
Design of a USB Device Driver
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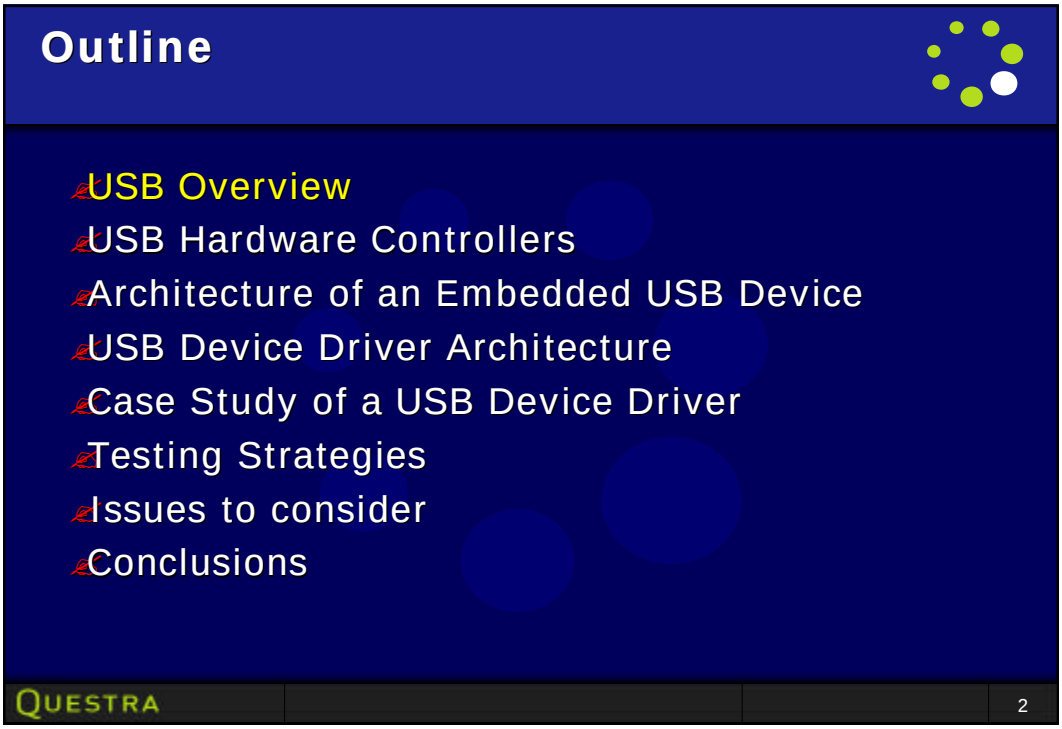
Outline
USB Overview
USB Hardware Controllers
Architecture of an Embedded USB Device
USB Device Driver Architecture
Case Study of a USB Device Driver
Testing Strategies
Issues to consider
Conclusions
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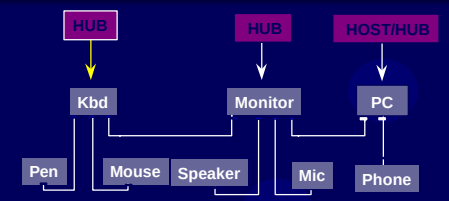
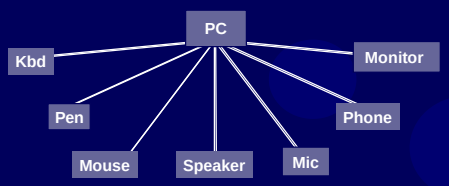
USB Overview

- Hardware Overview
  - –Topology
- Protocol Characteristics
  - –Packet Types
  - –USB Transactions
- Enumeration
  - –Enumeration States
- Examples of USB devices

Hardware Overview



Physical Hardware View



Logical Hardware View

- Topology
  - – Tiered Star (Distributes Connectivity Points)
  - – 127 logical connections (up to 5 meters per segment)
  - – Up to 6 tiers
- Bus transactions
  - – Speed: 12Mbps aggregate
    - 1.5Mbps sub-channel
  - – Isochronous and Asynchronous
  - – Media access controlled by host
- Configuration
  - – Dynamic insertion-removal
  - – Autoconfiguration on change
- Physical Layer
  - – 2-wire differential signaling, NRZI coded with bit stuffing
  - – 4 pin connector, 4 wire cable
  - – Supply Sourcing +5V

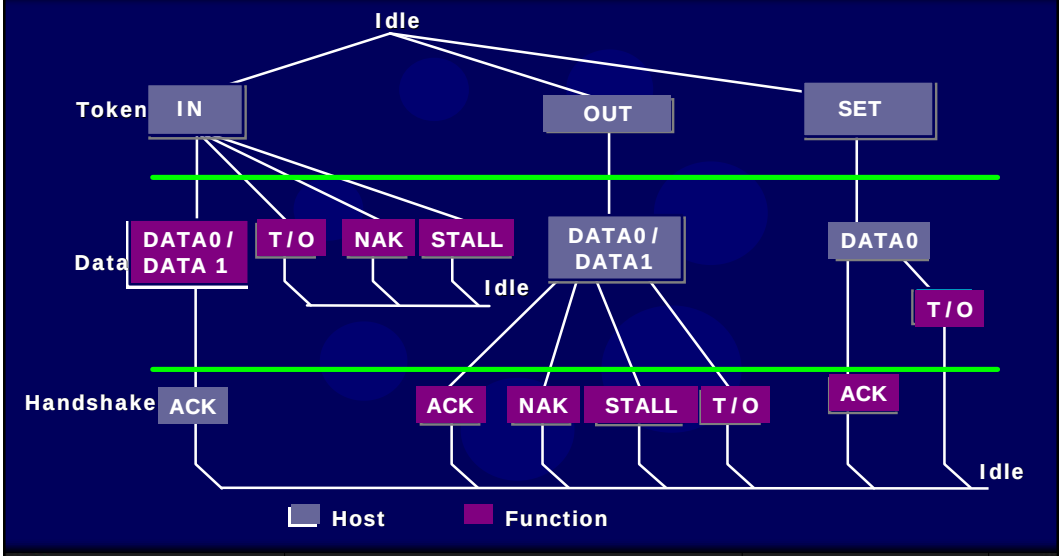
The Transaction Protocol is Host Based

- Host based token polling
  - Data from host-to-function and function-to-host
  - Host handles most of the protocol complexity
  - Peripheral design is simple and low-cost
- Robustness
  - Handshake to acknowledge data transfer and flow control
  - Very low raw physical bit error rate ($<10^{-10}$)
  - CRC protection plus hardware retry option
  - Data Toggle Sequence bits
- Bounded transfer characteristics
  - Data transfer bandwidth and latency prenegotiated
  - Flow control for peripheral buffer management

