Towards a Dynamic Framework for Interactivity

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Table Of Contents

Abstract

The Device Server provides both a methodology and an application for distributing control signals to software applications. The interface of the Device Server lets users see connections between devices and application functionalities, alter these connections and save alterations into configuration files for later use. The methodology abstracts knowledge of devices away from applications allowing developers to think of control signals in terms of functional usage rather than hardware specific constraints. The Device Server uses the Lua programming language for configuration and control signal processing; this provides a level of dynamism absent in other interactive frameworks. I wrote the Device Server with the goal of easing multi-user interaction inside the AlloSphere immersive instrument at the University of California, Santa Barbara.

1. Introduction

The realtime rendering of complex sonifications and visualizations often require a distributed computing architecture to be successfully realized. In large scale immersive environments such as the AlloSphere [1] the processing requirements of projects are amplified by the size of the physical space; more speakers and more projectors are required along with more processing power to drive them. Similarly, the infrastructure for dealing with interactivity in large spaces poses problems that are often absent in small interactive systems. How can multiple users interact with a visualization simultaneously? How can one device speak to multiple applications? How can an application use a variety of devices to control the same functionality? How can we free application developers from having to manage a myriad of device drivers and control signal processing scripts? How can we let users decide how to interact with data instead of having developers decide for them?

1.1 Problem Statement

This project focuses on the problem of providing a scalable, dynamic framework for interactivity. Existing interactive frameworks for virtual reality are inflexible and static; applications utilizing these frameworks must be recompiled whenever they want to change the configuration of devices controlling them.

Although this is arguably acceptable for virtual reality experiments where controls are well defined in advance, it does not allow fluid experimentation with devices in multi-user systems. The problem is further aggravated by a lack of graphical user interfaces in the server applications of existing frameworks. This lack prevents users and developers from seeing how devices are connected to application parameters and from changing these connections without having to modify or recompile application source code.

Creating usable control systems for navigating and manipulating Virtual Reality Environments (VREs) is challenging, especially when there are multiple users engaged in different tasks simultaneously. Defining control systems for musical and artistic performance systems is equally difficult; each artist will want to customize their controls to ensure as much expressive potential as possible. Interactive frameworks need to provide flexibility and dynamism that encourages experimentation and innovation with devices and control; instead, current frameworks serve as a stumbling block to these goals.

1.2 Project Goal

The Device Server was conceptualized as part of a framework to provide scalable, dynamic, multi-user interaction in the AlloSphere. The initial design allows multiple users to interact with multiple applications via multiple devices while avoiding the introduction of latency. It is intended to free application developers from incorporating device specific drivers into their applications and enforce the decoupling of specific devices from specific application functionalities. It should scale down to single user / single device systems and scale up to as many users and devices as possible. Finally, it should allow easy experimentation with interactive devices and let users individually customize their interfaces to applications.

1.3 Definition of Terms

Device - In this paper the term *device* will generally refer to a piece of hardware that provides interactive affordances to users. However, devices feeding into the Device Server can also be virtual; for example, a row of sliders on a computer screen could be seen as a “device” by the Device Server and used to control applications. Other example devices include gamepads, mobile phones and VR gloves.

Control - Usually one particular interface element of a *device*. For example, a single button is a *control* on a gamepad *device*. In some cases one interface element might have multiple *controls* associated with it, e.g. a joystick might generate both a X and a Y *signal* separately.

Signal - Any time-varying or spatial-varying quantity that a *control* on a *device* sends to the Device Server for distribution. I will not make any distinction between discrete and continuous time signals, nor discrete continuous valued signals; all signals are created equal for purposes of this paper.

Message - The Device Server outputs *messages* to client *applications*. The messages are formatted according to The Open Sound Control protocol (OSC), which will be discussed later.

Application - An *application* is a computer program that is a client to the Device Server; it registers to receive *messages* created from the *signals* of *devices*.

Functionality - A *functionality* is one dimension of control inside a client application. For example, changing the X position of a camera is one functionality an *application* might expose; changing the Y position could be another.

Interface - Each *application* has a single Lua[2] *interface* file that defines what functionalities the *application* exposes and the range of values these functionalities expect to utilize.

Implementation - A Lua file that gives *mappings* (see below) for a particular *interface.* There can be many different *implementations* for a single *interface*; users can select which *implementation* script they would like to use through the Device Server GUI.

Mapping - A *mapping* takes an application functionality described in the application's *interface* file and routes a *signal* from a *control* to that functionality. It may also contain processing scripts that transform the *signal.*

1.4 Document Overview

I will begin Section 2 by looking at existing interactivity frameworks, three of which were designed for Virtual Reality applications, one of which was designed for musical applications. Section 3 will provide a detailed functional and architectural description of the current Device Server. Section 4 will discuss previous iterations of the Device Server and the design decisions that brought it to its current state. Section 5 focuses on usage, evaluation and comparison to existing interactive frameworks. Section 6 discusses further directions for development and concludes.

2. Background Research

2.1 Interactive Frameworks Integrated Into Virtual Reality Toolkits

Many early Virtual Reality (VR) toolkits incorporated interactive functionality intended to free application developers from worrying about device drivers (references... panda, diver , etc.). However, in most cases the functionality provided was not designed to be scalable, extensible or abstracted to easily accommodate different device configurations. As stated on the homepage of the Vrui [3] VR toolkit from UC Davis "Although all toolkits have some kind of built-in input device driver to hide hardware details, none provide a higher-level semantic interface that allows to write an application once, and run it in VR environments with widely differing input environments." [4] Gadgeteer[5], part of the VR Juggler[6] package, is a notable exception to this rule along with the Vrui VR toolkit itself.

Gadgeteer inserts a level of abstraction between device drivers and applications; this layer attempts to classify devices into one of eight categories: Analog, Command, Digital, Glove, Gesture, Position, Simulator and String. The Simulator category is another level of abstraction that allows devices of one type of category to pose as another, a design paradigm that can also be found in the Virtual Reality Peripheral Network (VRPN) [7] which will be discussed shortly. The advantage of abstracting devices into categories is that any two devices of the same category can be used interchangeably. This means VREs have a better chance of successfully running in physical locations possessing different devices.

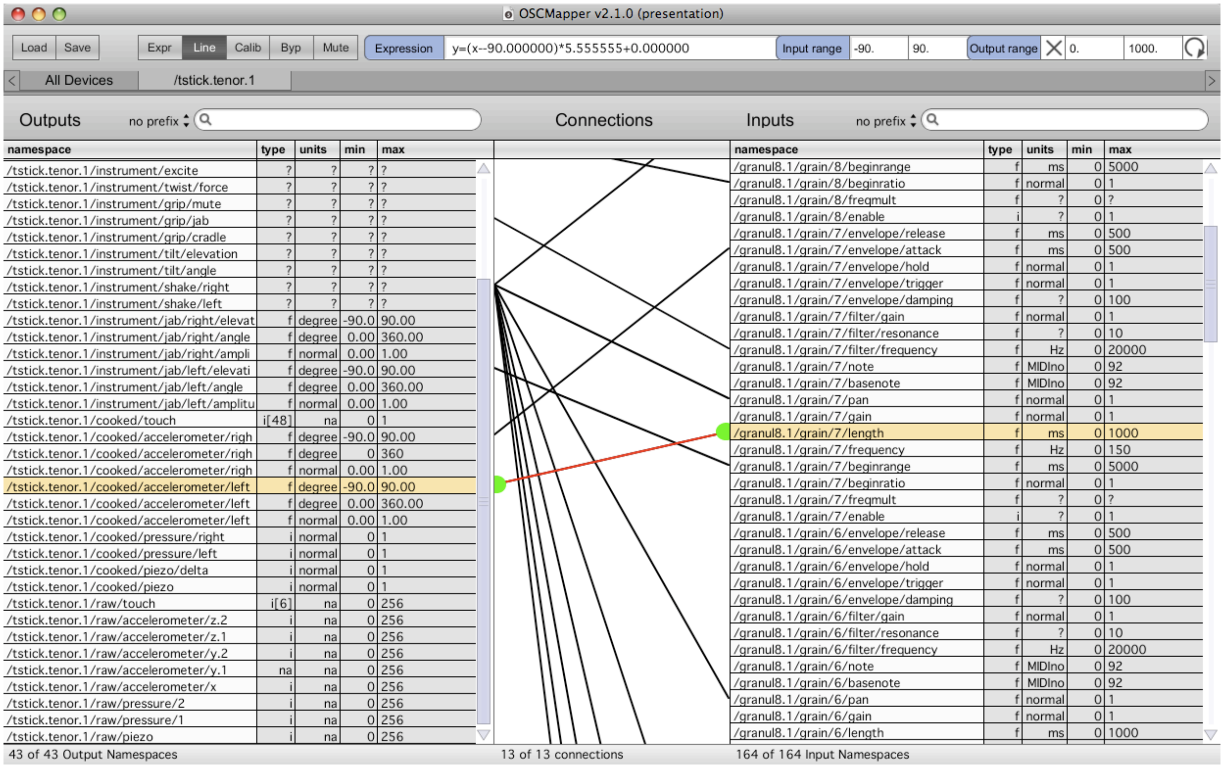
The Vrui VR toolkit also has this level of device abstraction; however, it goes one step further by introducing the concept of *tools*. Tools provide a set of functionality while leaving the the inner composition of the functionality hidden. As one example, multiple devices could be combined to create a navigation tool. Other navigation tools composed of differing devices might exist but any two tools of the same type are guaranteed to provide the same range of control signals and can be used interchangeably.

Enforcing these abstractions comes with a price: individual controls of one category cannot easily be exchanged for controls of another category. In the Device Server the signals generated by all controls are treated equally as floating point numbers and any control signal maybe exchanged for any other. This difference between the Device Server and other VR frameworks is discussed in detail in Section 5.

2.2 Standalone Interactive Frameworks

The Virtual Reality Peripheral Network (VRPN) is the most commonly used standalone library for interfacing with high-end virtual reality devices. It presents a distributed client / server model, where a server can provide a number of device streams and a typical client is a virtual reality application that registers to receive one or more streams from one or more servers. VRPN also supports the first abstraction layer found in Vrui VR and Gadgeteer, i.e. users can request to receive messages from a Tracker object without worrying about which particular model of tracking device they will be accessing. The developers of VRPN put a great deal of emphasis on ensuring low latency performance; input messages from devices often reach connected clients in less than a millisecond. The existence of multiple servers simultaneously allows for a great deal of flexibility in interactive systems architecture. If a VRE contained ten devices each device could be connected to its own dedicated computer with its own dedicated VRPN server program running or all ten could run on a single machine with a single server program. Anything in between these two extremes is also possible. By connecting client applications directly to the computers hosting devices without using an intermediary (as is the case with the Device Server) VRPN reduces network overhead and creates the lowest latency connection possible. Disadvantages of decentralization include more network connections to manage and the lack of a central location for monitoring connections and signals.

The Digital Orchestra Toolbox (DOT) mapping tools [8] is a standalone framework created at McGill University designed to “create a system that allows mapping between controller and sound parameters without requiring a high level of technical knowledge, and which needs minimal manual intervention for tasks such as configuring the network and assigning identifiers to devices”. As befitting a project focusing on ease of use, DOT mapping tools is the only framework discussed in this section that features a GUI. The GUI of DOT mapping tools allows users to drag connections between device parameters (outputs) and functional application parameters (inputs). The GUI also allows users to define simple expressions for manipulating control signals. The connections that users create can be saved into XML files that can be loaded back into Mapping tools. The authors of DOT mapping tools state that they want to support multiple prototyping and development environments but currently only have a Max / MSP object available for download. The DOT mapping tools are not designed to run as a server like the Device Server is. Devices and applications cannot be connected automatically via network messages; some manual use of the GUI is required to initialize connections.



Expression: y=(x--90.000000)*5.555555+0.000000

Input range: -90. 90.

