* flags to use in case the lower level driver couldn't
283 *      pre-allocate all necessary memory with the request.
284 *
285 * This tells the device controller to perform the specified request through
286 * that endpoint (reading or writing a buffer).  When the request completes,
287 * including being canceled by usb_ep_dequeue(), the request's completion
288 * routine is called to return the request to the driver.  Any endpoint
289 * (except control endpoints like ep0) may have more than one transfer
290 * request queued; they complete in FIFO order.  Once a gadget driver
291 * submits a request, that request may not be examined or modified until it
292 * is given back to that driver through the completion callback.
293 *
294 * Each request is turned into one or more packets.  The controller driver
295 * never merges adjacent requests into the same packet.  OUT transfers
296 * will sometimes use data that's already buffered in the hardware.
297 * Drivers can rely on the fact that the first byte of the request's buffer
298 * always corresponds to the first byte of some USB packet, for both
299 * IN and OUT transfers.
300 *
301 * Bulk endpoints can queue any amount of data; the transfer is packetized
302 * automatically.  The last packet will be short if the request doesn't fill it
303 * out completely.  Zero length packets (ZLPs) should be avoided in portable
304 * protocols since not all usb hardware can successfully handle zero length
305 * packets.  (ZLPs may be explicitly written, and may be implicitly written if
306 * the request 'zero' flag is set.)  Bulk endpoints may also be used
307 * for interrupt transfers; but the reverse is not true, and some endpoints
308 * won't support every interrupt transfer.  (Such as 768 byte packets.)
309 *
```

```
310 * Interrupt-only endpoints are less functional than bulk endpoints, for
311 * example by not supporting queueing or not handling buffers that are
312 * larger than the endpoint's maxpacket size.  They may also treat data
313 * toggle differently.
314 *
315 * Control endpoints ... after getting a setup() callback, the driver queues
316 * one response (even if it would be zero length).  That enables the
317 * status ack, after transfering data as specified in the response.  Setup
318 * functions may return negative error codes to generate protocol stalls.
319 * (Note that some USB device controllers disallow protocol stall responses
320 * in some cases.)  When control responses are deferred (the response is
321 * written after the setup callback returns), then usb_ep_set_halt() may be
322 * used on ep0 to trigger protocol stalls.
323 *
324 * For periodic endpoints, like interrupt or isochronous ones, the usb host
325 * arranges to poll once per interval, and the gadget driver usually will
326 * have queued some data to transfer at that time.
327 *
328 * Returns zero, or a negative error code.  Endpoints that are not enabled
329 * report errors; errors will also be
330 * reported when the usb peripheral is disconnected.
331 */
```

MC SYSTEM, 2008-12-13

MS4

```
222/**
223 * usb_ep_free_request - frees a request object
224 * @ep:the endpoint associated with the request
225 * @req:the request being freed
226 *
227 * Reverses the effect of usb_ep_alloc_request().
228 * Caller guarantees the request is not queued, and that it will
229 * no longer be requeued (or otherwise used).
230 */
```

MC SYSTEM, 2008-12-13

MS5

```
202/**
203 * usb_ep_alloc_request - allocate a request object to use with this endpoint
204 * @ep:the endpoint to be used with with the request
205 * @gfp_flags:GFP_* flags to use
206 *
207 * Request objects must be allocated with this call, since they normally
208 * need controller-specific setup and may even need endpoint-specific
209 * resources such as allocation of DMA descriptors.
210 * Requests may be submitted with usb_ep_queue(), and receive a single
211 * completion callback.  Free requests with usb_ep_free_request(), when
212 * they are no longer needed.
213 *
214 * Returns the request, or null if one could not be allocated.
```