Packet Types

- Token - OUT, IN, SOF, SETUP
  - First packet in any transaction
  - Specifies function address, endpoint
  - Specifies data direction
- Data - DATA0, DATA1
  - 0 - 1023 bytes
- Handshake - ACK, NAK, STALL
  - Report status of data transaction
  - Flow control
  - Stall conditions
- Special - PRE
  - Enables Hub for low speed communications

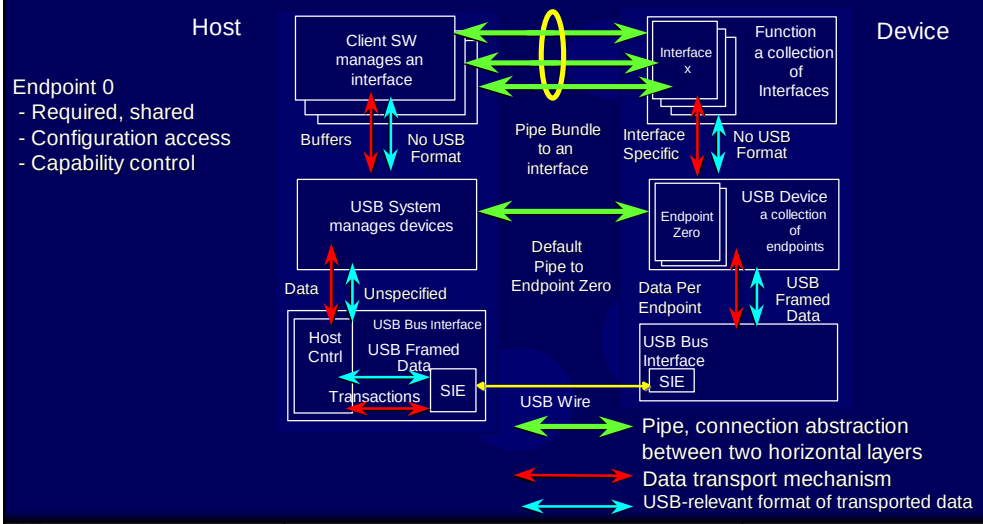
A Typical USB Transaction Consists of Three Packets



There are Four Types of USB Transactions

- Isochronous (Audio, telephony …)
  - –Periodic, Bounded latencies, guaranteed bandwidth
- Interrupt (Mouse, joystick …)
  - –Asynchronous, bursty, non-periodic, low bandwidth
- Bulk (Printer, scanner, digital camera …)
  - –Non-periodic, bursty, high bandwidth utilization
- Control (Configuration messages …)
  - –Bursty, host-initiated (bus management, configuration)

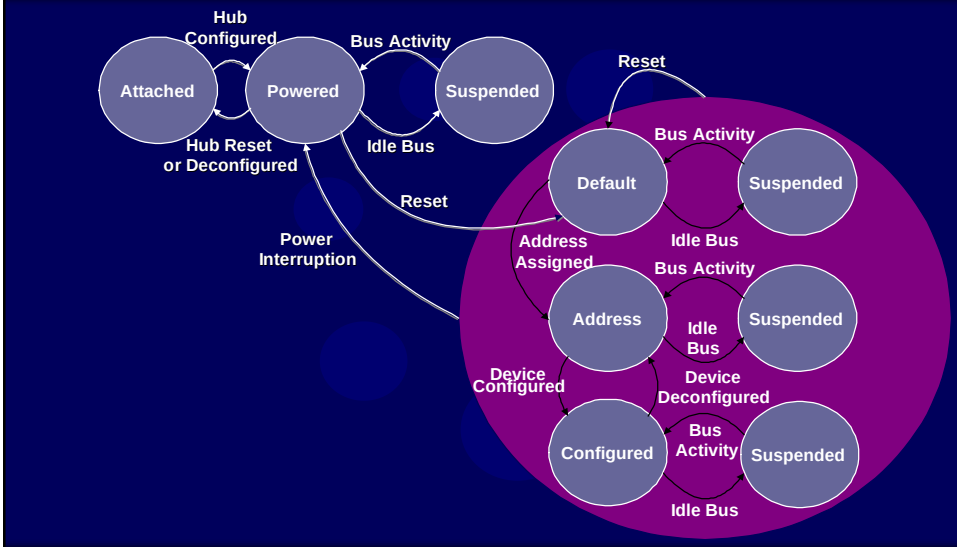
The Basic USB Model has Several Layers of Abstraction