Output range: 0. 1000.

namespace	type	units	min	max
/tstick.tenor.1/instrument/excite	?	?	?	?
/tstick.tenor.1/instrument/twist/force	?	?	?	?
/tstick.tenor.1/instrument/grip/mute	?	?	?	?
/tstick.tenor.1/instrument/grip/jab	?	?	?	?
/tstick.tenor.1/instrument/grip/cradle	?	?	?	?
/tstick.tenor.1/instrument/tilt/elevation	?	?	?	?
/tstick.tenor.1/instrument/tilt/angle	?	?	?	?
/tstick.tenor.1/instrument/shake/right	?	?	?	?
/tstick.tenor.1/instrument/shake/left	?	?	?	?
/tstick.tenor.1/instrument/jab/right/elevat	f	degree	-90.0	90.00
/tstick.tenor.1/instrument/jab/right/angle	f	degree	0.00	360.00
/tstick.tenor.1/instrument/jab/right/ampli	f	normal	0.00	1.00
/tstick.tenor.1/instrument/jab/left/elevati	f	degree	-90.0	90.00
/tstick.tenor.1/instrument/jab/left/angle	f	degree	0.00	360.00
/tstick.tenor.1/instrument/jab/left/amplitu	f	normal	0.00	1.00
/tstick.tenor.1/cooked/touch	i[48]	na	0	1
/tstick.tenor.1/cooked/accelerometer/righ	f	degree	-90.0	90.00
/tstick.tenor.1/cooked/accelerometer/righ	f	degree	0	360
/tstick.tenor.1/cooked/accelerometer/righ	f	normal	0.00	1.00
/tstick.tenor.1/cooked/accelerometer/left	f	degree	-90.0	90.00
/tstick.tenor.1/cooked/accelerometer/left	f	degree	0.00	360.00
/tstick.tenor.1/cooked/accelerometer/left	f	normal	0.00	1.00
/tstick.tenor.1/cooked/pressure/right	i	normal	0	1
/tstick.tenor.1/cooked/pressure/left	i	normal	0	1
/tstick.tenor.1/cooked/piezo/delta	i	normal	0	1
/tstick.tenor.1/cooked/piezo	i	normal	0	1
/tstick.tenor.1/raw/touch	i[6]	na	0	256
/tstick.tenor.1/raw/accelerometer/z.2	i	na	0	256
/tstick.tenor.1/raw/accelerometer/z.1	i	na	0	256
/tstick.tenor.1/raw/accelerometer/y.2	i	na	0	256
/tstick.tenor.1/raw/accelerometer/y.1	na	na	0	256
/tstick.tenor.1/raw/accelerometer/x	i	na	0	256
/tstick.tenor.1/raw/pressure/2	i	na	0	256
/tstick.tenor.1/raw/pressure/1	i	na	0	256
/tstick.tenor.1/raw/piezo	i	na	0	256

43 of 43 Output Namespaces

13 of 13 connections

namespace	type	units	min	max
/granul8.1/grain/8/beginrange	f	ms	0	5000
/granul8.1/grain/8/beginratio	f	normal	0	1
/granul8.1/grain/8/freqmult	f	?	0	?
/granul8.1/grain/8/enable	i	?	0	1
/granul8.1/grain/7/envelope/release	f	ms	0	500
/granul8.1/grain/7/envelope/attack	f	ms	0	500
/granul8.1/grain/7/envelope/hold	f	normal	0	1
/granul8.1/grain/7/envelope/trigger	f	normal	0	1
/granul8.1/grain/7/envelope/damping	f	?	0	100
/granul8.1/grain/7/filter/gain	f	normal	0	1
/granul8.1/grain/7/filter/resonance	f	?	0	10
/granul8.1/grain/7/filter/frequency	f	Hz	0	20000
/granul8.1/grain/7/note	f	MIDIno	0	92
/granul8.1/grain/7/basenote	f	MIDIno	0	92
/granul8.1/grain/7/pan	f	normal	0	1
/granul8.1/grain/7/gain	f	normal	0	1
/granul8.1/grain/7/length	f	ms	0	1000
/granul8.1/grain/7/frequency	f	Hz	0	150
/granul8.1/grain/7/beginrange	f	ms	0	5000
/granul8.1/grain/7/beginratio	f	normal	0	1
/granul8.1/grain/7/freqmult	f	?	0	?
/granul8.1/grain/7/enable	i	?	0	1
/granul8.1/grain/6/envelope/release	f	ms	0	500
/granul8.1/grain/6/envelope/attack	f	ms	0	500
/granul8.1/grain/6/envelope/hold	f	normal	0	1
/granul8.1/grain/6/envelope/trigger	f	normal	0	1
/granul8.1/grain/6/envelope/damping	f	?	0	100
/granul8.1/grain/6/filter/gain	f	normal	0	1
/granul8.1/grain/6/filter/resonance	f	?	0	10
/granul8.1/grain/6/filter/frequency	f	Hz	0	20000
/granul8.1/grain/6/note	f	MIDIno	0	92
/granul8.1/grain/6/basenote	f	MIDIno	0	92
/granul8.1/grain/6/pan	f	normal	0	1
/granul8.1/grain/6/gain	f	normal	0	1
/granul8.1/grain/6/length	f	ms	0	1000

164 of 164 Input Namespaces

Fig.1 The mapping tools GUI. Devices are on the left, application parameters are on the right.

3. The Device Server in Detail

This section will discuss the functional and architectural details of the Device Server.

3.1 An Overview of the Device Server

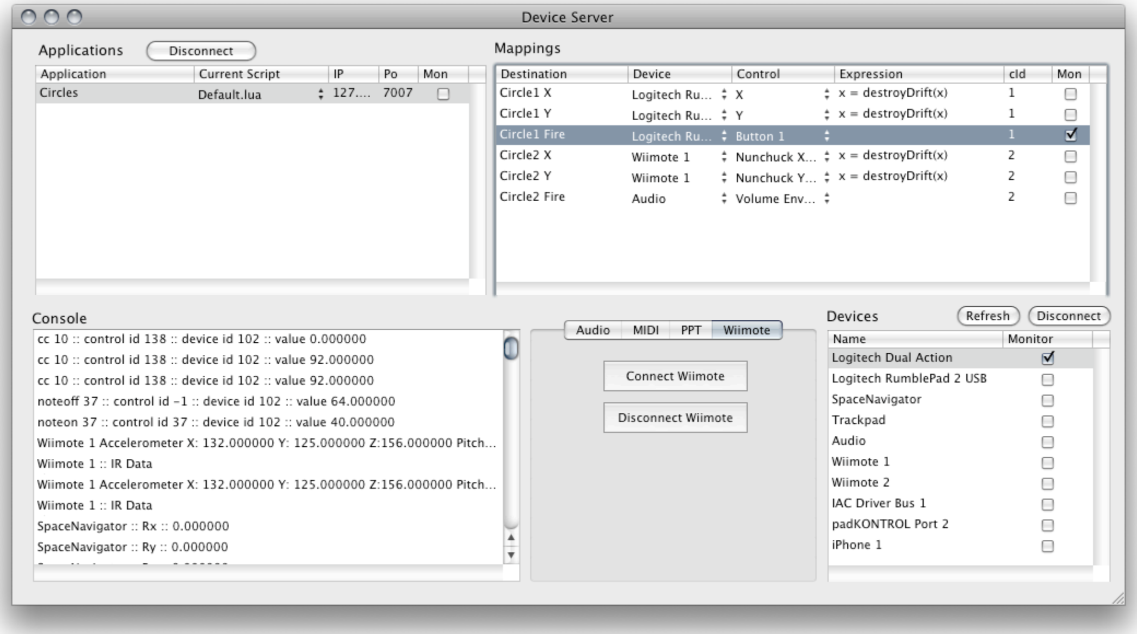
The Device Server is a router for the signals generated by interactive devices. It aggregates the access of all devices into a single interface and provides a flexible configuration mechanism allowing client applications to decide which device signals will be forwarded to them as messages and how those signals will be transformed. The configuration files are written in Lua; this is also the language used to write expressions for signal transformation.

Multiple client applications may be connected to the Device Server simultaneously; in the AlloSphere, typical client applications include data visualizations, scientific simulations and works of visual and sonic art. Multiple clients can be registered to receive signals from the same controls on the same devices; the signals can be transformed differently for each application.

Each client application has a single Lua interface file defining the functionalities it exposes for control. Applications also have implementation files defining which devices and controls are assigned to the functionalities exposed in the interface. There can be multiple implementations for each application; different implementation files can be defined to accommodate different numbers of users and different devices. For example, one implementation for an application might define a configuration for a single user using a single device while another defines a configuration for multiple devices used by a single user. Yet another implementation might describe a multiuser setup employing a variety of devices. The application implementation file in current use can be easily changed in the Device Server GUI; neither the Device Server nor the application needs to be restarted when an implementation file is selected. This makes it simple to change configurations when a device is malfunctioning or a user wants to experiment with a different device.

The Device Server primarily communicates using Open Sound Control (OSC) [9], a network communications protocol used extensively in the media arts and found in a wide variety of prototyping platforms. Client applications begin communicating with the Device Server by sending a “handshake” message using OSC; this message tells the Device Server what the name of the application is, what IP address the client application is using and what port it would like to receive OSC messages at. When the handshake is received the Device Server registers the client application and reads in the Lua configuration files associated with it. The first configuration file, the *interface*, describes the functionalities that the application exposes. The second file, the *default implementation*, describes which controls should be connected to each functionality and what transformations should be applied to the signals the controls generate. Once the Device Server reads these files it begins serving OSC messages to the client application as described in the configuration files.

3.2 The Device Server Graphical User Interface (GUI)



Application	Current Script	IP	Po	Mon
Circles	Default.lua	127....	7007	□

Destination	Device	Control	Expression	cId	Mon
Circle1 X	Logitech Ru...	X	x = destroyDrift(x)	1	□
Circle1 Y	Logitech Ru...	Y	x = destroyDrift(x)	1	□
Circle1 Fire	Logitech Ru...	Button 1		1	☑
Circle2 X	Wiimote 1	Nunchuck X...	x = destroyDrift(x)	2	□
Circle2 Y	Wiimote 1	Nunchuck Y...	x = destroyDrift(x)	2	□
Circle2 Fire	Audio	Volume Env...		2	□

```
cc 10 :: control id 138 :: device id 102 :: value 0.000000
cc 10 :: control id 138 :: device id 102 :: value 92.000000
cc 10 :: control id 138 :: device id 102 :: value 92.000000
noteoff 37 :: control id -1 :: device id 102 :: value 64.000000
noteon 37 :: control id 37 :: device id 102 :: value 40.000000
Wiimote 1 Accelerometer X: 132.000000 Y: 125.000000 Z:156.000000 Pitch...
Wiimote 1 :: IR Data
Wiimote 1 Accelerometer X: 132.000000 Y: 125.000000 Z:156.000000 Pitch...
Wiimote 1 :: IR Data
SpaceNavigator :: Rx :: 0.000000
SpaceNavigator :: Ry :: 0.000000
```

Name	Monitor
Logitech Dual Action	☑
Logitech RumblePad 2 USB	□
SpaceNavigator	□
Trackpad	□
Audio	□
Wiimote 1	□
Wiimote 2	□
IAC Driver Bus 1	□
padKONTROL Port 2	□
iPhone 1	□

`Fig.2 Device Server GUI

1. Applications - This table view displays all the applications currently connected to the Device Server and the implementation script they are running, their IP address, port and whether the application is monitoring messages sent to it and sending them to the console window. When an application is selected in this menu, all their mappings are displayed to the right.
2. Mappings - This table view shows all the mappings for the application selected in 1. Each row shows the device and control assigned to the mapping, any expression the mapping might have, the control ID (to be discussed later) and whether the mapping is monitoring its output. Pulldown menus can be used to change the control / device assigned to each mapping and users may also enter expressions directly into the text field.

3. Console - Various messages can be sent from the Device Server to the console window including application handshake messages, device specific connection instructions and monitoring of signals and messages. The console is also accessible through the Lua scripting environment for debugging expressions.
4. Device Specific Controls - Devices that require extra GUI controls for utilization are represented with a tab here.
5. Devices - All devices connected to the Device Server are displayed here. You can remove them from the Device Server application and refresh the list in the event new devices are added and don't automatically appear. You can also monitor all of a devices messages here.

The GUI is an essential feature of the Device Server and is not found in any of the interactivity frameworks geared towards VR applications. The GUI allows users to alter implementation scripts on-the-fly by changing the devices, controls, expressions and control IDs assigned to mappings. This encourages experimentation using different devices and widgets to control application functionality. Changes to implementation scripts can overwrite the current script file or be saved to new documents. This makes it easy to develop configurations for different users; an initial configuration script is created and subsequently altered by users who choose the devices and control systems they prefer to use. Each user can save their own implementation script with their own control preferences; these scripts can be recalled through the Device Server GUI.

Another important element of the GUI is signal monitoring; the Device Server allows monitoring at many different levels in its architecture. First, the signals from each device can be monitored after they are initially modified by any existing device expressions. Next, individual mappings can be monitored; the values sent to the console from individual mappings are after the signal has been processed with any expression the mapping may contain. Finally, monitoring can happen at the application level, where all messages outputted to a client application can be viewed. This flexibility in monitoring is helpful when debugging problems in implementation files and device drivers.

3.3 Lua Configuration Files

Along with the information given in this section further examples of configuration files from existing applications can be found in Appendix 1.

3.3.1 Master Device List

The Master Device List is a Lua file that contains a list of all the devices that can be connected to the Device Server. It's important to note that being on this list is not a guarantee that a device will be connected, only that it is usually available in whatever VRE the Device Server is running. Each device is enumerated with its human readable name (in most cases this is the name reported by whatever driver the device uses) and unique id number. The id number is arbitrary (as long as each is unique); but it is important that the Master Device List is available to look at so developers can reference the list and see what each device's id number is when making implementation files (for which the ids are required). Below is an example of a very simple Master Device List document.

```
devices = {
      { id = 1, name = "Wiimote 1" },
      { id = 11, name = "PPTTracker 1" },
      { id = 21, name = "Logitech Dual Action" },
      { id = 22, name = "Logitech Cordless RumblePad 2" },
      { id = 23, name = "Logitech RumblePad 2 USB" },
      { id = 24, name = "USB 2-Axis 8-Button Gamepad" },
}
```

3.3.2 Device Configuration Files

Every device listed in the Master Device List has its own Lua document that enumerates each control in the device. The enumerations include a unique id for the control (arbitrary), HID usage page and usage numbers (if applicable), a human readable name (usually whatever name is reported by the device drivers), the range of values the control generates and an expression that can be applied to every message the control generates. This expression is important in assuring that devices output a range of value useful to developers. The Musical Instrument Digital Interface (MIDI) protocol, for example, specifies that most output values are seven bit numbers in the range of {0. 127}. With the exception of controlling other MIDI devices, this range of values has very little practical usage. Changing these values to the range {0, 1} with an expression at the device level removes the need for the expression to be scattered throughout multiple application implementation files, or, even worse, for an application developer to handle the scaling and offsetting in their own code. As another example, tracking systems such as the WorldViz Precision Point Tracking (PPT) system used in the AlloSphere output the physical location of a tracker object in three dimensional space. This output varies greatly in different installations due differing physical sizes. In order to provide a constant range of values between multiple spaces the device configuration files in each space could be configured to output values in the range of {-1, 1}. This helps ensure the portability of applications between different VREs using the Device Server.