```
 215 */
```
MC SYSTEM, 2008-12-13

MS6
```
 22/**
 23 * struct usb_request - describes one i/o request
 24 * @buf: Buffer used for data.  Always provide this; some controllers
 25 *      only use PIO, or don't use DMA for some endpoints.
 26 * @dma: DMA address corresponding to 'buf'.  If you don't set this
 27 *      field, and the usb controller needs one, it is responsible
 28 *      for mapping and unmapping the buffer.
 29 * @length: Length of that data
 30 * @no_interrupt: If true, hints that no completion irq is needed.
 31 *      Helpful sometimes with deep request queues that are handled
 32 *      directly by DMA controllers.
 33 * @zero: If true, when writing data, makes the last packet be "short"
 34 *     by adding a zero length packet as needed;
 35 * @short_not_ok: When reading data, makes short packets be
 36 *     treated as errors (queue stops advancing till cleanup).
 37 * @complete: Function called when request completes, so this request and
 38 *      its buffer may be re-used.
 39 *      Reads terminate with a short packet, or when the buffer fills,
 40 *      whichever comes first.  When writes terminate, some data bytes
 41 *      will usually still be in flight (often in a hardware fifo).
 42 *      Errors (for reads or writes) stop the queue from advancing
 43 *      until the completion function returns, so that any transfers
 44 *      invalidated by the error may first be dequeued.
 45 * @context: For use by the completion callback
 46 * @list: For use by the gadget driver.
 47 * @status: Reports completion code, zero or a negative errno.
 48 *      Normally, faults block the transfer queue from advancing until
 49 *      the completion callback returns.
 50 *      Code "-ESHUTDOWN" indicates completion caused by device disconnect,
 51 *      or when the driver disabled the endpoint.
 52 * @actual: Reports bytes transferred to/from the buffer.  For reads (OUT
 53 *      transfers) this may be less than the requested length.  If the
 54 *      short_not_ok flag is set, short reads are treated as errors
 55 *      even when status otherwise indicates successful completion.
 56 *      Note that for writes (IN transfers) some data bytes may still
 57 *      reside in a device-side FIFO when the request is reported as
 58 *      complete.
 59 *
 60 * These are allocated/freed through the endpoint they're used with.  The
 61 * hardware's driver can add extra per-request data to the memory it returns,
 62 * which often avoids separate memory allocations (potential failures),
 63 * later when the request is queued.
 64 *
 65 * Request flags affect request handling, such as whether a zero length
 66 * packet is written (the "zero" flag), whether a short read should be
```

```
 67 * treated as an error (blocking request queue advance, the "short_not_ok"
 68 * flag), or hinting that an interrupt is not required (the "no_interrupt"
 69 * flag, for use with deep request queues).
 70 *
 71 * Bulk endpoints can use any size buffers, and can also be used for interrupt
 72 * transfers. interrupt-only endpoints can be much less functional.
 73 */
 74        // NOTE this is analagous to 'struct urb' on the host side,
 75        // except that it's thinner and promotes more pre-allocation.
```

USB Gadget驱动实例

- zero gadget
- 串口gadget

```
/*  注册USB gadget驱动和驱动.
570*/
571static int __init gs_module_init(void)
572{
573       int i;
574       int retval;
575
576       retval = usb_gadget_register_driver(&gs_gadget_driver);
          ...
600       retval = tty_register_driver(gs_tty_driver);
          ...
609       return 0;
610}
```

- file storage

USB OTG协议

OTG补充规范对USB的扩展

更具节能性的电源管理;允许设备以主机和外设两种形式工作

SRP协议

1. 为了节约电源延长电池的使用寿命,当总线上没有活动时,OTG主机将挂起总线电源VBUS。
2. B-device将先后执行数据线脉冲调制(data-line pul-sing)和VBUS脉冲调制(VBUS pulsing) 。
3. A-device检测到数据线脉冲调制或者VBUS脉冲调制后, 使能VBUS准备开始一个传输事务。

HNP协议

1. A-device在完成对B-device的使用后，可以通过查询B-device的 OTG性能描述符来判断是否支持HNP协议。如支持HNP，B-device将返回有效的OTG性能描述符，A-device 则产生一个set_feature命令（即HNP_Enable）来通知B-device可以在总线挂起的时候以主机方式工作，随后A-device挂起总线。
2. B-device通过上拉电阻（全速时）或者下拉电阻（高速时）拉低D+以示连接断开。随后，作为对B-device断开的响应，A- device使能它的数据线并开始以从机方式工作。完成这些转换后，B-device和A-device便各自以主机角色和外设角色使用总线。
3. 当B-device正常结束传输事务时便挂起VBUS使能其上拉电阻，重新以从机方式运行。A-device检测到总线挂起后，发出一个连接断开信号并重新以主机方式工作。

USB OTG驱动(1)

设备控制器新接口