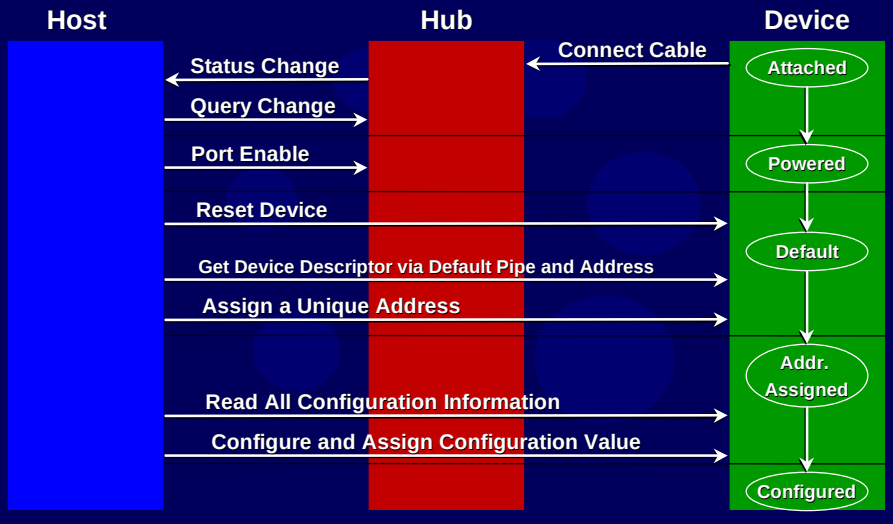
Enumeration: Device perspective

- Attached State
  - –Entered by attaching USB Cable
- Powered State
  - –USB Host Applies power
- Default state
  - –USB Host resets bus
- Addressed State
  - –USB Host sends Set Address with non-zero address
- Configured state
  - –USB Host sends Set Configuration with non-zero value
- Suspended state
  - –USB Host stops sending SOF for 3 msec

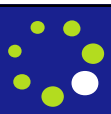
The Device State Machine



Enumeration is the Process of Assigning Addresses and Setting Configurations



Outline



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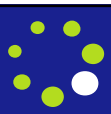
Types of USB Controllers

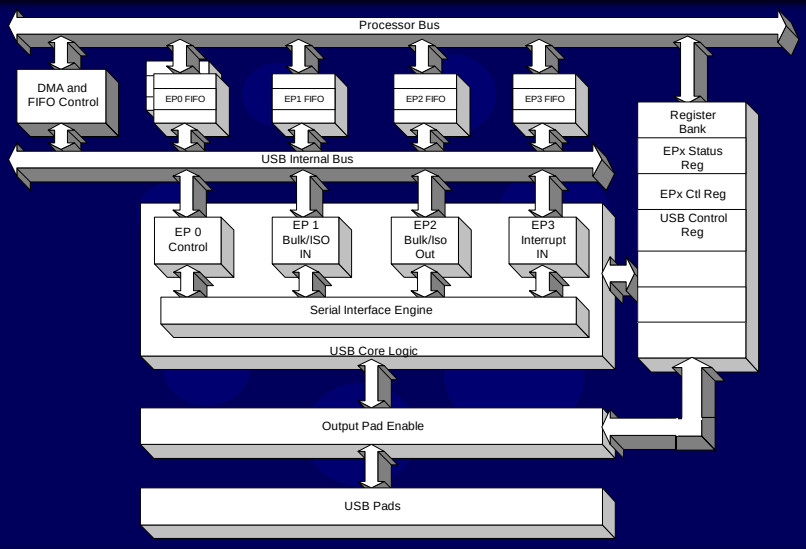


- Discrete Components
  - –NetChip, Intel, National Semiconductor, Phillips
- USB IP Cores as part of an ASIC
  - –Sand, Motorola, Texas Instruments, .etc
- Combination USB Host and USB Peripheral chip
  - –ScanLogic
- Combination micro-processor and USB Core
  - –8/16 bit processor Mitsubishi, .etc
- Single Chip Solutions
  - –Netchip NET1031 Single chip scanner controller.

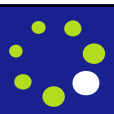
USB Controller Hardware Architecture

- USB Core
- Registers for Control and Endpoint Data Transfer
- FIFO Controller
  - Input and Output FIFOs for Control Endpoint
  - Input or Output FIFO for other Endpoints
- DMA Controller
- Internal Bus
- Serial Interface Engine
- Output Pads

Example of USB Controller

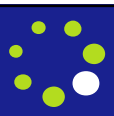


Key Features of a USB Controller



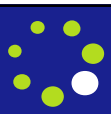
- Implements most USB Requests in hardware
  - Standard Requests
    - GET_DESCRIPTOR and SET_DESCRIPTOR may be implemented in software for versatility
  - Class/Vendor Requests as appropriate
- USB Event Interrupts and status
  - Setup, Suspend, Resume, SOF, Reset, Zero Byte Packet
  - DMA Complete
  - Transmit/Receive Ack/Nack/Error status
  - FIFO empty/full or at high/low threshold level
- FIFOs supporting
  - multiple packet depth
  - Hardware Retry of Packet Transfers on error

Key Features of a USB Controller II



- Hardware should provide ability to
  - initiate a Remote Wakeup
  - detect a USB Reset
  - reset USB Controller
  - Select endpoint as DMA destination
  - Detect enumeration
  - Read Current Configuration and Interface
  - Stall endpoints