Below is an example of a device configuration file for one tracker in a PPT system. The tracker outputs its location in physical space by providing an X, a Y and a Z coordinate. This particular configuration has expressions and variables optimized for use on the AlloSphere bridge. All expressions are written to yield values between {-1, 1}. The variables at the top of the configuration file can be changed to account for spaces of different sizes.

```
local width = 4.5   -- values are -4.5 (left) to positive 4.5 (right)
local height = 2    -- values are 0 (floor) to 2 (7.5 feet in the air)
local depth = 2     -- values are -1 (back of bridge) to 1 (front)

atrributes = {
  name = "PPTTracker 1"
}

controls = {
  { id = 0,  usagePage = 1,  usage = 48,  name = "X", minimum = -1, maximum =
1, expression = "x = x / width" },
  { id = 1,  usagePage = 1,  usage = 49,  name = "Y", minimum = -1, maximum =
1, expression = "x = -1 + ((x / height) * 2)" },
  { id = 2,  usagePage = 1,  usage = 50,  name = "Z", minimum = -1, maximum =
1, expression = "x = x / depth" },
}
```

The attributes dictionary is reserved for future use; one potential use of this dictionary will be to expose force feedback mechanisms in devices.

3.3.3 Application Interface and Implementation Files

Each application has a single Interface file, named Interface.lua, that defines the functionalities the application exposes. Each functionality is identified by a human readable name that will appear in the Device Server GUI. The only additional information provided in this file is the range of values that the client application is expecting to receive for each functionality. Knowing this range enables an important feature of the Device Server: by knowing the range of values a device creates and knowing the range of values an application expects to receive the Device Server can automatically offset and scale the signals outputted by devices to the range client applications expect. Different controls on different devices can easily be interchanged using the Device Server GUI knowing that the appropriate range of signals will always be passed on to client applications. This encourages experimentation and play.

There can be multiple implementation files per application; users select which implementation they would like to use on a per application basis through a pulldown menu in the Device Server GUI. Separate implementation files are created to accommodate different configurations of devices. For example, one implementation might use a wired joystick for control while another uses a wireless one. Users of an application can also create separate implementation files that express their individual control preferences; these files can saved from within the Device Server application at which point they will appear in the application script pulldown menu for future use.

The implementation files contain a list of mappings that each correspond to a functionality defined in the interface file for the application. Each mapping contains the name of an application functionality, a device and a control (identified by id) that will feed that functionality, an expression that can be applied to the signal from the device, an OSC address where the signal will be sent to, and a unique control ID number.

The device number is retrieved from the Master Device List while the control number is gathered from the device's configuration file. Expressions will be discussed in detail further on in this section.

The control ID number (called cID in the implementation file) is an arbitrary integer that is added to the end of every OSC message sent out by the mapping. Its intended usage scenario is for when multiple controls on different devices are routed to the same OSC address; the cID number can be used to differentiate between the different signals. For example, let's say the client application is a multiplayer game in which every player can "fire". One way to handle this in the implementation file is to create a separate OSC address for every player, e.g. "/fire1", "/fire2", "/fire3" etc. Another way to do this is to assign all the messages to "/fire" but then have a different cID value for each of the different controls. If the players are stored in an array in the client application using a cID makes life much easier for development; developers just use the cID value to index which player in the array a particular control message should affect.

Below is a sample interface and implementation file for an application that only exposes two control parameters: the ability to move an object horizontally and vertically across the screen.

START INTERFACE FILE

```
signals = {
      { name = "Circle1 X",    min = -1,  max = 1 },
      { name = "Circle1 Y",    min = -1,  max = 1 },
}
```

END INTERFACE FILE

START IMPLEMENTATION FILE

```
mappings = {
      { name = "Camera Rotate X", destination = "/nav/a1x",  device = 31,
control = 0,  expression = "", cID = 0 },
      { name = "Camera Rotate Y", destination = "/nav/a1y",  device = 31,
control = 1,  expression = "", cID = 0 },
}
```

END IMPLEMENTATION FILE

The location of interface and implementation files is a preference in the Device Server. When a client application handshakes with the Device Server, the server looks in the location specified in the preference sand then looks for a directory with the same name as the client application. It reads the Interface.lua file from this directory and then immediately reads an implementation file called Default.lua. The default implementation is in place so that users don't have to manually choose an implementation in the Device Server GUI every time a client application launches; this one particular file will load automatically.

3.4 OSC Communication

OSC communication has four general purposes within the Device Server:

1. Connection and disconnection between clients and the Device Server
2. Sending mapped messages from the Device Server to client applications
3. Dynamically registering or unregistering to receive control messages from devices
4. Devices can communicated with the Device Server via OSC; one example of a device that does this is the Apple iPhone.

3.4.1 Connecting and Disconnecting

The first message sent by any client app to the Device Server is the handshake message. This registers the client application and tells the Device Server to load the application's implementation and interface files. The arguments to the OSC message are the name of the client application, the IP address of the computer the application is running on and the network port the application would like to receive the messages at. A sample handshake would look like the following:

```
/handshake “Hydrogen Bond” “192.168.1.3” 9600
```

When applications are ready to terminate, they send a disconnection message:

```
/disconnectApplication “Hydrogen Bond”
```

3.4.2 Sending Messages

In the Interface file specific OSC addresses are defined for each application functionality; when a mapped control sends a signal to the Device Server it is routed to its appropriate destination using the IP address and port of the application (provided when the application first shook hands with the Device Server) and the OSC address from the interface file. A sample message might look as follows:

```
/changeCameraXOrientation .25 0
```

The first number is the processed value of the control. The second is the controlD number, as described in section 3.3.3.

3.4.3 Dynamically registering to receive control messages

Configuration files alone are not always enough to provide mappings for applications. When the number of users and / or devices is not known configurations cannot be created that will take into account all possible variations. For example, if users are asked to use their iPhones to control an application there will likely be a different number of iPhones connected to the Device Server every time that application is run depending on the number of users carrying iPhones.

The Device Server provides notifications to connected applications when new devices are added (or removed) to the system; this notification includes the ID number of the device. The Master Device List should account for the maximum possible number of devices that will be connected to the system at once e.g. if it is possible that 30 iPhones may be connected to the Device Server then there should be thirty iPhone entries in the Master Device List. The server then allows for applications to dynamically change their mappings in order to account for new devices. A typical chain of events is illustrated below:

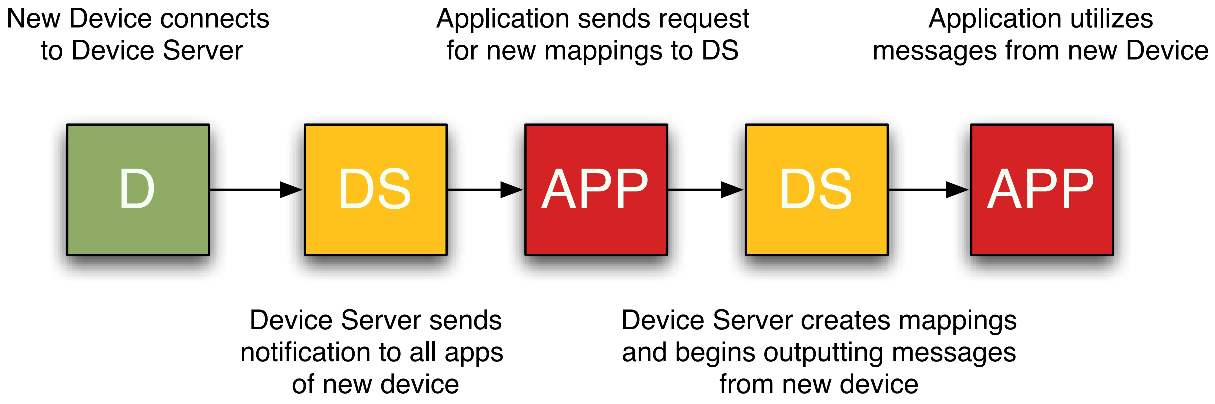

New Device connects to Device Server
Application sends request for new mappings to DS
Application utilizes messages from new Device
D
DS
APP
DS
APP
Device Server sends notification to all apps of new device
Device Server creates mappings and begins outputting messages from new device

Fig.3 v1.0 connection timeline

The arguments to the connect control message are: Application Name, Functionality Name, OSC Destination, Device Number, Control Number, Minimum value for messages, Maximum Value for messages, Expression, controlID. This is everything needed to create a complete mapping. An example OSC message to declare a dynamic mapping is given below:

```
/connectControl 'Circles' 'Circle1X' '/x' 31 9 0.0 1.0 'x = x * -1' 1
```

3.4.4 Device Communication

Certain devices use OSC to send signals to the Device Server; these “devices” are most often pieces of software running other computers or on mobile computing platforms. The first step is for device to register with the Device Server by providing their name, IP address and the port they are communicating on (example below):

```
/registerDevice “192.168.2.1” 9999
```

After the registration is completed the Device Server will send back a notification that the registration is complete. The device can then begin sending signals to the Device Server. These OSC messages contain three arguments: the name of the device, the name of the control issuing the signal, the value of the signal (example below):

```
/OSCDeviceMsg “iPhone 1” “Slider 1” .5
```

When the device is disconnecting it should also send an OSC notification to the Device Server. Devices can also be disconnected manually through the Device Server GUI in the event that a device crashes before it is able to issue a notification.

3.5 Homogenizing Device Signals and Encouraging Experimentation

The Device Server uses the ranges described in mappings along with ranges in the device description files to offset and scale the signal received from a device to match the range of values an application functionality is expecting to receive. For example, analog joysticks often output a signal in the range {0, 255}. If an application mapping has a joystick is assigned to it but is expecting to receive a range of values {-1, 1} the Device Server will take the value from the joystick, divide it by 255, multiply it by two and then subtract one. Having the Device Server do this automatically means that, within reason, any control on any device can be assigned to a mapping and still generate the range of values the application is expecting to receive. For many cases this is only transformation necessary, but more complicated transformations (non-linear, look-up-tables etc.) can also be completed using the Lua expression engine described in 3.6. Although initial device and control mappings are created when an application handshakes with the Device Server, the device and control assigned to a particular mapping may be changed afterwards using pulldown menus in the Device Server GUI. Users can easily experiment with using different devices / controls to control application parameters without having to recompile the client application or modify Lua implementation files. When new mappings are found that are of interest they can saved into new implementation files and recalled for later use. It is important that process of experimenting with devices is as easy as possible so that users feel empowered to find the system of controls that will make them most comfortable using visualizations.

3.6 The Lua Expression Engine

The signals sent out by devices can be transformed through the usage of Lua expressions. Lua functionality is currently included in the Device Server through the use of the LuaCore framework [10]which binds Lua to Objective-C. This allows Objective-C mapping objects to be passed into the Lua state, where the expression for the mapping can be read in and executed. Lua expressions are used in a couple of different parts of the Device Server; refer to Fig. 5 for a detailed diagram showing when and where device signals are modified by Lua.

Expressions are normally placed in the implementation files for a client application, but can also be used inside of device configuration files. The functions used in expressions can be stored in separate Lua files and read into the Lua state in order to promote code reuse; for example, if every application was using a table lookup function for a control it would make sense to have that function in a separate file that could be included using Lua's dofile() function.

The format for an expression inside a mapping is as follows:

```
x = destroyDrift(x)
```

The variable x is both used as the number to feed destroyDrift() and is also the final return value; in this case destroyDrift() is expected to return a value that will be assigned to x and used as the output. One example of a destroyDrift function that would remove analog drift when a joystick is centered is below:

```
function destroyDrift(value)
      if(value > -.07 and value < .07) then
            return 0
      else
            return x
      end
end
```

A complete example of an implementation file that uses this function can be found in Appendix 1. As mentioned previously, Objective-C mapping objects are passed into the Lua state every time an expression is evaluated. The object representing the client application is also passed in; this application object contains an array of all the mappings associated with the application. By accessing this application object any mapping can look at the previous value(s) of any other mapping. You can also access that value of mappings before Lua expressions were applied to it (but after scaling and offsetting) or access the raw signal of the device. Finally, you can print to the Device Server console from inside the Lua expression engine. For a complete reference to Device Server specific Lua functionality, please see Appendix 2.

3.7 Software Architecture

Much of the software architecture for the Device Server is determined by design patterns found in the Cocoa framework [11]. The most important object in the Device Server application is the DeviceServer object; this object is a singleton that can be accessed by any other object in the DeviceServer. The DeviceServer object allocates memory for the LuaManager and ExpressionParser objects and is the gateway to accessing them. As the application delegate it is also responsible for dealing with commands from the menubar, such as saving new scripts or setting preferences.

