Device Driver Overview

Matt Genovese
Mark McDermott

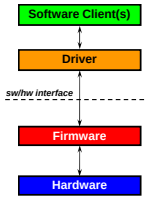
Outline

- Driver basics
  - What are drivers?
  - Where do they fit in embedded system design?
  - What are the general responsibilities of drivers?
  - What are application drivers versus OS drivers?
  - How can the driver's client interface be architected?
  - Discuss some basics of Linux drivers.
- Details of Linux drivers
  - Linux driver fundamentals
  - Char drivers
  - Memory allocation
  - Char driver read and write
  - Blocking
  - Hardware access
  - I/O ports
  - I/O memory

Driver basics

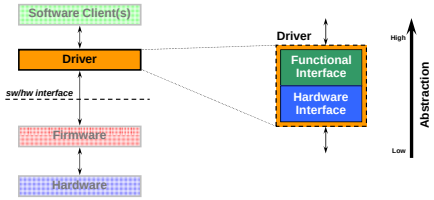
What is a driver?

- **Drivers are software…**
  - Create a clean separation between upper-level client software and the hardware
    - Provide an abstraction layer above direct hardware communication
    - Manage bandwidth across the communication channel to the hardware
  - Restrict the client interface state-space to only what is possible on the hardware
    - Control access to hardware from multiple clients
    - Ensure hardware errors translate into recoverable errors in the above software



- **Drivers are NOT applications.**
  - Applications are executable.
  - Drivers are part of an application (library), or a module that registers itself with the kernel (Linux).

What is a driver?



- **Drivers conceptually have two interfaces**
  - The *Functional Interface* interacts with the software application or OS kernel, receiving commands and returning responses.
  - The *Hardware Interface* interacts with the hardware device to execute commands and receive results and status.

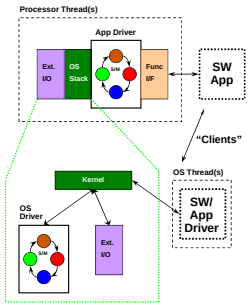
Drivers: Philosophy

- **Mechanism versus policy**
  - Mechanism: Make something at the lower level look like something else at the higher level. Emphasizes *capabilities*.
  - Policy: Who can access it, what can be done with it, etc. Emphasizes *usage*.

- **In general, drivers should implement the mechanism, and leave the policy to the OS or application.**
  - Drivers should implement the function-space of what is permissible and possible at the low-level.
  - A driver that implements a policy also implements an inherent restriction on all possible applications above it.
  - Very few instances when a driver should implement a policy.
    - When driver can affect global resources, multiple users, system stability, policy checks are present in the driver.

Drivers: Application versus OS

- **Application drivers cleanly separate and abstract device communication.**
  - Function at a higher level than OS drivers to further abstract communication based on an application's needs.
- **OS drivers enable safe and unified access to hardware.**
  - Accessed via kernel by software applications (e.g. application driver) to communicate with hardware.



Types of drivers

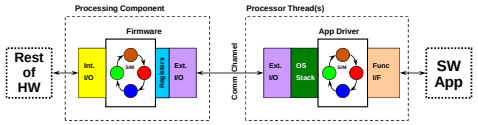
- **Application-level driver libraries**
  - The software application(s) are the direct clients of the driver.
  - Applicable within a specific set of software applications.
  - Represents a software architecture decision.
  - Driver software interface and architecture is largely unrestricted.

- **Operating system (OS) drivers (aka "stack")**
  - The OS is the primary client of the driver, and applications access the driver via the kernel.
  - Applicable within the OS, and any possible application written.
  - Represents an OS stability and maintainability decision.
  - Driver software interface and architecture is quite restricted.

Software communication with the hardware

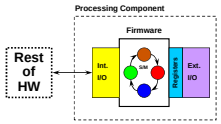
- **Firmware manages basic hardware and time-sensitive tasks, and provides a low-level software interface.**
  - Small embedded memory footprint can limit functionality to providing the basics.
- **Communication to firmware occurs over a communication channel (e.g. USB, RS232, SRIO, SATA, etc.)**

- **Client software communicates with the driver via a high-level software interface.**
- **Application driver vets client requests and manages channel communication with firmware.**
- **The OS stack for the channel protocol is used for primitive communication with the hardware.**



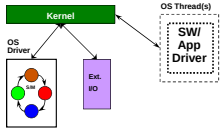
Firmware

- Needs to manage…
  - Reset
  - Debug
  - Basic functional operation
  - Administrative tasks (e.g. upgrade)
- Typically architected as a state machine
  - Incoming commands from driver via the external I/O channel translate into state machine traversals, or message passing.
  - Command status reported back to driver.
  - Based on each device, firmware capabilities may be relatively basic and low-level, or could be more advanced.
  - Error detection and basic error recovery capabilities may exist in firmware, but advanced recovery can be pushed up to the driver.
  - If firmware is not employed on the hardware, then the driver must manage these responsibilities.



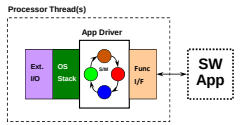
Linux OS drivers

- Needs to manage…
  - Reset, debug, functional operation, administrative tasks in hardware
  - Error recovery
  - OS driver specifications
- Linux drivers are modules that communicate with the hardware in a structured, safe way.
- Provide implementation of base methods for communicating with the hardware.
  - Result: The device can be used by existing and new applications and other drivers seamlessly.
- Drivers may manage access to a communication channel or to a specific device.