Outline



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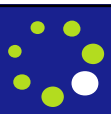
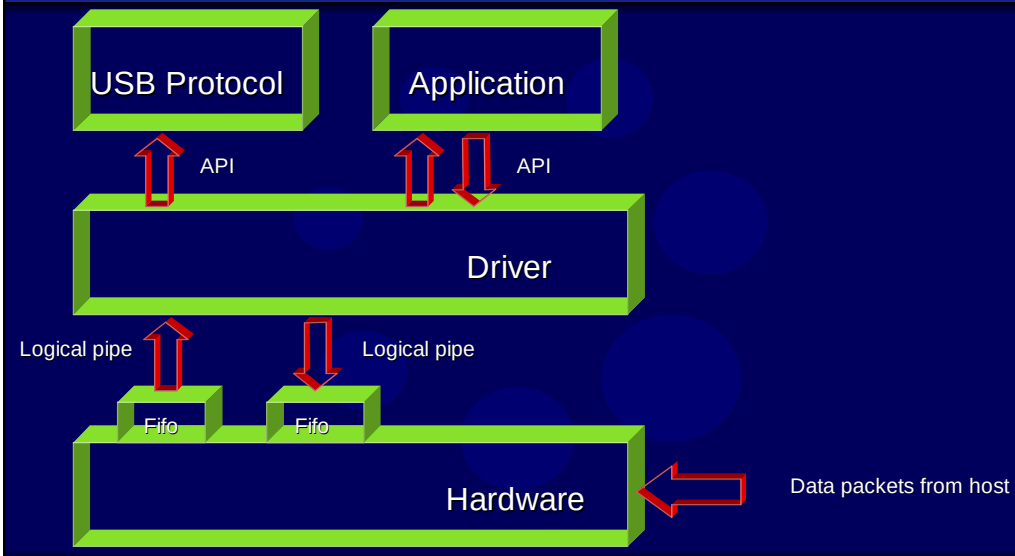
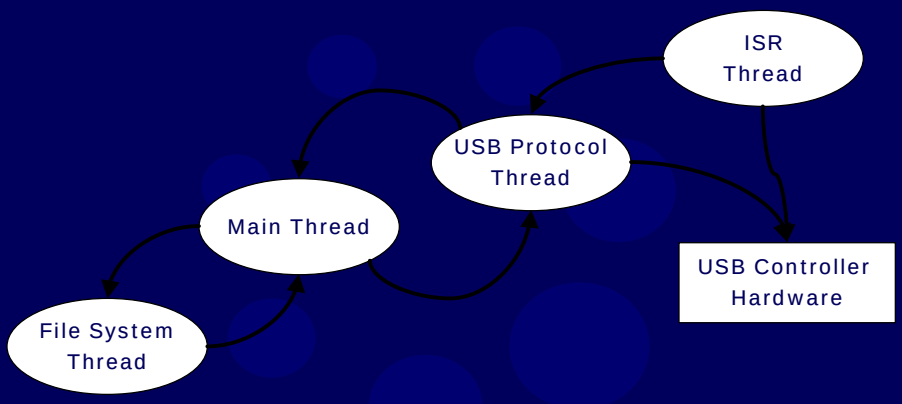
Architecture of an Embedded USB Device





System Architecture



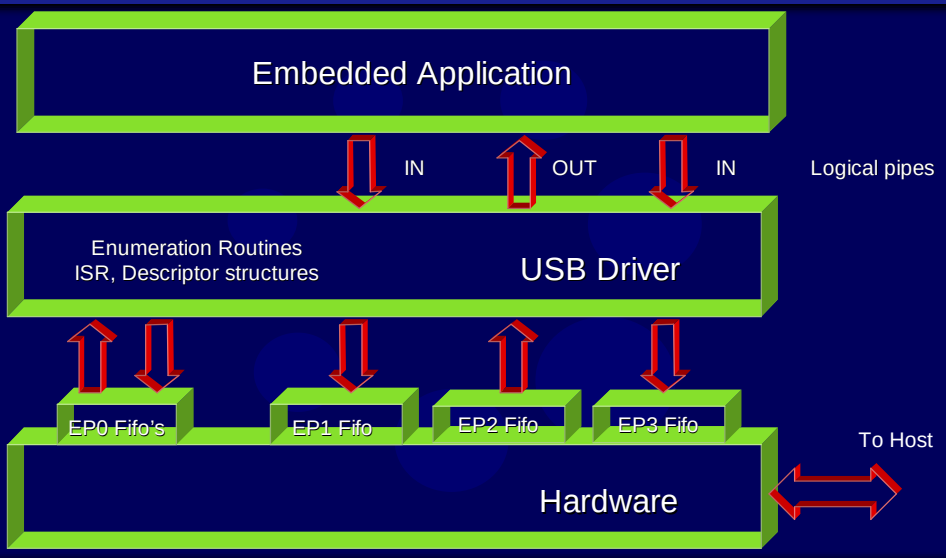
USB Peripheral Threads

- ISR Thread
  - –Low Level Interrupt Service routine(s)
    - •USB Controller Interrupt
    - •DMA Controller Interrupt
- USB Protocol Thread
  - –Task which implements USB Protocol
    - •Control, Bulk, Isochrnous, Interrupt Endpoints
    - •Attach/Dettach, SOF, Suspend/Resume
- Main Thread
  - –Thread which executes the product application
  - –Calls and is triggered by Callback from USB Driver layer
- File System Thread
  - –Lower Priority File System Thread

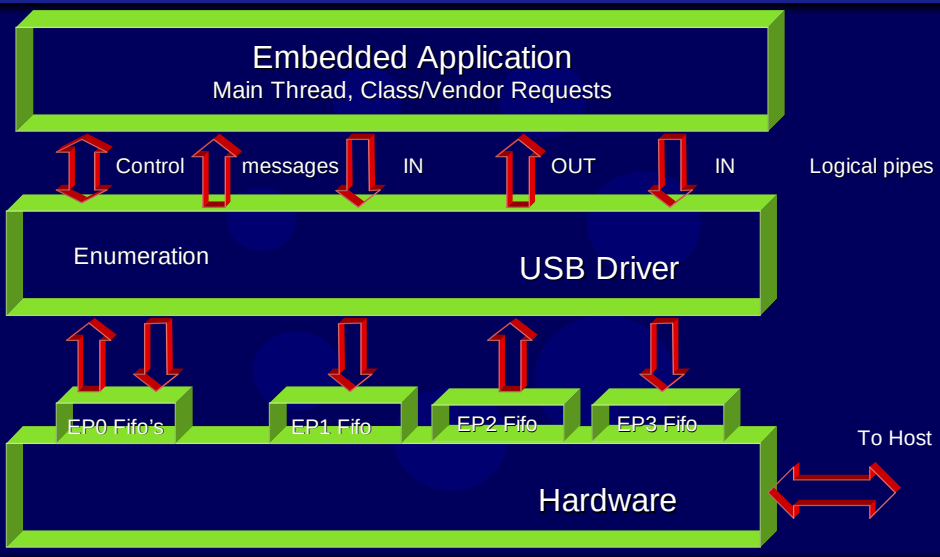
Interrupt Sources

- SOF
- Attach/Dettach
- Suspend/Resume
- Setup Packet
- Data IN Ack
- Data OUT Ack
- FIFO Empty or Low level threshold met
- FIFO Full or High level threshold met
- DMA Complete

