Marionnet: a virtual network laboratory and simulation tool

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ABSTRACT

We present Marionnet[1], a high-level simulation tool allowing to accurately reproduce the behavior of physical computer networks made by computers, hubs, switches and routers; virtual machines run unmodified GNU/Linux binaries for the x86 architecture at nearly native speed.

Individual virtual devices can be *dynamically* created, destroyed or modified while the rest of the virtual network is running, providing many opportunities for experimentation without any need for clumsy hardware setup.

Marionnet has a very intuitive graphical user interface also suitable to inexperienced users, and is being used with success for teaching computer networks at Université Paris 13.

We believe its adoption can be extended to other specialits in the field of network, in order to ease the design and debug of computer networks, applications and protocols.

This work presents Marionnet from a *user* point of view, complementing its description with a practical use scenario showing an example of how the application could be profitably employed in the industry.

Categories and Subject Descriptors

I.6.7 [**Simulation Support Systems**]; I.6.3 [**Applications**]; H.4 [**Information Systems Applications**]: Miscellaneous

General Terms

Experimentation

Keywords

simulation, computer networks, GUI, interactive, UML

1. INTRODUCTION

One of the main purposes of Marionnet is enabling users to test computer network cablings, network protocols, services and applications. The application allows to easily define and configure a virtual network complete with hubs, switches and routers, and then to actually run unmodified GNU/Linux x86 software on virtual computers.

Marionnet is a free software application running on GNU/ Linux built on UML[2] and VDE[3].

Not only Marionnet benefits from the efficiency and stability of Linux, but its free software license has been the very reason making Marionnet possible in the first place: we actually modified and adapted User Mode Linux ([7], [5], [6]) and VDE ([4]).

Network devices like hubs, switches, routers and cables also need to be simulated to be able to closely reproduce the behavior of a physical network.

In this paper we describe Marionnet *from the point of view of a user*, providing only some brief hints to the implementation. [12] describes the inner workings of Marionnet at a reasonable level of detail.

2. BASIC USAGE

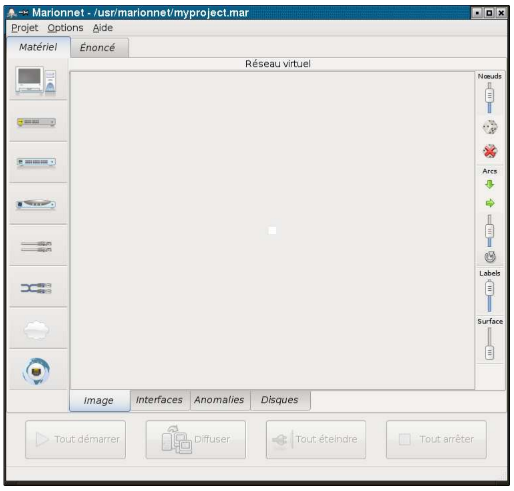
Marionnet is an interactive software with a graphical user interface based on GTK+ ([13]). If exposes to the users the usual project-oriented metaphore: in order to start using the application the user can create a new empty project or open an existing one. In both cases a dialog window pops up, asking to choose a file name. Once a project is created or opened the user can freely navigate through the functionalities offered by the interface: the *device palette*, the graphical network representation (henceforth the *network graph*) and the panes providing advanced functionalities (*Interfaces*, *Anomalies*, *Filesystem history*) become active. Figure 1 shows the interface as it looks right after the creation of a new project.

[1]Marionnet is financed by Université Paris 13.

[2] *User Mode Linux*, by Jeff Dike et al., is a port of the Linux kernel to the GNU/Linux system consisting in a *guest* kernel which runs on the *host* operating system as a normal user-level process, but exposing the complete Linux kernel API to its *guest* processes.
Even at the cost of an excessive simplification, in this paper we make the conscious decision of *not* distinguishing among such a solution, emulation, simulation and paravirtualization: the *internal* architecture of the software compoents we build upon is not relevant for the application.

[3] *Virtual Distributed Ethernet*, by Renzo Davoli et al., is a low-level communication infrastructure which we heavily reused for implementing virtual devices. Marionnet internals, including our modification to VDE, are described in [12].

Figure 1:
The interface how it looks right after the creation of a new project



2.1 Devices palette

Network devices can be created, modified and controlled from the device palette within the *Hardware* pane.

The user is freed from the burden of physically placing device icons in the network graph two-dimensional space: placement is automatic, but several parameters (for example the length of edges and the size of icons) can be tuned if needed (see Figure 1, on the right).

The network graph is automatically updated at each device state change (such as startup, pause or resume) to reflect the current state.

The device palette offers two kinds of functionalities:

1. virtual network *editing*, including *definition*, *modification* and *removal* of individual devices.

2. virtual network *control* features: each device can be *started-up*, *paused*, *resumed*, *shutdown* and *powered-off*.