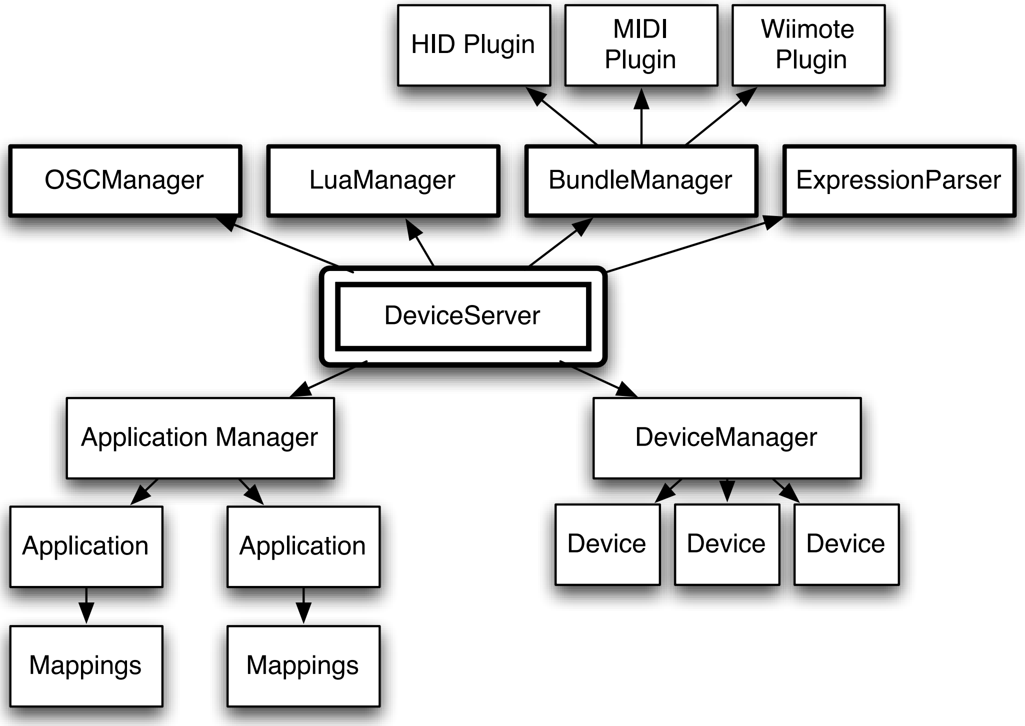
At the next level down in importance we have the ApplicationManager and the DeviceManager. These are both array controller objects; the ApplicationManager controls an array of connected applications while the DeviceManager controls an array of connected devices. The Applications table view and Devices table view in the GUI are bound to these objects; any changes in the arrays these objects control is immediately reflected in the GUI. This is a classic instance of the Model-View-Controller design pattern: Application objects (Models) are stored in the ApplicationManager (Controller) whose contents are displayed in the interface created by Interface Builder (View). The same follows for devices and the DeviceManager.

Each Application object is a controller for an array of Mapping objects. Application objects are responsible for reading in interface and implementation files (with the help of the LuaManager object that parses them) and converting them into the appropriate set of Mapping objects.

Mapping objects have a number of responsibilities and, in many ways, do the bulk of the work in the Device Server. When a signal travels from a device through the Device Server, the Mapping objects are the last stop in the processing chain before an OSC message is sent to the client application.

Device objects are little more than glorified property lists. The only functionality they expose is returning id numbers of controls based on their human readable names (and vice-versa), equality testing and a pretty printing description method. They also store an array of dictionaries containing information about every control in the device including the control's name, its range of values and whether or not it has any expressions associated with it. The actual generation of device objects and management of device drivers is handled by plugins that are loaded by the BundleManager object which will be discussed shortly.

`Fig.4 Device Server Architecture



3.8 Signal Flow

Fig. 5 shows signal flow in the Device Server, from the generation of signals by devices to the end reception by client applications. Each stage is numbered and described below.

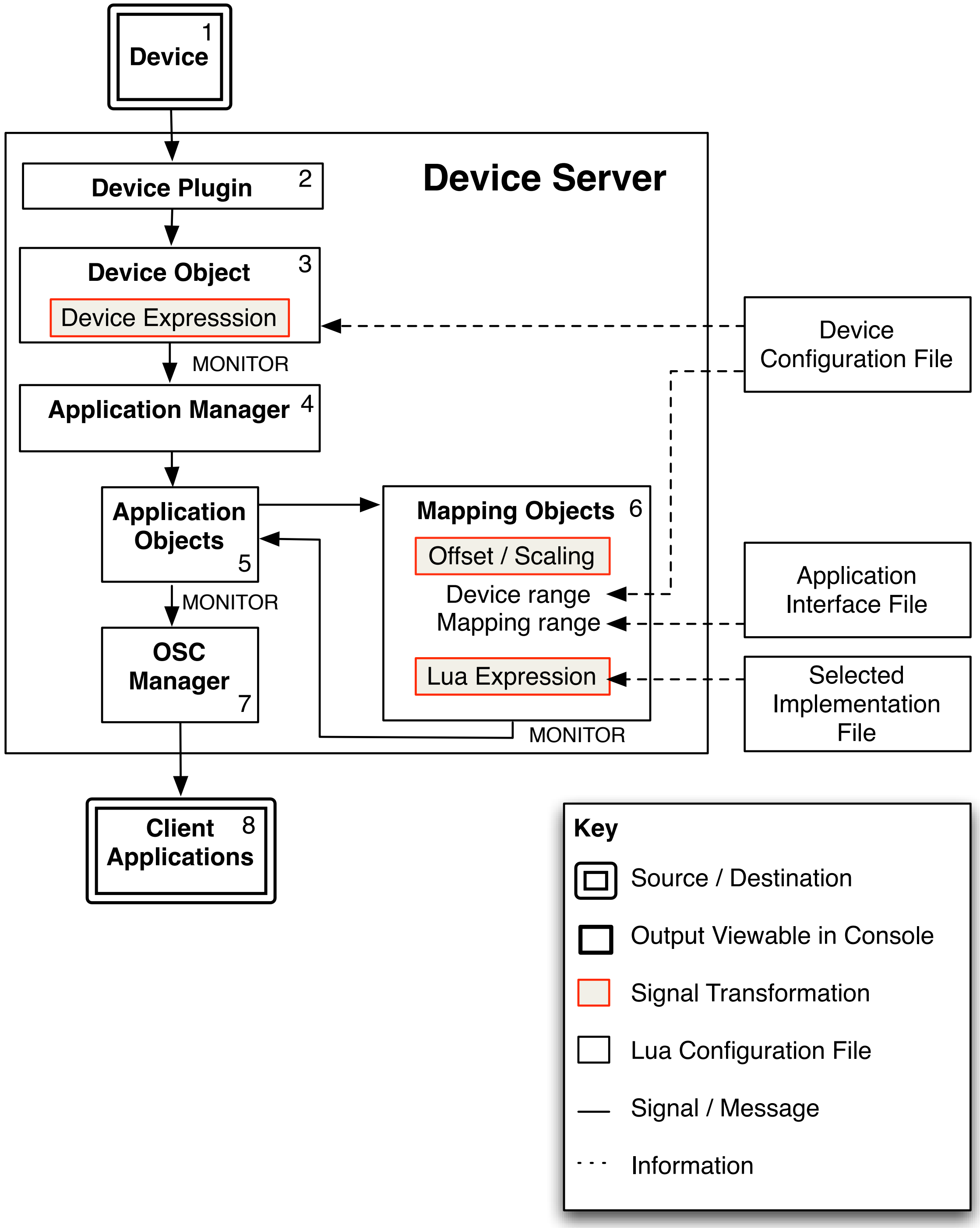


Fig.5 Device Server Signal Flow

1. A signal is generated by the device
2. The signal is read by the device plugin and passed to the device object representing it

3. If a Lua expression exists for a particular control, the Device object evaluates it using the signal it receives. It then forwards values to the Application Manager. If the device has been selected for monitoring in the Device Server GUI, the values are printed to the Console window.
4. The Application Manager forwards the signal to every Application object in the Device Server.
5. Each Application checks each of its Mapping objects to see if the device / control generating that generated the values match the device / control combination the mapping represents . If so, the Application object sends the signal to the Mapping object for processing.
6. The Mapping object first performs scaling and offsetting on the signal to make it match the range of values the client application is expecting. If the mapping contains a Lua expression the expression is evaluated. The message is then sent back to the Application object which passes it to the OSC Manager; if the Mapping is selected for monitoring the current value is sent to the console window.
7. The OSC Manager creates an OSC message and sends it to the client application
8. The client application receives an OSC message.

3.9 Extensibility

The Device Server is designed to be easily extensible; there are multiple ways to add device functionality it. In order of complexity they are:

1. Create configuration files for devices whose drivers are already included in the Device Server (least complex)
2. Use the OSC protocol to send the Device Server messages from an application that can already communicate with the device
3. Write a custom plug-in for the Device Server

If a driver already exists for a device (for example, a new MIDI device) then it usually makes the most sense to use option 1 and simply create a Lua description file for the device; the driver is already setup to discover and utilize it. If the device needs to be hooked up to another computer for specialized processing (for example, a camera-based tracking system) then using the OSC protocol to communicate over the network is a good choice. If no driver exists and the device is to be plugged in to the Device Server directly, writing a plugin is the best option. Plugins are also the best option to use if a GUI is needed for communication with the device.

Configuration files for devices are discussed in section 3.3.2 and the use of the OSC for devices is covered in 3.4.4. The process of writing a custom plug-in is described below.

3.9.1 Device Server Plug-ins and the Bundle Manager

Device drivers were originally compiled straight into the Device Server application; recent versions of the Device Server support the ability to dynamically load plug-ins containing drivers and GUIs needed to communicate with devices. Using a plugin architecture keeps the Device Server modular and allows developers to add new devices without having to modify the Device Server itself.

The Device Server comes with an XCode project template that automates the process of writing plug-ins. The template contains a basic GUI hooked into a plug-in manager class with example code for how to use the GUI and send device signals to applications. The plug-ins are NSBundle objects from the Cocoa framework. They include a framework called DeviceServerBundle.framework that has all the necessary header files to interface with the Device Server. There is also a flag that indicates whether or not an optional GUI is included in the plug-in; in the current version of the Device Server the HID !!!plug-in does not utilize a GUI while all other plug-ins do.

GUIs are often a necessary to interface with devices. For example, a Bluetooth pairing process needs to be completed before you can use a Nintendo Wiimote with a personal computer. The pairing process consists of telling the computer to scan for signals from Wiimotes and then pressing two buttons on the Wiimote simultaneously to register it with the computer. Without a GUI of some sort there is no easy way to tell the computer to begin the scanning process. The Wiimote plugin for the Device Server includes a

GUI with a button that starts the connection process and also allows users to disconnect Wiimotes from the computer.

GUIs can also be used to provide visual feedback about device signals, or provide standard 2D user interface widgets to control applications. The Device Server ships with an Audio plugin that generates control signals from connected microphones. The plugin outputs both a volume envelope for the microphone signal and bin magnitudes from a sixteen band FFT analysis. The magnitude of the sixteen FFT bins is visualized with a simple display of rising and falling bars.

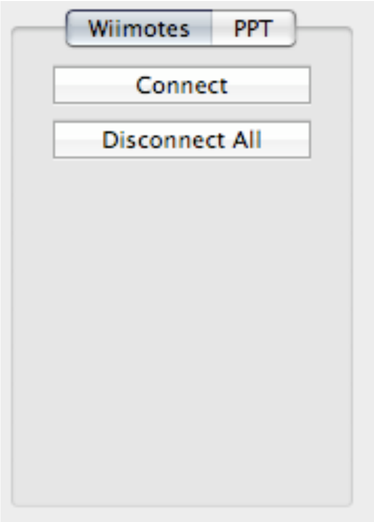


Fig.6 GUI for connecting and disconnecting Wiimotes in the Device Server. Each Device plug-in can have its own tab as needed in the tab view.

Besides the GUI and the device drivers themselves, a Device Server plugin should also contain a device description file as described in section 3.3.2.

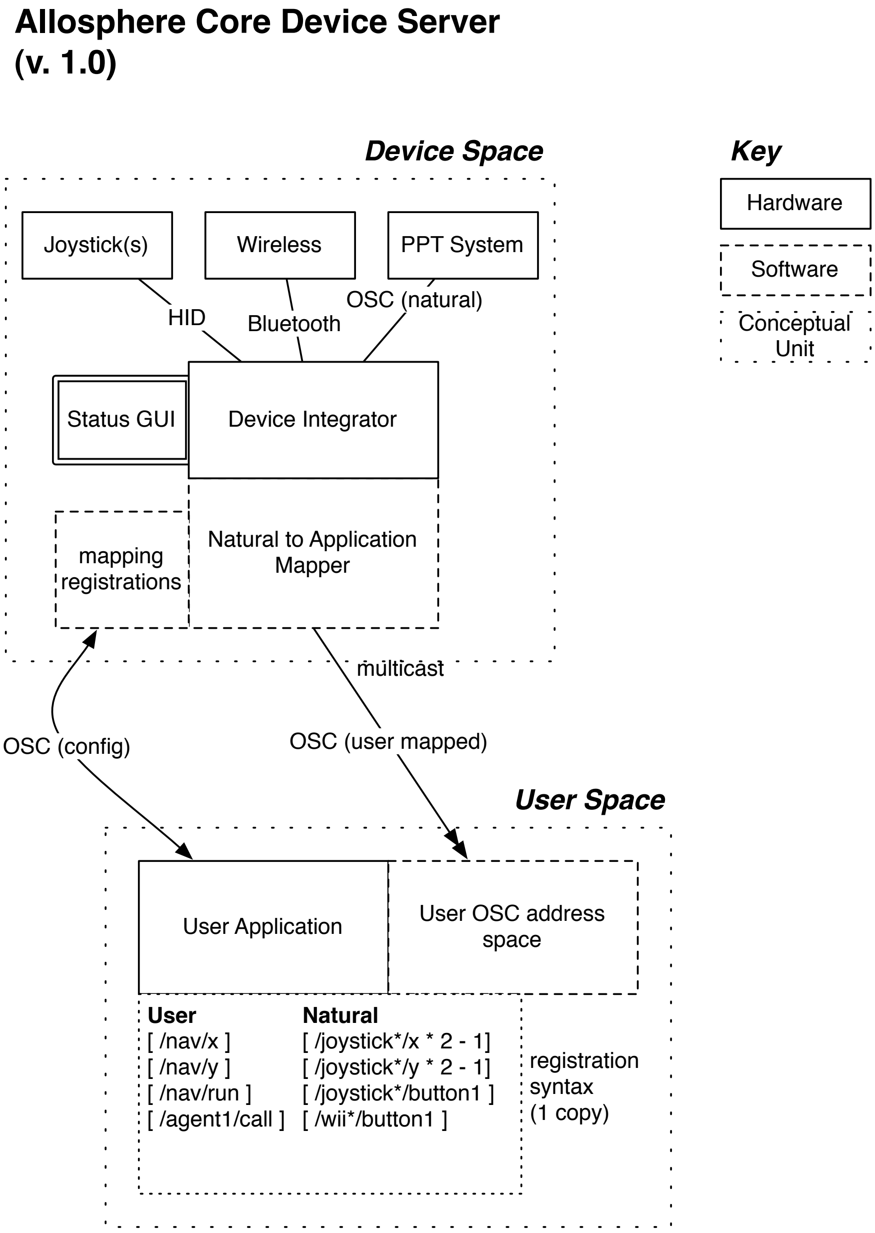
4. Early Implementations & Lessons Learned

The creation of the Device Server was an iterative process. It began with an application whose sole purpose was to convert messages from Nintendo Wiimotes and a WorldViz Precision Point Tracking system into OSC messages that could be delivered over a network to client applications. Although this early implementation was used by a few prototype interactive applications, it was never intended to be a final dynamic, extensible solution for interactivity in the AlloSphere. Members of the AlloSphere working group began discussing plans for a new Device Server in October of 2008. The goals for the Device Server were outlined as follows:

1. Ensure a layer of abstraction between devices and application parameters; applications should announce their functionalities [12] and devices should be connected to their functionalities through a mapping layer

2. Provide a scripting mechanism for manipulating signals; this processing should occur on the server and not in the client application
3. Centralize devices and device drivers to a single server; client applications only need to know a single IP address / port to have access to every device in the system.
4. A Console should be present so that messages sent by devices can be monitored and displayed; this helps troubleshoot device connectivity, driver issues and problems in the mapping layer.