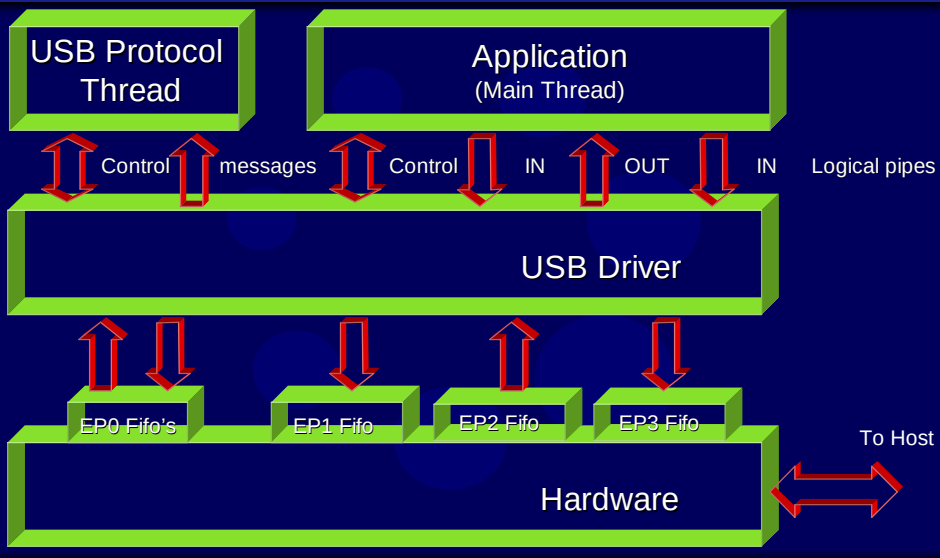
Driver / Hardware Enumeration Architecture



Single Thread Architecture



Multiple Thread Architecture



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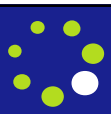

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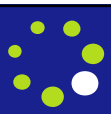
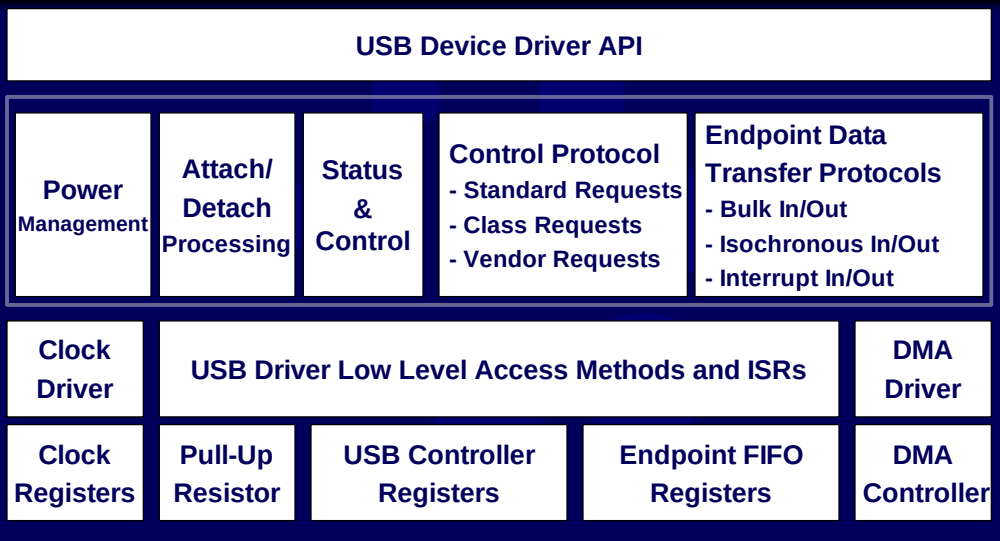
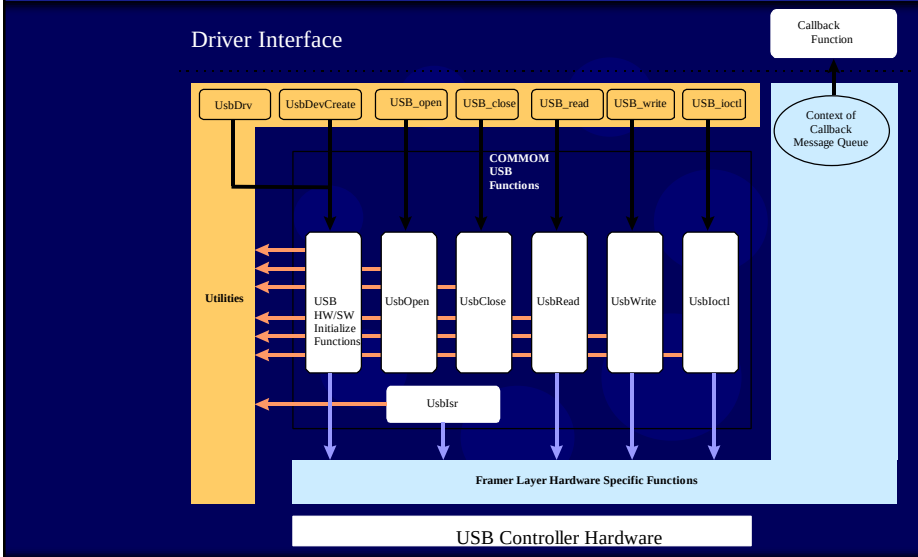
USB Device Driver Components





USB Device Driver Architecture

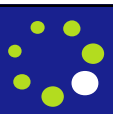


USB Device Driver API

- USBInit()
- USBDelete()
- USBOpen()
- USBClose()
- USBRead()
- USBWrite()
- USBIoctl()

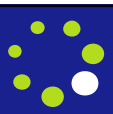
- Callback Message Queue

USBInit() and USBDelete()