```
struct usb_gadget {
        ...
    unsigned        is_otg:1;
    unsigned        is_a_peripheral:1;
    unsigned        b_hnp_enable:1;
    unsigned        a_hnp_support:1;
    unsigned        a_alt_hnp_support:1;
        ...
};

/* used by external USB transceiver */
int usb_gadget_vbus_connect(struct usb_gadget *gadget);
int usb_gadget_vbus_disconnect(struct usb_gadget *gadget);

/* call this during SET_CONFIGURATION */
int usb_gadget_vbus_draw(struct usb_gadget *gadget, unsigned mA);

/* these logically control the USB D+ pullup */
int usb_gadget_connect(struct usb_gadget *gadget);
int usb_gadget_disconnect(struct usb_gadget *gadget);

static inline int usb_gadget_wakeup (struct usb_gadget *gadget);
```

USB OTG驱动(2)

- Gadget驱动的修改
  - 当gadget->is_otg 为真时，为每个配置提供一个OTG描述符
  - 在SET_CONFIGURATION中通过“用户接口”（如printk、LED等）报告HNP可用
  - 当suspend开始时，通过“用户接口” 报告HNP角色切换（B设备变为B主机，A设备变为A主机）的开始

USB OTG驱动(3)

- 主机侧：USB core的更新
- *OTG 枚举和目标外设列表*

```
struct usb_bus {
        ...
    u8 otg_port;            /* 0, or index of OTG/HNP port */
    unsigned is_b_host:1;       /* true during some HNP roleswitches */
    unsigned b_hnp_enable:1;    /* OTG: did A-Host enable HNP? */
        ...
};
```

- *CONFIG_USB_SUSPEND*

```
/* selective suspend/resume for HNP */
extern int usb_suspend_device(struct usb_device *dev, u32 state);
extern int usb_resume_device(struct usb_device *dev);
```

- *其他电源管理问题*

USB OTG驱动(4)

OTG收发器

```
struct otg_transceiver {
    struct device       *dev;
    const char          *label;
    u8                  default_a;
    enum usb_otg_state  state;
    struct usb_bus      *host;
    struct usb_gadget   *gadget;
    /* to pass extra port status to the root hub */
    u16                 port_status;
    u16                 port_change;
    /* bind/unbind the host controller */
    int     (*set_host)(struct otg_transceiver *otg,
                struct usb_bus *host);
    /* bind/unbind the peripheral controller */
    int     (*set_peripheral)(struct otg_transceiver *otg,
                struct usb_gadget *gadget);
    /* effective for B devices, ignored for A-peripheral */
    int     (*set_power)(struct otg_transceiver *otg,
                unsigned mA);
    /* for B devices only:  start session with A-Host */
    int     (*start_srp)(struct otg_transceiver *otg);
    /* start or continue HNP role switch */
    int     (*start_hnp)(struct otg_transceiver *otg);
};
```

华清远见Linux驱动课程

- 嵌入式Linux驱动初级班
- 通过本课程的学习，学员可以掌握Linux下字符设备、块设备、网络设备的驱动程序开发，同时掌握嵌入式Linux的系统开发和分析方法。

- 嵌入式Linux驱动开发高级班
- 本课程以案例教学为主，系统地介绍Linux下有关FrameBuffer、MMC卡、USB设备的驱动程序开发。

- 嵌入式Linux驱动开发教材

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