The remainder of this section discusses features of versions 1.x and 2.x of the Device Server. Design decisions involving the mapping abstraction layer, the GUI, configuration scripts and the techniques used for parsing expressions are all discussed.



User	Natural
[/nav/x]	[/joystick*/x * 2 - 1]
[/nav/y]	[/joystick*/y * 2 - 1]
[/nav/run]	[/joystick*/button1]
[/agent1/call]	[/wii*/button1]

Initial design diagram of the Device Server.
Image by Lance Putnam

4.1 Version 1.0

Version 1.0 (and subsequent versions) of the Device Server software was created for the OS X operating system using Cocoa as its interface library. In v1.0, the mapping abstraction between applications and the devices they were connected to was not implemented; applications connected to the devices they were interested in explicitly by registering with the Device Server via OSC.

There were two types of Extensible Markup Language (XML) configuration files used in v1.0. The first was identical to the Master Device List currently used except that it is formatted in XML instead of Lua. A small sample script is given below; the full Master Device List currently used in the AlloSphere currently can be found in Appendix A.

```
<?xml version="1.0" encoding="UTF-8" ?>
<devices>
      <device id="1" name="Wiimote 1" />
      <device id="2" name="PPTTracker 1" />
      <device id="3" name="Logitech Dual Action" />
      <device id="4" name="Logitech Cordless RumblePad 2" />
</devices>
```

The second type of configuration file used describes device features; there is one XML document per device connected to the Device Server. A small example for a PPT infrared tracker is provided below, another example written in Lua and currently used in the AlloSphere can be found in Appendix A.

```
<?xml version="1.0" encoding="UTF-8" ?>
<device name="PPTTracker 1" type="OSC">
      <control id="0" usagePage="1" usage="48" name="X" minimum="-1"
maximum="1" range="2" expression="" />
      <control id="1" usagePage="1" usage="49" name="Y" minimum="-1"
maximum="1" range="2" expression="" />
      <control id="2" usagePage="1" usage="50" name="Z" minimum="-1"
maximum="1" range="2" expression="" />
</device>
```

Each signal output of the device is enumerated in the device description file. The enumeration assigns a unique id number, identifies the usage page and usage number in the Human Interface Device (HID) protocol, gives the human readable name of the control and the range of values that the control creates.

Once these configuration files were written, the Device Server was ready to operate and handle connections. To create a connection to a particular control, a user would first “handshake” with the Device Server using OSC; this handshake is identical to the handshake message used in v3.0. The messages used to connect controls to the application are very similar what is used in v3.0 for dynamically registering mappings. A sample OSC message for connecting a control in v1.0 given below:

```
/connectControl “Hydrogen Bond” 31 1 “x = x / 2” “/cameraTilt” 0
```

An application would normally send out series of these messages once the handshake message from the Device Server has been returned. When the Device Server receives these messages it creates the mappings asked for and begins sending the messages associated with the mappings out to the client application.

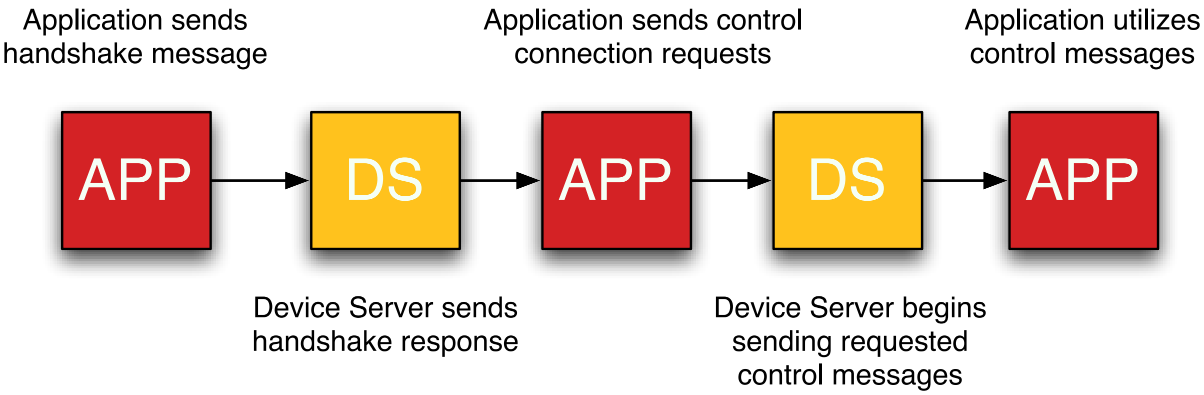
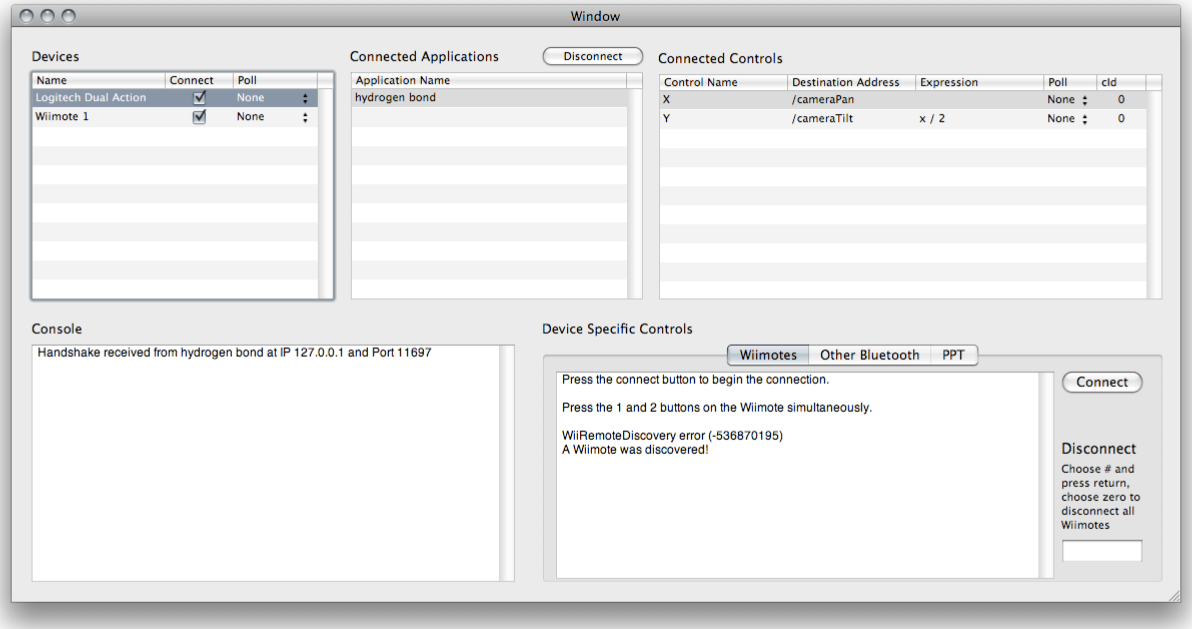

Application sends handshake message
Application sends control connection requests
Application utilizes control messages
APP
DS
APP
DS
APP
Device Server sends handshake response
Device Server begins sending requested control messages

Fig.8 Timeline for client / server initialization in v1.0 of the Device Server application

Fig.9 shows the v.2.0 Device Server GUI.



Devices

Name	Connect	Poll
Logitech Dual Action	☑	None
Wiimote 1	☑	None

Connected Applications

Application Name
hydrogen bond

Connected Controls

Control Name	Destination Address	Expression	Poll	cId
X	/cameraPan		None	0
Y	/cameraTilt	x / 2	None	0

Console

```
Handshake received from hydrogen bond at IP 127.0.0.1 and Port 11697
```

Device Specific Controls

```
Press the connect button to begin the connection.

Press the 1 and 2 buttons on the Wiimote simultaneously.

WiiRemoteDiscovery error (-536870195)
A Wiimote was discovered!
```

Disconnect

Choose # and press return, choose zero to disconnect all Wiimotes

Fig.9 Initial Device Server interface

In Figure 9 the Device Server is running with a Logitech joystick and a Wiimote connected to it. Since the Logitech joystick is highlighted, the GUI shows us the applications which are connected and utilizing the Logitech in the Connected Applications table. Although only one application is connected to the joystick in this image, many could be connected and receive messages from it simultaneously. Since the "hydrogen bond" application is highlighted the Device Server shows us which particular controls the hydrogen bond application is interested in. It also tells us the OSC namespace where messages from that device will be sent to, an expression that can be applied to the control signal to modify it, and a control ID number.

There is a general console for displaying messages along with a more specific console for displaying messages related to the Wiimotes. In future iterations these console windows are consolidated into a single entity. The last major piece of the Device Server to change between v1.0 and v2.0 is the expression engine; v1.0 used an object I created myself to parse and evaluate the expressions.

4.2 Device Server Version 2.0

4.2.1 The Mapping Layer

Version 2.0 brought about substantial changes to the Device Server. The most important of these changes was the introduction of the mapping abstraction layer. The mapping layer now defined the connections between devices and applications; this meant that client applications no longer needed to explicitly create connections using a /connectControl OSC message. In v2.0 (and v3.0) client applications effectively have no awareness of devices whatsoever; they simply announce what parameters they have available to be controlled and the mapping layer of the Device Server takes care of the rest. Version 2.0 used one XML file to define the mapping layer. This file read like an XML version of all the /connectControl OSC messages that were used in v1.0 to map controls to application OSC addresses.

The addition of the mapping layer made the connection process much simpler; client applications simply handshake with the Device Server as shown in Figure 10:

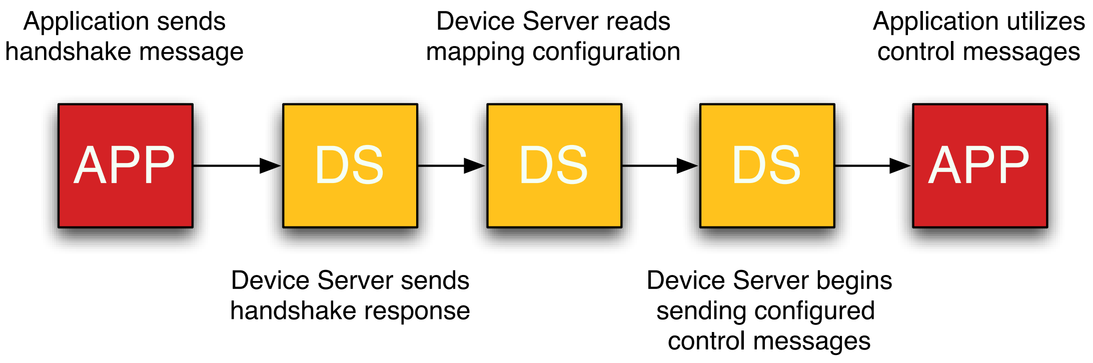

Application sends handshake message
Device Server reads mapping configuration
Application utilizes control messages
APP
DS
DS
DS
APP
Device Server sends handshake response
Device Server begins sending configured control messages

Fig.10 Device Server GUI

v2.0 also added the ability for users to change mappings in the GUI, and added the offsetting and scaling to ensure that no matter what device and control is assigned to an application functionality that functionality will always receive the range of values it expects (see section 3.5).

Below is an example of XML mapping document for a simple app that allows a joystick to control the coordinates of an object on the screen.