- USBInit() - Initialize USB Driver
  - Installs driver in IO system
  - Creates or acquires OS resources
    - Semaphores, queues, ISR vector, task, memory, etc.
  - Initializes USB Controller hardware
  - Enable USB Controller to allow enumeration
- USBDelete() - Delete USB Driver
  - Disable USB Controller Hardware
  - Return OS resources
    - Semaphores, queues, ISR vector, task, memory, etc.
  - Remove driver from IO system

USBOpen() and USBClose()

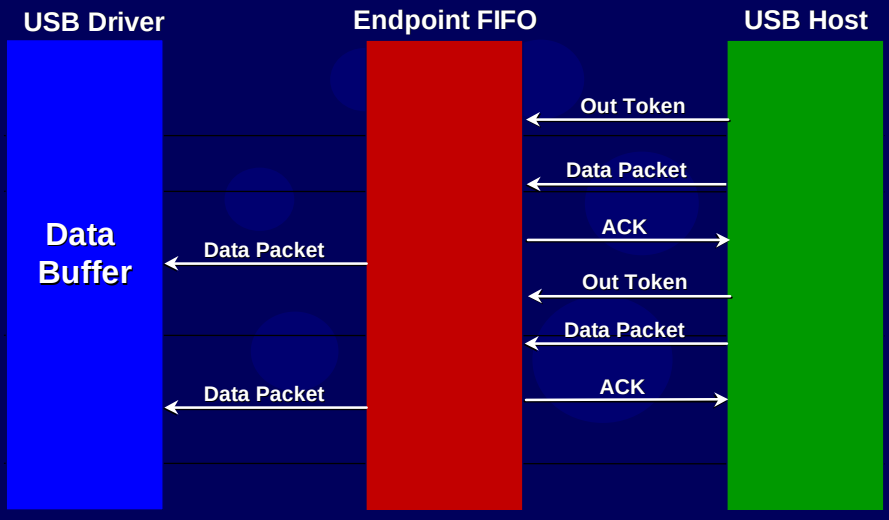


- USBOpen() - Opens an endpoint
  - If not the Control endpoint
    - Verifies device is enumerated
    - Verifies endpoint is part of current configuration/interface
  - Selects CPU or DMA transfer mode
    - If DMA selects endpoint's FIFO for use with DMA
  - Set Endpoint states to OPENED
- USBClose() - Closes an endpoint
  - Disables DMA controller's use of endpoint's FIFO
  - Set endpoint state to CLOSED

USBRead()

- Read from Bulk, Isochronous or Interrupt endpoint
  - –Verify endpoint is open
  - –If transfer mode is DMA
    - •Setup and start DMA read of fixed size from Endpoint FIFO
    - •Block until DMA is complete or a timeout occurs
  - –else
    - •ISR Called
    - •Loop until all data is read, a timeout occurs or a short packet is received
    - •Exit ISR

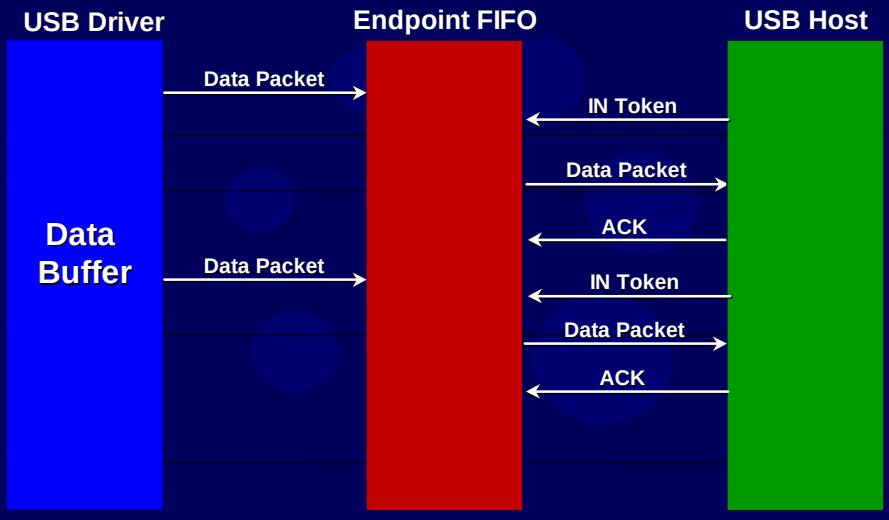
USB Read Process



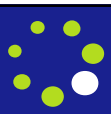
USBWrite()

- Write to Bulk, Isochronous or Interrupt endpoint
  - –Verify endpoint is open
  - –If transfer mode is DMA
    - •Setup and start DMA write of fixed size to Endpoint FIFO
    - •Block until DMA is complete or a timeout occurs
  - –else
    - •ISR Called
    - •Loop until all data is written, or a timeout occurs
    - •Exit ISR

USB Write Process

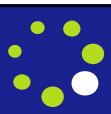


Control Read



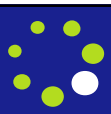
- Call USBRead(EP0) to read a Setup Packet
  - Read from EP0 OUT FIFO
- Identify Setup Packet
  - Standard, Class or Vendor
- Create response to Setup Packet
  - For example prepare to return a Descriptor
- Call USBWrite(EP0) to write the response
  - Perform normal USBWrite() function to EP0 IN FIFO
  - Wait for Host to return a Zero Byte packet terminating Control transfer
- Repeat

Control Write



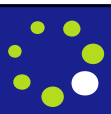
- Call USBRead(EP0) to read a Setup Packet
  - Read from EP0 OUT FIFO
- Identify Setup Packet
  - Standard, Class or Vendor
- Prepare to receive data from Host
- Call USBRead(EP0) to read data from the Host
  - Perform normal USBRead() function from EP0 OUT FIFO
  - Send a Zero Byte packet to the Host terminating the Control transfer
- Repeat

Callback Message Queue



- Message Interface used to send notification to application of asynchronous events
  - –USB Reset
  - –Enumeration
  - –Configuration Change
  - –Interface Change
  - –Suspend/Resume
  - –Attach/Dettach
  - –SOF
  - –Report Setup Packet received by Control Endpoint 0