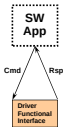
Application drivers

- Needs to manage…
  - Reset, debug, functional operation, administrative tasks in firmware (not already managed by OS driver - device specific).
  - Advanced debug and error recovery (for hardware, and client software)
- Purpose: Provide an advanced feature set relevant to the specific device used by the client application.
  - Functionality provided to application is higher-level than OS driver, combining appropriate low-level OS driver functions.
- For application drivers, many architectures are possible.
  - Dependent upon the needs of the intended client applications.



Client-driver communication: Commands

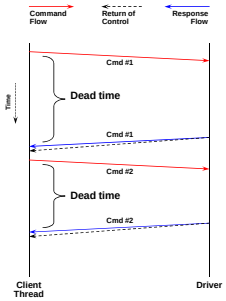
- Definitions:
  - A command holds the desired driver operation and inbound data.
  - A response holds the command status/result and return data.
- How does the client issue commands to the driver?
  - Application driver: Likely C-style global functions to driver library
  - Linux: C-style global functions to kernel
- Application drivers: We have options for client interface:
  - Command call: Client calls functions, each of which represents a command to the driver. Easiest for blocking drivers.
    - Pass in command as function's arguments, and the data + status are returned by that function.
  - Command object: Use a single function for passing command objects. Useful for non-blocking drivers.
    - The command object is filled with the desired operation and data, and given to the driver.
    - After the driver executes the command, the response is encapsulated in or otherwise directly linked to that command object.
    - Advantage: Upgrade driver without changing command interface.
- Linux OS drivers: Kernel registration; client calls system functions:
  - More secure because kernel vets all access to drivers
  - Enables categorization of drivers, and unified client interface to each
  - Ensures privileged access (i.e. policy enforcement)
  - This is the method Linux uses – discussed later.



Client-driver communication: Flow of control

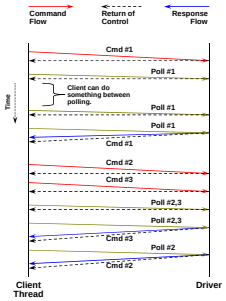
- In general, there are a variety of ways a software client can interface with a driver in terms of program flow control. For example:
  - Blocking interface
    - Call to driver blocks client thread execution until command is completed.
    - Easy to implement, but restrictive by forcing sequential operation.
  - Non-blocking (NB) interface, client polling
    - Call to driver returns immediately, even if command did not complete.
    - Client polls for command completion.
    - Allows for pipelining of commands, if supported by firmware.
    - Can create a blocking interface from a non-blocking interface.
  - Non-blocking (NB) interface, driver call-back or software interrupt to client
    - Same benefits as above (control returned immediately, pipelining).
    - Call-back: Requires client registration with the driver.
    - Driver alerts client when command has completed; no polling required.

Client-driver interface: Blocking



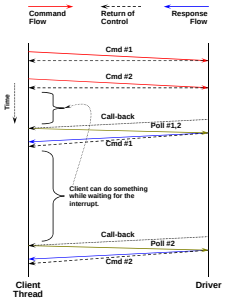
- Client commands to driver will block client thread until the driver fully executes the command.
- When the command is fully executed by the driver, the response is returned and the command has completed.
- Program control flow is coincident with command and response flow.

Client-driver interface: NB with polling



- Client sends command to driver, and receives control back immediately.
- Meanwhile driver executes command, and eventually queues up the result.
- Client polls driver to see if command completed.
  - Client has control: client can do other things while waiting.
- Client can pipeline commands, if driver allows.
  - Driver may enforce in-order execution, or all out-of-order for specific/all commands.

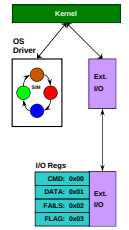
Client-driver interface: NB w/ interrupt or call-back



- Same benefits as the NB with polling scenario.
- If software interrupt, driver hits interrupt when command completes, and client polls only once.
- If call-back, after command completes, driver calls client directly. Then…
  - Client polls for result, or
  - Driver passed back results w/ call-back.
- Relieves client from polling after commands are issued.

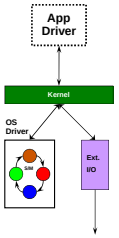
OS driver ⇒ direct hardware communication

- The OS driver communicates with registers via the I/O channel provided by the OS.
  - Devices may be memory mapped, or port accessed (depending upon processor architecture).
  - 8/16/32-bit hardware registers are accessed to configure and monitor state, and initiate activity.
  - Responsibility of OS driver is to translate basic commands into individual I/O register accesses that execute them on the hardware.
  - OS stability should never be compromised.



Application driver ⇒ OS driver communication

- The OS driver has taken care of basic communication with the hardware.
  - OS driver interface is basic and standardized for all Linux devices (of a given driver category)
- Application driver now uses OS driver to…
  - Build higher-level commands relevant to the upstream client (e.g. using command-response methodology).
  - Create program control interface(s) applicable to the upstream client (blocking, NB varieties).
  - Provide "nice" error recovery via timeouts, etc.
    - A crash of the hardware or firmware should not crash the client application.



Application driver ⇒ firmware communication

- For hardware that employs firmware, the application driver communicates with the firmware to execute commands.
  - Driver may communicate with the device's firmware via messages (higher-level than register accesses).
  - Device firmware may be written using a simple state machine approach. Driver takes firmware through states to execute commands.
  - Driver manages unique functionality of the device that is not directly managed or understood by the OS driver.
  - Prevent clients from "getting into trouble" by restricting scenarios that cause bad states in firmware.