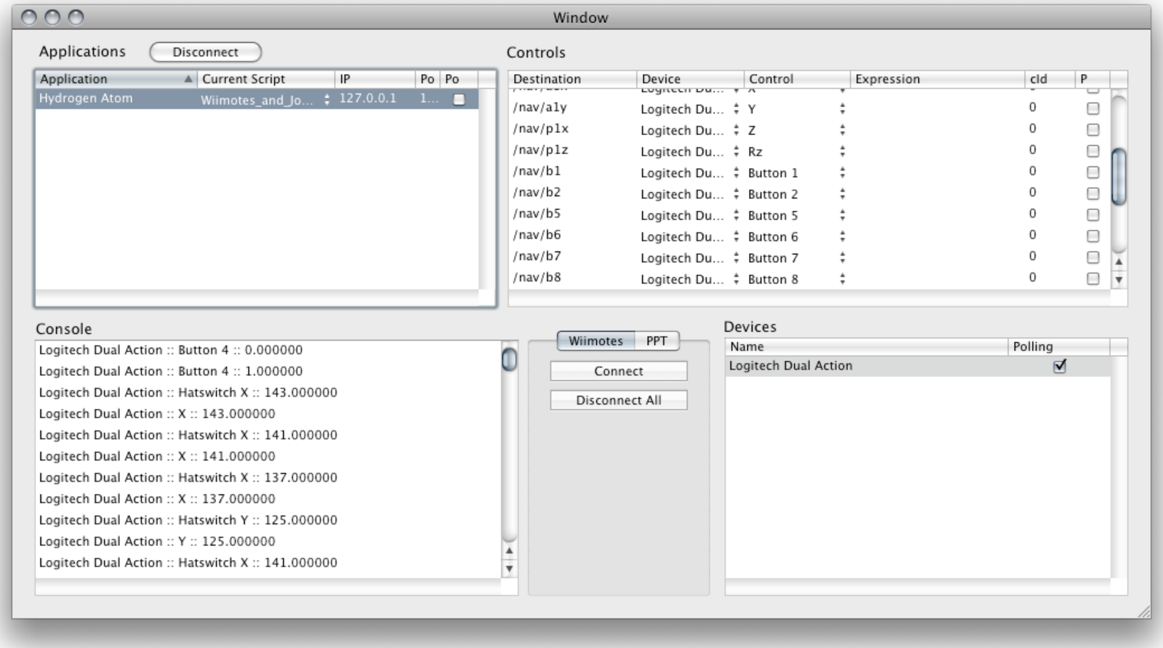
```
<?xml version="1.0" encoding="UTF-8"?>
<mappings>
      <map destination="/X" device="31" control="0" min="-1" max="1"
expression="" cID="0" />
      <map destination="/Y" device="31" control="1" min="-1" max="1"
expression="" cID="0" />
</mappings>
```

4.2.2 Expression Engine

Another important change in v2.0 was the introduction of JavaScript based expression engine. By including the WebKit library the Device Server was able to take advantage of the highly optimized SquirrelFish JavaScript engine. This enabled more complex expressions to be written that were also more efficient.

4.2.3 Application Centric View vs. Device Centric View

The GUI in v1.0 was centered around devices; the user selected which device they were interested in monitoring and the Device Server would then show which applications were connected it and what controls in particular the application was interested in. As v1.0 was utilized in the AlloSphere, users came to the conclusion that it would be useful to see an applications entire collection of mappings at once. The GUI in v2.0 switched to an application centric view where users see all the controls for a selected client application simultaneously. This switch simplified the GUI; only two views (Applications, Mappings) were needed to monitor connections rather than the three (Devices, Applications, Mappings) found in earlier versions. The GUI for v2.0 is shown below in Fig. 11.



Application	Current Script	IP	Po	Po
Hydrogen Atom	Wiimotes_and_Jo...	127.0.0.1	1...	□

Destination	Device	Control	Expression	cId	P
/nav/a1y	Logitech Du...	Y		0	□
/nav/p1x	Logitech Du...	Z		0	□
/nav/p1z	Logitech Du...	Rz		0	□
/nav/b1	Logitech Du...	Button 1		0	□
/nav/b2	Logitech Du...	Button 2		0	□
/nav/b5	Logitech Du...	Button 5		0	□
/nav/b6	Logitech Du...	Button 6		0	□
/nav/b7	Logitech Du...	Button 7		0	□
/nav/b8	Logitech Du...	Button 8		0	□

```
Logitech Dual Action :: Button 4 :: 0.000000
Logitech Dual Action :: Button 4 :: 1.000000
Logitech Dual Action :: Hatswitch X :: 143.000000
Logitech Dual Action :: X :: 143.000000
Logitech Dual Action :: Hatswitch X :: 141.000000
Logitech Dual Action :: X :: 141.000000
Logitech Dual Action :: Hatswitch X :: 137.000000
Logitech Dual Action :: X :: 137.000000
Logitech Dual Action :: Hatswitch Y :: 125.000000
Logitech Dual Action :: Y :: 125.000000
Logitech Dual Action :: Hatswitch X :: 141.000000
```

Name	Polling
Logitech Dual Action	☑

Fig.11 v.2.0 Device Server GUI

4.3 Lessons Learned (Device Server 3.0)

Although there were very few changes to the GUI from v2.0 to v3.0, there were a large number of changes under the hood. These changes have (so far) stood the test of time; 3.0 has been deployed in the AlloSphere for about six months and no major changes to the software architecture have been needed since deployment. The changes in v3.0 resulted from growing use in the AlloSphere; as more applications were ported to rely on the Device Server for interactivity more developers began making requests for new features or changes in functionality. These requests led to a number of notable improvements in v3.0 which will be detailed in this section.

4.3.1 Moving from XML / JavaScript to Lua

In v2.0 of the Device Server XML was used for the configuration files and JavaScript was used for the writing expressions. There was resistance to developers in the AlloSphere working group to using XML; many preferred Lua as a data descriptor language. Although I was initially hesitant to put in the work to change from XML to Lua, the more I studied the possibilities the more convinced I was that the change was needed. This section outlines the many benefits of transitioning to Lua.

4.3.1.1 Code Reuse and Dynamism

By using Lua we gain the ability to have custom functions for manipulating control signals included in the configuration files. With the XML / JavaScript combination in v2.0 this wasn’t really possible; expressions in v2.0 were stored as a string in the XML and usually consisted of a single line of JavaScript. By using Lua reusable functions can be defined that are then used by multiple mappings in a client application; these functions can even be shared across applications. A common example of a function that might be used this way is one that corrects analog drift. In v2.0, each analog mapping needed to have a JavaScript expression for drift prevention similar to the following:

```
x = (x > -.07 && x < .07) ? 0 : x
```

This expression basically says: “If x is in between -.07 and .07 then make the value 0” with the goal of eliminating spurious values when the joystick is at rest in its center position. The problem is that this expression might be placed into a configuration file seven or eight times; if a developer decided that the values should be {-.6, .6} instead of {-.7, .7} he or she would have to change the code eight times. Using Lua we can define a function once, such as:

```
function destroyDrift(value)
      if(value > -.07 and value < .07) then
            return 0
      else
            return x
      end
end
```

Then the expression used in the mapping file just becomes `x = destroyDrift(x)`. Developers can now perform any needed modifications in the function rather than the expressions themselves; these modifications will be instantly reflected in all mappings utilizing it.

Another advantage of using Lua is that mappings and device descriptions can be dynamically generated. The device description files for MIDI (Musical Instrument Digital Interface) devices, for example, are particularly redundant, with many controls possessing the same range of values {0, 127} and one of four names (note, cc, program change, pitchbend). It would take 127 lines of code to describe the full range of notes that most MIDI keyboards could send; another 127 would be required for CC (continuous control) messages, another 127 for noteoff etc. A single MIDI device configuration file could wind up having well over 500 lines of code if all controls were individually enumerated. The description file for a MIDI device that only sent NoteOn messages would like like the following:

```
controls = {
  id=0, usagePage=0, usage=0, name=“noteon 0”, min=0, max=0, expression=””,
  id=1, usagePage=0, usage=0, name=“noteon 1”, min=0, max=0, expression=””,

  <insert lines 2 - 126 here>

  id=127, usagePage=0, usage=0, name=“noteon 127”, min=0, max=0,
expression=””,
}
```

By using Lua we can shorten the 127 lines of code to the following for loop:

```
controls = {}

for i = 0, 127 do
      controls[i + 1] = {
            id = i,
            usagePage = 0,
            usage = 0,
            name = "noteon " .. i,
            minimum = 0,
            maximum = 127,
            expression = "",
      }
end
```

(Note: .. is the concatenation operator in Lua, and tables are usually indexed starting with one, not zero).

The two short scripts shown here are already much more complex than anything v2.0 of the DeviceServer was capable of. It is theoretically possible that longer, more complicated scripts could have been stored in the XML configurations found in v2.0 and parsed out into JavaScript but having them available as interpretable Lua is a much more elegant solution.

4.3.1.2 Speed and Efficiency

Lua is widely considered to be the fastest scripting language available. The LuaJIT library takes this speed one step further by adding just-in-time compilation to functions. The only scripting engines that even come close to matching LuaJIT in speed are the newest JavaScript engines: V8 from Google, Nitro from Apple and TraceMonkey from Mozilla. But even the new JavaScript engines are all still substantially slower than LuaJIT 1.0. LuaJIT 2.0 has just begun beta testing and promises dramatic performance improvements; SciMark scores recently posted to the Lua mailing list score LuaJIT 2.0 faster than the Java Virtual Machine, and in some benchmarks (Jacobi Successive Over-relaxation, Monte Carlo integration) LuaJIT 2.0 outperforms C code compiled with GCC 4.3.2..

By using LuaJIT in the Device Server application developers get very fast scripting of signal transformations and the flexibility of changing scripts as much as they want without having to recompile their application.

4.3.2 Abstracting the Abstraction Layer

One problem with the XML mappings file used in v2.0 was that many mappings wound up containing identical sets of information. In particular, the range of values each mapping was expecting to receive was identical between all the different mapping configuration files for a given application. if an application changes the controls that were available to it, or changes the accepted range of signals it wants to see, then mappings in all the separate configuration files would have to be changed individually. The solution for this in v3.0 was to place all the static information associated with mappings into a separated file, which was termed the *Interface* file for the application. The information that might change for mappings (which device / control was connected, expressions to be applied to the signal etc.) was placed in *Implementation* files. For example, you might have one implementation that uses a wired joystick for navigation, another that used a wireless joystick and a third that used a MIDI device. Each of these configurations would have its own implementation file but all would look to the same interface file to determine what controls were available for mapping and what range of values each control was expecting to receive. The implementation and interface files for v3.0 are described in detail in section 3.3.3.

4.3.3 Device Driver Plugins

Prior to v3.0, device drivers were hardcoded into the Device Server project. This meant the Device Server itself had to be modified in order use new devices. In v3.0, there is a plugin system that allows developers to write their own modular device driver for the Device Server. Developers can use an XCode template that comes with a framework giving them access to all the main objects in the Device Server application. Simple GUIs can be added if communication with devices is needed; for example, a handshake message has to be sent to the PPT system. The drivers and the GUIs are dynamically loaded when the Device Server first begins running. The plugin system is described in detail in section 3.9.1.

5. Comparison and Evaluation

In Section 2 various alternatives to the Device Server were discussed; in this section they will be explicitly compared to the Device Server. Most of the discussion will be dedicated to VRPN; many of the architectural differences between the Device Server and VRPN are also present in VRui and Gadgeteer. The Mapping tools of the Digital Orchestra Toolbox will also receive a more detailed treatment as it is conceptually most similar to the Device Server of all the frameworks reviewed. User feedback and latency concerns will also be discussed.

5.2.1 VRPN

VRPN is perhaps the most widely used framework for interactivity. There are fundamental design differences in the architecture between VRPN that create benefits and drawbacks to using either platform.

5.2.1.1 Dynamism

With the Device Server no recompilation is necessary to change what device is feeding your application; you simply change the implementation file for your app and refresh the script. This allows for a level of experimentation with devices that would be difficult to achieve in a static setup (mapping tools reference). In a multiuser setup dynamism becomes particularly important. If you have five users in a VR environment and each user is experimenting with different roles and different devices, it would be practically impossible to configure with a server that could not be dynamically configured. Every time a person would want to change a device or the filtering of a device signal in some way the entire application would have to be recompiled. The Device Server provides a very fluid way to deal with these issues by giving a GUI to select which devices / controls are assigned to which application functionalities. Lua scripts can also be modified and refreshed via the Device Server GUI while the application is running.

In their article "Using a scripting engine to facilitate the development of force fields in a distributed haptic setup"[13] the authors talk about their efforts to bring dynamism to VRPN. They created a custom VRPN force-field server object that interpreted Lua code sent to it by clients after a connection link had been established. This type of functionality is available within the Device Server out of the box. Change the Lua script assigned to a mapping, hit refresh, and you're done.

This dynamism also includes introduction of devices into virtual environments. Mobile devices can be dynamically introduced to the Device Server and immediately utilized by running applications, who are automatically sent notification of their introduction. Applications are also sent a notification whenever devices are disconnected so that they can respond accordingly.

5.2.1.2 OSC

Although not necessarily an advantage for computer scientists, choosing OSC as the communication protocol for the Device Server greatly eases using devices for artists, musicians and hybrid engineers. As of this writing, Max/MSP is the only common prototyping library used that has a library or object for handling VRPN connections. Pd, Processing, Quartz Composer and OpenFrameworks all have excellent support for OSC communication.

5.2.1.3 Device Agnosticism

In VRPN there are several different classes of devices; when you register to receive messages from one type of device and assign it to control parameters of your application that's the only type of device that can be used for that callback. There are exceptions, but they are what might be called "hacks"; for example, the vrpn_AnalogFly object takes in messages from a joystick and outputs vrpn_Tracker messages. Any conversion between different types of devices requires this type of specialized, compiled object to be created in VRPN. With the Device Server, all signals are treated equally and any object can be used to feed any parameter of an application.