Outline



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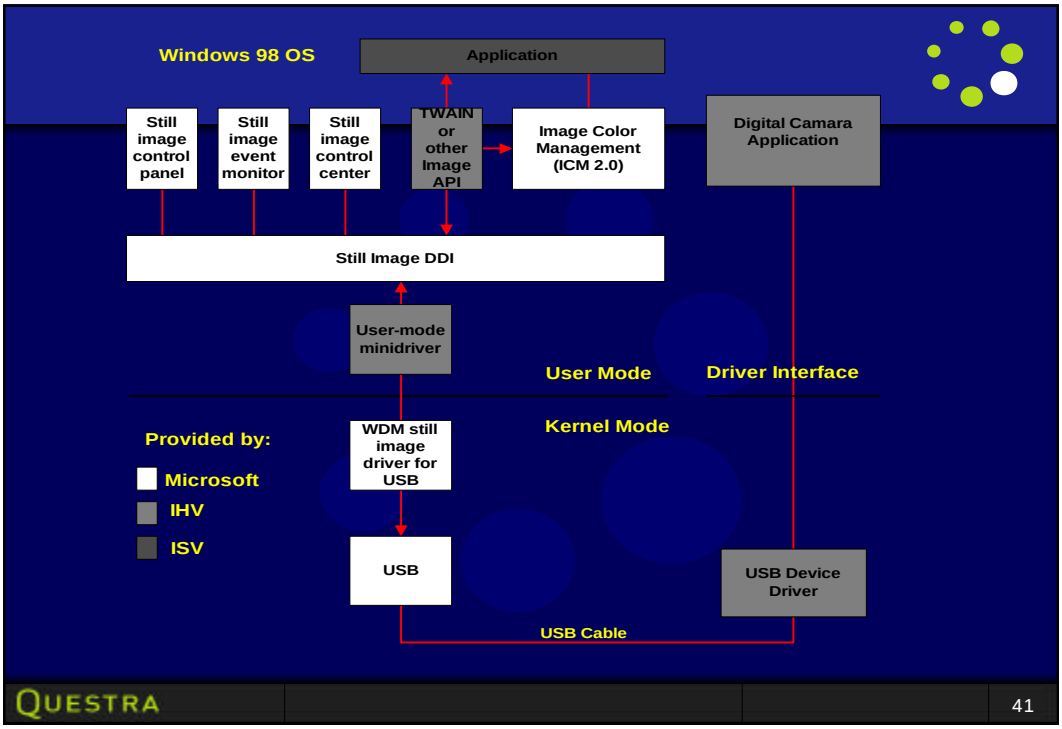
Windows 98 OS
Application
Still image control panel
Still image event monitor
Still image control center
TWAIN or other Image API
Image Color Management (ICM 2.0)
Digital Camara Application
Still Image DDI
User-mode minidriver
User Mode
Driver Interface
Kernel Mode
Provided by:
Microsoft
IHV
ISV
WDM still image driver for USB
USB
USB Device Driver
USB Cable
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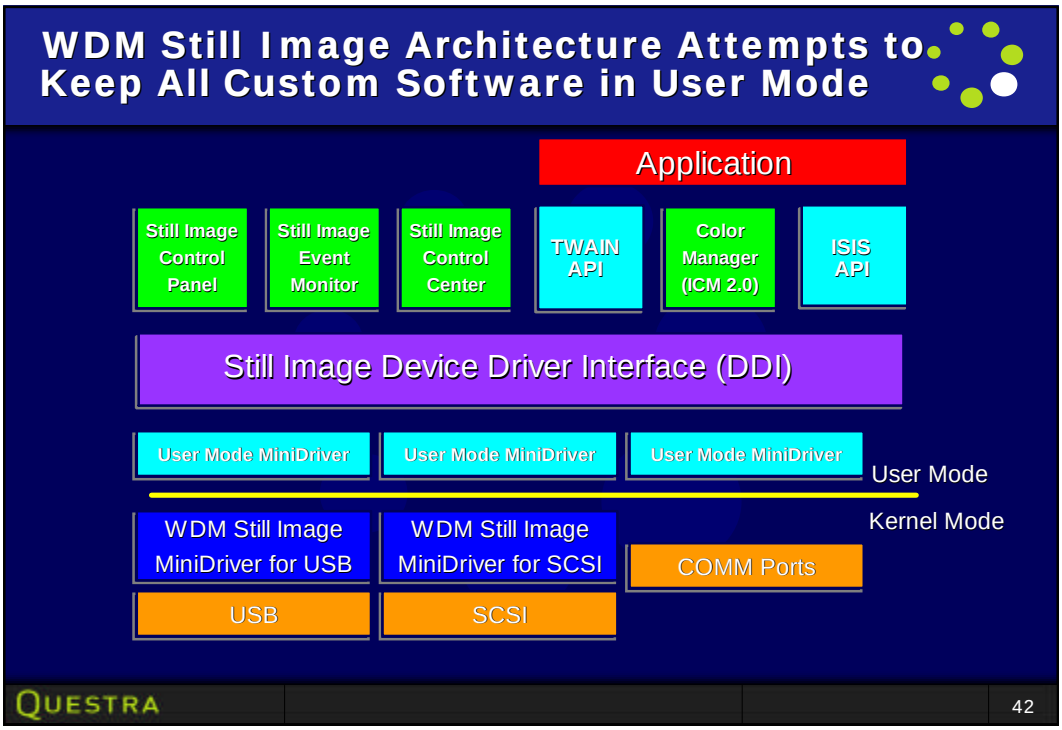
WDM Still Image Architecture Attempts to Keep All Custom Software in User Mode
Application
Still Image Control Panel
Still Image Event Monitor
Still Image Control Center
TWAIN API
Color Manager (ICM 2.0)
ISIS API
Still Image Device Driver Interface (DDI)
User Mode MiniDriver
User Mode MiniDriver
User Mode MiniDriver
User Mode
Kernel Mode
WDM Still Image MiniDriver for USB
WDM Still Image MiniDriver for SCSI
COMM Ports
USB
SCSI
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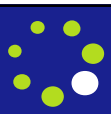
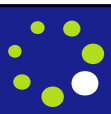
Design Constraints