The downside to this is that it’s not possible to easily switch one entire device for another in the Device Server because it doesn’t have that extra layer of abstraction present (classes of devices). Switching individual controls is easier, including switching from one button to another button on the same device, but switching an entire device is more difficult.

5.2.1.4 Distributed Servers, Latency and GUIs

There is no GUI application available to establish and monitor VRPN connections between devices. This is possibly due to differences in the client / server models between VRPN and the Device Server. The Device Server has one centralized aggregation point for all devices in a system; VRPN does not have any such aggregation point out of the box. Rather, VRPN assumes that client applications will connect directly to computers that are serving up device signals. A simplified comparison of the interfaces in the two architectures is given below in Fig. 12.

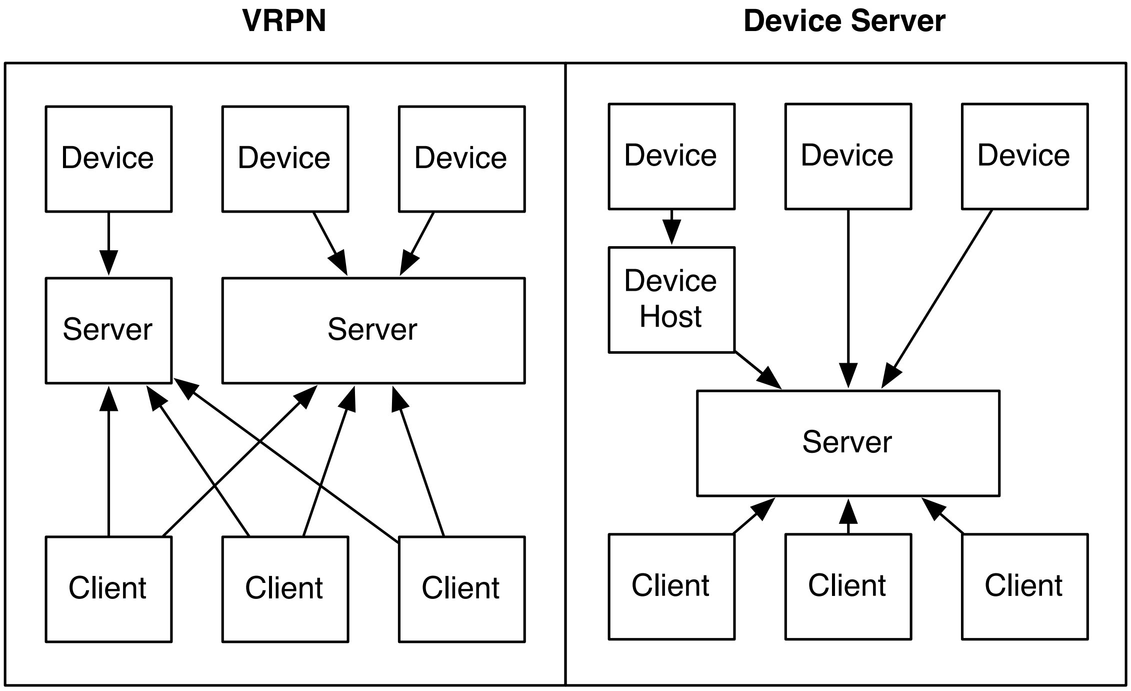


Fig.12 Device Server / VRPN comparison

Without a centralized aggregation point, there is no easy computer to locate a GUI based monitoring app on. A special VRPN (a VRPN Server is a program that sends out signals from one or more devices) could be specially configured to aggregate the signals of other VRPN servers, but no server like this has been created as of yet.

The VRPN model is in some cases a lower latency model than the Device Server as clients almost always have direct network connections to the computers hosting the devices. In Fig. 12 one of the devices has an intermediary computer that it is hosted on; an example of this in the AlloSphere is the WorldViz PPT system. The cameras are hooked up to a dedicated computer that performs the computer vision analysis necessary to obtain the three dimensional coordinates of each tracking device. This coordinate information is then sent to the Device Server, which in turn sends it out to client applications. In a typical VRPN setup the client applications would be interfaced directly with the computer performing the vision processing; this would avoid one network hop and the associated overhead.

A final disadvantage of having multiple servers (as in VRPN) is that there is potentially a large number of IP addresses that a client application needs to be aware of as opposed to the single IP address needed when using the Device Server.

5.2.1.5 Control Signal Processing

The Device Server features the ability to write custom expressions for control processing; these expressions are dynamic and can be adjusted without having to recompile a client application. Although it is definitely possible to perform control signal processing using a VRPN, any adjustment of the processing will require the developers to recompile their VRPN server. It is possible to embed a scripting engine into a VRPN plugin (earlier force-field reference), but it is extra work that would be required for every single device in a interactive system.

5.2.2 Gadgeteer

Gadgeteer has the same device abstraction layer that VRPN has with the same costs and benefits. Devices of the same type can easily be interchanged, but mixing and matching individual control objects becomes difficult. In Gadgeteer, abstract device categories also have predefined ranges of output, for example, devices of type Analog always return a floating point number in the range of {0, 1}. This means controls in a client application have to be hardwired to accept a range of values that will not apply to other abstract input types. If a control in an application only knows how to use numbers from {0, 1} there is no way for it to successfully process, for example, positional data measured in meters.

5.2.3 VRui

As mentioned in 2.1 VRui has an extra layer of abstraction called *tools*. In effect, a tool is a meta device; a tool combines the controls of multiple devices into a single interface and also states a functionality for the aggregation. In VRPN and Gadgeteer individual devices can be swapped for one another if they are of the same type; VRui takes this one step further by allowing collections of devices and controls that represent functionalities to be interchanged easily.

5.2.4 DIVERSE ToolKit (DTK)

The DIVERSE (Device Independent Virtual Environments- Reconfigurable, Scalable, Extensible) ToolKit [14](DTK) provides an architecture similar to other virtual reality frameworks mentioned in this thesis. It distinguishes itself by using a shared object memory model for distribution instead of a client / server messaging model.

There is no GUI for the DTK. Device objects are treated as dynamic shared objects, and thus can be loaded and unloaded at runtime. This allows servers to be reconfigured and different devices to be connected to running applications without the need for recompilation. However, the loading and unloading of devices is all done through the command line and there are no monitoring mechanisms for examining signals and troubleshooting them.

The DTK does not provide any mechanism for transformation of control values.

5.2.5 Mapping tools of the Digital Orchestra Toolbox

The DOT mapping tools are conceptually closest to the Device Server of all the frameworks compared. However, there are still fundamental differences between the two. The DOT mapping tools thinks of every object that it manages connections for as a device. Devices in the mapping tools can have both inputs and outputs; interaction devices would typically only have outputs while applications would typically only have inputs. This allows easy bi-directional communication to take place; a good example of when communication would need to flow from application to device (rather than vice-versa) is force feedback. The Device Server does not currently possess any mechanisms for force feedback. In many ways, the DOT mapping tools solution of having all objects (applications and devices) treated as a collection of inputs and outputs is a more elegant than having a distinction between the two that starts to breakdown when bi-directional communication is necessitated.

The current implementation of the DOT mapping tools is also not intended to act as a server. There is no way to have an application register with the mapping tools and automatically begin receiving messages; users must manually load in an XML file after navigating to its container directory. With the Device Server, the Default.lua implementation is loaded automatically upon receiving a handshake message and messages are immediately transmitted from the Device Server. This is possible due to the directory structure that the Device Server enforces for applications and their scripts; there is never a need to search for implementation files. Running virtual environments in the AlloSphere is a complicated task; adding an extra step of having users navigate to configuration files every time a new application is loaded is not acceptable.

The Lua scripting environment of the Device Server provides a great deal more flexibility than the single line expressions and static XML files of the DOT mapping tools.

Even though the DOT mapping tools framework was discovered many months after work on the Device Server had begun, the similarities between the two is notable, particularly in comparison to the other frameworks described in this section. The Device Server also has a GUI that makes it easy to alter connections between devices and applications. The Device Server also uses a data description format (Lua instead of XML in the current version) to both describe devices and store the connections used in applications. The similarities between the two are interesting considering that both were developed by hybrid musicians / engineers instead of virtual reality researchers.

5.3 Latency

Latency of the Device Server was measured while fifteen accelerometers were running through the Device Server simultaneously. Over the course of a hundred samples, the mean latency was found to be .490 ms with a standard deviation of .169 ms while running on a dual core Mac Pro. The amount of latency introduced by the Lua expression engine is variable according to the complexity of the script, however, recent improvements to the JIT compilation in Lua are greatly increasing the speed of the expression engine.

5.4 User Feedback

I conducted a short lesson on how to use the Device Server with (primarily) graduate students in the Media Arts and Technology program at the University of California, Santa Barbara with different levels of experience in regards to both programming and the use of interactive devices. Afterwards students were asked to submit thoughts and opinions about the Device Server. All users reported that they would consider using the Device Server for projects not running in the AlloSphere. The universal complaint was regarding the need for documentation and examples:

- “step by step instruction, flowchart, and debug tips”,
- “create a video tutorial or/and make a web based listing, step by step of the process, breaking the steps into chunks.”,
- “make/receive code in the general languages (should be easy since people have already completed it) ... i.e. have a basic max patch on hand for max users, lua for lua users, etc”.

Watching students attempt to use the Device Server led me to believe that the need for example client applications and configuration files is the most critical of their concerns. As mentioned in the final comment above, these example clients should come from a variety of platforms (Max/MSP, Pd, Processing, C++, Lua etc.) so that everyone has a template ready to be altered and used. These examples should be included in the source code repository.

6. Future Directions and Conclusion

I would prefer if the Device Server wasn't tied to Cocoa and OS X; i am most interested in porting the Device Server to Java and some work has already been done to this effect. However, in terms of application development time, Cocoa adds many luxuries that speed development. For example, there was little code required to write the Application and Device array controllers; the array controller objects included in Cocoa handle the addition and removal of objects and update attached displays in the Device Server GUI with very little glue code required. Creating a plugin architecture was also relatively simple; the NSBundle handles dynamic loading and unloading of objects at runtime. Still, I think it would spur outside usage and development contributions if the Device Server was not platform specific. There is also a much larger community of Java developers than Objective-C developers to get involved in the project.

There are a number of reasons I would prefer to port the Device Server to Java rather than C++. With Java, there is no need to worry about platform specific drivers for MIDI, HID etc. The Java drivers will work cross-platform; not having to worry about platform specific driver issues is another major advantage of initially limiting myself to OS X development. VRPN illustrates this problem perfectly as the VRPN library contains many classes that only function under one operating system. The most recent version as of the time of this writing, v 7.22, was the first to add HID support for OS X and there are many other devices that only work under Windows. Java also provides a unified GUI development environment with Swing whereas C++ possesses a myriad of GUI options (Qt, wxWidgets, GTK, etc.). If the Device Server used Swing all Java developers would have at least some experience with GUI programming; there is no similar alternative for C++ that all developers would be familiar with.

The device abstraction layers found in the other frameworks (VRPN, VRui etc) yield interesting benefits that should be explored. I would like to figure out a way to provide similar abstractions in the Device Server without sacrificing the ability to have any control replace any other control in a mapping. I am particularly interested in the tools concept found in VRui; that is, the ability group devices and controls into units defined by their functionality rather than the controls they present. The ability to quickly map a navigation tool to camera movement in a VRE would be an excellent addition to the Device Server.

I am interested in adding a full eatured back-end for VRPN to the Device Server. I believe the VRPN community could benefit from the configuration abstractions and scripting capabilities that the Device Server has to offer. Although it would require some hacks to get working, creating a VRPN based Device Server would be a valuable contribution to the virtual reality community.

A final goal is to make the Device Server easier for artists and musicians as opposed to developers. The ability to dynamically configure performance applications to accept a variety of controls and devices would be valuable in the digital arts community. However, there are currently some significant barriers to entry to use the Device Server; the most significant of these is the ability to program in Lua. Although it is very easy to change configurations and save them on-the-fly with the Device Server, the initial configuration files must currently be created in a text editor. One possibility for simplification is to augment the Device Server GUI so that it is capable of creating interface and implementation files from scratch. This would allow users to avoid having to use Lua for configuration purposes although they would still need to learn basic Lua syntax if they needed to write custom expressions for transforming control signals.

Conclusion

The Device Server provides a dynamic, scalable solution for multi-user interactivity. As compared to other VR interactive frameworks its dynamism encourages users to experiment with interactivity by simplifying the process of experimentation. Users can change control configurations via simple pull-down menus without having to recompile or reprogram applications. The Device Server homogenizes the values sent from devices to applications so that users don't have to worry about the signals different devices emit; they are all transformed to the ranges expected by client applications. This dynamism is of great value in multi-user setups as it is relatively straightforward to change the functionalities assigned to different devices and the roles of users employing them. Once changed these configurations can be easily saved and recalled for future use.

The Device Server assists VRE developers by managing the disparate protocols used to communicate with interactive devices. Instead of worrying about how to programmatically include device drivers into VREs developers can concentrate on the interactive affordances of different devices and how best to utilize them. Developers also benefit from the Lua scripting environment which allows them to offload the transformation of control signals onto to the Device Server so that the CPUs of rendering computers are not taxed. Finally, developers are not required to create different versions of their software in order to accommodate different devices; the Device Server handles all device configuration concerns for them.

The Device Server benefits interactive system architectures by providing a single central location for all device signals to be accessed. It allows multiple applications to access connected devices and provides a convenient method for monitoring all connections and the signals traveling between them. Devices requiring a dedicated computer for signal processing can forward messages to the Device Server post-processing at which point they are available to all connected applications.

The Device Server is currently being used by multiple applications inside the AlloSphere scientific instrument located at the University of California, Santa Barbara. Development and design of the Device Server progresses iteratively and benefits from the input of both developers and VRE participants. Future work on the server will focus on incorporating input abstractions found in other VR frameworks, opening development to outside developers and making the server as simple as possible for use in the digital arts community.

Appendix 1 - Sample Lua Configuration Files and Scripts

Below is the current Master Device List used in the AlloSphere.

MASTER DEVICE LIST:

```
devices = {
      -- 0 - 10 reserved for Wiimotes
      { id = 1, name = "Wiimote 1" },
      { id = 2, name = "Wiimote 2" },
      { id = 3, name = "; 3" },
      { id = 4, name = "Wiimote 4" },

      -- 11 - 30 reserved for PPTTrackers
      { id = 11, name = "PPTTracker 1" },
      { id = 12, name = "PPTTracker 2" },
      { id = 13, name = "PPTTracker 3" },
      { id = 14, name = "PPTTracker 4" },

      { id = 31, name = "Logitech Dual Action" },
      { id = 32, name = "Logitech Cordless RumblePad 2" },
      { id = 33, name = "Logitech RumblePad 2 USB" },
      { id = 50, name = "USB 2-Axis 8-Button Gamepad" },

      { id = 61, name = "iPhone 1" },
      { id = 62, name = "iPhone 2" },
      { id = 63, name = "iPhone 3" },
      { id = 64, name = "iPhone 4" },
      { id = 65, name = "iPhone 5" },
      { id = 66, name = "iPhone 6" },
      { id = 67, name = "iPhone 7" },

      { id = 70, name = "Griffin PowerMate" },
      { id = 72, name = "Accelerometer" },
      { id = 101, name = "padKONTROL Port 1" },
      { id = 102, name = "padKONTROL Port 2" },
      { id = 103, name = "padKONTROL Port 3" },
      { id = 104, name = "IAC Driver Bus 1" },
      { id = 104, name = "IAC Driver IAC Bus 2" },
      { id = 105, name = "UltraLite MIDI Port" },
      { id = 106, name = "nanoKONTROL Port 1" },
      { id = 107, name = "nanoKEY Port 1" },
      { id = 108, name = "Audio" },
}
```

Hydrogen Atom

The Hydrogen Atom is currently the only multi-user demo running in the AlloSphere. It allows one user to act as a navigator while two other users direct particle streams to probability currents and gradients. In the AlloSphere we have a device configuration that consists of one Logitech gamepad for the navigation and two Nintendo Wiimotes for the particle streamers. There is another configuration that allows a single user to navigate and fire the streamers; the streamers stay locked to the camera position since there are no other users to guide them. The Lua configuration files are below:

INTERFACE FILE: (there is only one interface file for each application)

```
signals = {
      { name = "Camera Rotate X",     min = -1, max = 1 },
      { name = "Camera Rotate Y",     min = -1, max = 1 },
      { name = "Camera Move X",       min = -1, max = 1 },
      { name = "Camera Move Y",       min  = -1, max = 1 },
      { name = "Dust Cloud",          min = 0,  max = 1 },
      { name = "Next Preset",           min = 0,  max = 1 },
      { name = "Previous Preset",       min = 0,  max = 1 },

      { name = "Current Avatar Fire",   min = 0,  max = 1 },
      { name = "Current Avatar Center", min = 0,  max = 1 },
      { name = "Current Avatar X",      min = -1, max = 1 },
      { name = "Current Avatar Y",      min = -1, max = 1 },
      { name = "Current Avatar Z",      min = -1, max = 1 },

      { name = "Gradient Avatar Fire",    min = 0,  max = 1 },
      { name = "Gradient Avatar Center",  min = 0,  max = 1 },
      { name = "Gradient Avatar X",       min = -1, max = 1 },
      { name = "Gradient Avatar Y",       min = -1, max = 1 },
      { name = "Gradient Avatar Z",       min = -1, max = 1 },
}
```

MULTI-USER IMPLEMENTATION FILE:

```
mappings = {
  { name = "Current Avatar Fire",    destination = "/prbC/b1",  device = 1,
      control = 17,  expression = "", cID = 0 },
  { name = "Current Avatar Center",  destination = "/prbC/b3",  device = 1,
      control = 16,  expression = "", cID = 0 },
  { name = "Current Avatar X",       destination = "/prbC/p1x", device = 1,
      control = 18,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Current Avatar Y",       destination = "/prbC/p1y", device = 1,
      control = 19,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Current Avatar Z",       destination = "/prbC/a0z", device = 1,
      control = 14,  expression = "x = x/90", cID = 0 },

  { name = "Camera Rotate X",      destination = "/nav/a1x",  device = 32,
      control = 0,   expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Rotate Y",      destination = "/nav/a1y",  device = 32,
      control = 1,   expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Move X",        destination = "/nav/p1x",  device = 32,
      control = 2,   expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Move Y",        destination = "/nav/p1z",  device = 32,
      control = 3,   expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Dust Cloud",           destination = "/nav/b1",   device = 32,
      control = 4,   expression = "", cID = 0 },
  { name = "Next Preset",            destination = "/nav/b7",   device = 32,
      control = 10,  expression = "", cID = 0 },
  { name = "Previous Preset",        destination = "/nav/b8",   device = 32,
      control = 11,  expression = "", cID = 0 },

  { name = "Gradient Avatar Fire",   destination = "/prbG/b1",  device = 2,
      control = 17,  expression = "", cID = 0 },
  { name = "Gradient Avatar Center", destination = "/prbG/b3",  device = 2,
      control = 16,  expression = "", cID = 0 },
  { name = "Gradient Avatar X",      destination = "/prbG/p1x", device = 2,
      control = 18,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Gradient Avatar Y",      destination = "/prbG/p1y", device = 2,
      control = 19,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Gradient Avatar Z",      destination = "/prbG/a0z", device = 2,
      control = 14,  expression = "", cID = 0 },
}

-- FUNCTIONS

function destroyDrift(x)
  if x > -.07 and x < .07 then
    x = 0
  end
  return x
end
```

SINGLE USER IMPLEMENTATION FILE:

```
mappings = {
  { name = "Camera Rotate X", destination = "/nav/a1x",  device = 32,
      control = 0,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Rotate Y", destination = "/nav/a1y",  device = 32,
      control = 1,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Move X",   destination = "/nav/p1x",  device = 32,
      control = 2,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Camera Move Y",   destination = "/nav/p1z",  device = 32,
      control = 3,  expression = "x = destroyDrift(x)", cID = 0 },
  { name = "Dust Cloud",      destination = "/nav/b1",   device = 32,
      control = 4,  expression = "", cID = 0 },
  { name = "Current Avatar Fire",    destination = "/nav/b5",   device = 32,
      control = 8,  expression = "", cID = 0 },
  { name = "Gradient Avatar Fire",  destination = "/nav/b6",   device = 32,
      control = 9,  expression = "", cID = 0 },
  { name = "Next Preset",           destination = "/nav/b7",   device = 32,
      control = 10, expression = "", cID = 0 },
  { name = "Previous Preset",       destination = "/nav/b8",   device = 32,
      control = 11, expression = "", cID = 0 },
}

-- FUNCTIONS
```

```
function destroyDrift(x)
  if x > -.07 and x < .07 then
    x = 0
  end
  return x
end
```

EXAMPLE DEVICE CONFIGURATION DOCUMENT::

```
atrributes = {
  name = "Logitech Cordless RumblePad 2"
}

controls = {
  { id = 0, usagePage = 1, usage = 48, name = "X", minimum = 0,
      maximum = 255, expression = "" },
  { id = 1, usagePage = 1, usage = 49, name = "Y", minimum = 0,
      maximum = 255, expression = "" },
  { id = 2, usagePage = 1, usage = 50, name = "Z", minimum = 0,
      maximum = 255, expression = "" },
  { id = 3, usagePage = 1, usage = 53, name = "Rz", minimum = 0,
      maximum = 255, expression = "" },
  { id = 4, usagePage = 9, usage = 1, name = "Button 1", minimum = 0,
      maximum = 1, expression = "" },
  { id = 5, usagePage = 9, usage = 2, name = "Button 2", minimum = 0,
      maximum = 1, expression = "" },
  { id = 6, usagePage = 9, usage = 3, name = "Button 3", minimum = 0,
      maximum = 1, expression = "" },
  { id = 7, usagePage = 9, usage = 4, name = "Button 4", minimum = 0,
      maximum = 1, expression = "" },
  { id = 8, usagePage = 9, usage = 5, name = "Button 5", minimum = 0,
      maximum = 1, expression = "" },
  { id = 9, usagePage = 9, usage = 6, name = "Button 6", minimum = 0,
      maximum = 1, expression = "" },
  { id = 10, usagePage = 9, usage = 7, name = "Button 7", minimum = 0,
      maximum = 1, expression = "" },
  { id = 11, usagePage = 9, usage = 8, name = "Button 8", minimum = 0,
      maximum = 1, expression = "" },
  { id = 12, usagePage = 9, usage = 9, name = "Button 9", minimum = 0,
      maximum = 1, expression = "" },
  { id = 13, usagePage = 9, usage = 10, name = "Button 10", minimum = 0,
      maximum = 1, expression = "" },
  { id = 14, usagePage = 9, usage = 11, name = "Button 11", minimum = 0,
      maximum = 1, expression = "" },
  { id = 15, usagePage = 9, usage = 12, name = "Button 12", minimum = 0,
      maximum = 1, expression = "" },
  { id = 16, usagePage = 1, usage = 57, name = "Hatswitch", minimum = 0,
      maximum = 8, expression = "" },
  { id = 17, usagePage = 1, usage = 48, name = "Hatswitch X", minimum = 0,
      maximum = 255, expression = "" },
  { id = 18, usagePage = 1, usage = 49, name = "Hatswitch Y", minimum = 0,
      maximum = 255, expression = "" },
}
```

Appendix 2 - Device Server Lua Scripting Reference

General Usage
All expressions are introduced in one of two places: the implementation files of an application or the device configuration files. An expression normally takes the following form:

```
x = x + (x / 2)
```

or

```
x = someFunctionName(x)
```

where someFunctionName is the name of a Lua function that has been defined in the implementation file. In these expressions, x represents both the final value passed to the application (hence it appears on the left side of the equal sign) and also the value passed into the expression to be used. If we call a Lua function in the expression, it needs to return a value for X to be passed to the application. An example of a function that will pass the highest value stored is given below:

```
highestValue = -10000

function getHighestValue(x)
      if x > highestValue then
            highestValue = x
      end
      return highestValue
end
```

In the implementation file, this function would be called assigned in a mapping as follows:

```
expression = “x = getHighestValue(x)”
```

Console Object
The console object can be used to print to the console view in the Device Server Gui

Methods: print(*aString*)
Example script:

```
console:print(“The value is “ .. x)
```

Mapping Object
The Mapping object represents the mapping that the Lua expression currently being evaluated belongs to. It contains a number of properties and access to the Application object. rawX() is a particularly useful method that gets the value of the signal feeding into the mapping before any offsetting, scaling or expressions have been performed. preExpressionValue() is another useful method used to get the value after offsetting and scaling but before the expression has been evaluated

Methods: min(), max(), scalar(), rawX(), preExpressionValue(), application(), deviceID(), controlID()

min() - the low end of the device signal range

max() - the high end of the device signal range scalar() - a scalar is calculated when the mapping is created in order to match the signals to the range expected by the mapping's application

offset() - an offset is used in conjunction with the scalar for matching signal range to expected application range

rawX() - the value of the signal feeding into the mapping before any offsetting, scaling or expressions have been performed.

preExpressionValue() - the value of the signal after offsetting and scaling but before the expression has been evaluated

application() - returns the application object that the mapping belongs to

deviceID() - the ID number of the device feeding the mapping

controlID() - the ID number of the control feeding the mapping

The example script below feeds the raw value (in this case of a DPad on Logitech joystick) and creates a value in the range {-1, 1} using a lookup table.

```
expression = “x = haty(mapping:rawX())”

function haty(x)
      if x == 1 or x == 2 or x == 3 then
            return 1
      elseif x == 5 or x == 6 or x == 7 then
            return -1
      else
            return 0
      end
end
```

Application Object
The Application object represents the application the mapping belongs to. It is primarily used to get access to other mappings using the mappingForName(mappingName) function. The mappingForName function returns the application's mapping that matches the name provided. This allows one mapping to base its output off of the value of another mapping. One case where this could be used is in with coarse and fine pitch control. When the coarse control is changed, you want to output the value of the coarse signal plus whatever the last value of the fine signal was and vice versa. An example script for this is given below:

```
function coarse(x)
  -- we use the preExpressionValue because the final output of fine will
  -- have added the coarse value to it...
  f = application:mappingForName("fine"):preExpressionValue()
  x = x + f
  return x
end

function fine(x)
  f = application:mappingForName("coarse"):preExpressionValue()
  x = x + f
  return x
```

```
end
```

Constants

DNR - When a function returns DNR (Do Not Return) no value is sent out to applications. This can be used to create momentary triggers from continuous signals or to only send values under special circumstances. For example, if we only wanted to send a message when the volume of an audio signal was above a particular value we could do so as follows:

```
function audioThreshold(x)
      if x > .75 then
            return x
      else
            return DNR
      end
end
```

gPwd - gPwd is a global that refers to the present working directory when used with application Implementation files. It is used to assist in code reuse. For example, the Device Server first loads a file called “Default.lua” when an application handshakes it. One common use for gPwd is for Default.lua to point to an existing script that is named descriptively. A simple Default.lua that loads another file is given below:

```
dofile(gPwd .. "Wireless No Wiimotes.lua")
```

dofile simply runs the script at the provided location.

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