- Hardware Selection
  - Still image architecture requires Control, Bulk In, Bulk Out and Interrupt endpoints.
- Host application controls camera via control or bulk endpoints.
  - Design of the communications protocol is contingent on the Twain data source and any classes supported.
- Host Application defines
  - Features supported by camera application
  - Power Management requirements

Outline



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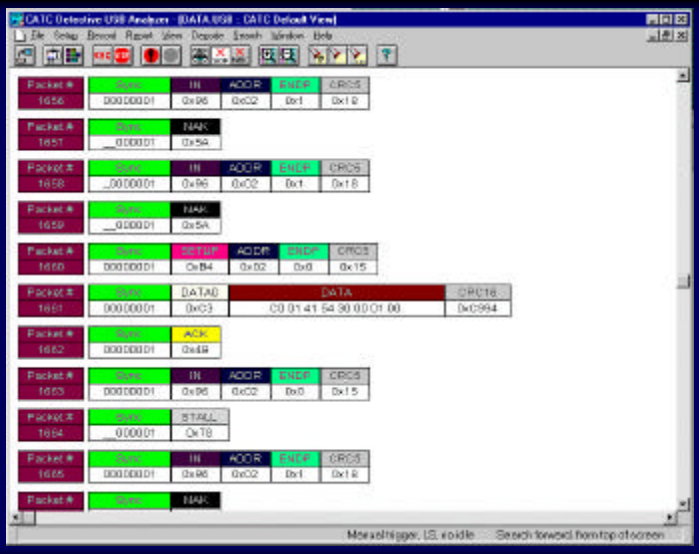
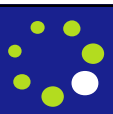
Effective Testing Strategies

- Develop Written Test Plans
  - Define Unit Tests
  - Define System Tests
- Define minimum USB Host Driver Test
  - Capabilities
  - Enumeration, Data Transfer, Loopback, etc.
- Acquire an USB Analyzer
  - Use analyzer for documenting test results
  - Debug Driver enumeration and Data Transfer
  - Verify System level behavior with analyzer
  - Execute Compliance Test in loop mode (>1000x)
- Purchase a USB Evaluation Board & source code
- Utilize USB Organizations Test Resources

Analyzer View



Host Software Testing Strategies



- Schedule availability of Host software
  - –USB mini-driver
  - –Host Test Application
- Request Host Test Application support
  - –Enumeration
  - –Data Transfer
  - –Data Transfer Loopback Testing
  - –Vendor/Class Request Support
- Leverage USB Evaluation sample source
  - –Stimulate USB peripheral using sample code
- System Tests
  - –Perform typical use cases with Product software

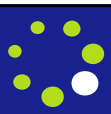
Embedded Software Testing Strategies

- Unit Tests
  - –Driver Install and Uninstall
  - –Enumeration Test
  - –Device Driver API
    - •Open/Close endpoints
    - •Data Transfer (read and write)
    - •Select Endpoint using DMA
    - •IO Control Test
  - –Loopback Testing (>1000x, vary transfer sizes)
  - –Vendor/Class Request Support
- System Tests
  - –Perform typical use cases with Product software
  - –System Level Power Management

USB Organization's Testing Resources

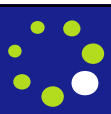
- USB-IF Compliance Program
  - Worksheets
    - Device Framework
    - Signal Quality
    - Power Distribution and Consumption
  - Interoperability Guidelines
  - Test Tools
    - USBCheck, HIDView
  - Compliance Workshops
    - Verifies USB Compliance and Interoperability
    - in-house USB Compliance and Interoperability
      - Verify throughout product development

USB Analyzers



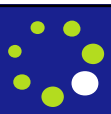
- Benefits of an USB Analyzer Tool
  - Passively monitors USB Bus
  - Allows debug of Enumeration, Vendor/Class Requests
  - Reveals system level behavior
  - Some tools allow for active introduction of faults, standard Requests or Vendor/Class Requests
- Drawbacks
  - Purchase Price
  - Selecting which one you want
  - Some PC's have demonstrated signal/noise errors with USB analyzer's attached

Outline



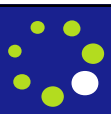
- USB Overview
- USB Hardware Controllers
- Architecture of an Embedded USB Device
- USB Device Driver Architecture
- Case Study of a USB Device Driver
- Testing Strategies
- Issues to consider
- Conclusions

Issues to consider



- More Class Support
  - –HID, Common, Mass Storage, Firmware Upgrade,
- USB 2.0
  - –Do you need it?
  - –NOT supported in Windows XP
- Protocol Stacks
  - –PIMA/ISO-15740
  - –USB Mass Storage Devices
  - –WDM Still Image Architecture

Outline



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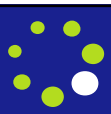
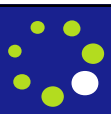
Conclusion

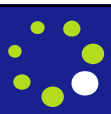


- Selecting a more capable USB controller simplifies the design USB Device Drivers
- Support both CPU and DMA transfers
- Data Transfer Speed is a priority
  - **Transfer Data inside ISR**
  - **Optimize code execution of critical routines**
  - **Design a solution with parallelism of processing and data transfer**
  - **Dedicate the DMA to the highest bus bandwidth scenarios**
- USB Compliance testing occurs throughout development
- Take advantage of
  - **USB Test tools**
  - **USB Analyzers**
  - **Compliance Worksheets**

For More Information



- USB Specification Rev 1.1, 1.0
- http://www.usb.org - the root node
- http://www.intel.com
- www.microsoft.com
  - Search for WDM, WinHEC, ActiveMovie, Still Image, etc.
- USB System Architecture, Don Anderson - Mindshare Inc.
- www.linux.org
- www.catc.com
- Questra Corporation (716) 381-0260 www.questra.com



Design of a USB Device Driver

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