Eight types of virtual network components are currently provided:

1. *computer*
2. Ethernet *hub*
3. Ethernet *switch*
4. IP *router*
5. *"straight" Ethernet cable*
6. *crossover Ethernet cable*
7. *Ethernet cloud*
8. *Ethernet socket*

We are now going to briefly review them, showing how the devices of each type can be tuned.

2.2 Virtual computer

The *virtual computer* device represents a computer running a GNU/Linux operating system. Just like a physical computer a virtual computer can be *off* or *running*. As an "extension" to what it is possible in a physical network we also provide the possibility of *pausing* computers: in the paused state computers do not react to incoming messages. Pausing allows to experiment with dynamic routing protocols, making a machine temporarily unreachable.

Different icons represent a virtual computer in *off*, *running* and *paused* state in the network graph:

Parameters

When a user adds or modifies a virtual computer the dialog window shown in Figure 2 allows to choose its *name* and to set several parameters.

The following parameters are *hardware*-related:

- *RAM*: the quantity of RAM reserved by the host system to the guest, seen by the guest as its physical memory. The default 48Mb setting is adequate for comfortably running even graphical applications like *Firefox* or *Ethereal/ Wireshark*.
  Of course swapping is also provided on virtual machines.

- *Number of Ethernet cards* (1 by default)

The user can also tune the *software* running on the virtual machine:

- the particular *GNU/Linux distribution*, chosen among the ones provided for guest systems by the Marionnet installation[4].

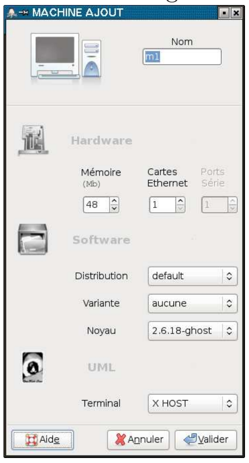
- a *variant* represents a modification to the filesystem of the selected GNU/Linux distribution. The *COW* (*Copy On Write*) technology supported by UML allows a very efficient implementation of this feature, involving a single *sparse* file containing only the blocks which are different from the unmodified distribution. A typical COW file takes only a few megabytes of disk space on the host.

- the particular guest *kernel*, chosen from several versions of Linux compiled with different features enabled.

- setting the *terminal* type allows to choose whether the machine displays its X clients using the *host* X server or an *Xnest* server of its own.
  When a machine has its terminal type set to *host* the user interacts with it in text mode using a simple *virtual terminal window*, and can launch graphical applications which draw their clients on the same X display

[4]It is quite easy to add support for more distributions: see the UML documentation for more information about how to create guest filesystem images.

Figure 2:
Virtual machine parameters dialog



Nom: m1
Mémoire (Mb): 48
Cartes Ethernet: 1
Ports Série: 1
Distribution: default
Variante: aucune
Noyau: 2.6.18-ghost
Terminal: X HOST

where Marionnet runs.
In *Xnest* mode, instead, a running virtual computer has a window (shown on the host display, of course) representing its monitor and running some graphical desktop system: the guest X clients are clearly separated from the host ones and the ones belonging to other guests. This setting is particularly appropriate for beginners.

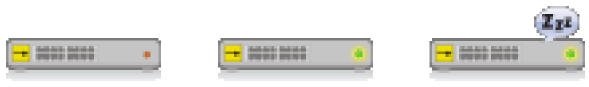
2.3 Virtual hub

A *hub* is a very simple electronic device reproducing the signals it receives from one of its port into all the other ports. All the network nodes connected to a hub belong to the same Ethernet collision domain.

Despite nowadays being mostly disregarded as obsolete variants of switches (see Section 2.4), hubs are often convenient for intercepting and analyzing network traffic: this can be easily realized by running a *sniffer* application such as *wireshark* or *tcpdump* on a virtual computer directly connected to a hub.

VDE (see [4] and [3]) allows to simulate an Ethernet switch, but some modifications to its C source code have been necessary in order to realize the behavior needed in Marionnet.

The following icons represent a hub in its *off*, *running* and *paused* state:



Parameters

A very simple dialog window allows to set the *name* and few other parameters of each virtual hub:

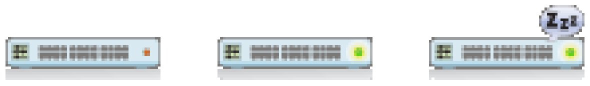
- an optional *label* to be shown on the network graph near the hub icon.

- the *number of Ethernet ports*, 4 by default.

2.4 Virtual switch

An Ethernet *switch* also allows to relay several Ethernet frames through a network, but differently from a hub it outputs data only to the intended receiving node.

A virtual switch is represented by the following icons in Marionnet:



Parameters

The dialog window allowing to edit a switch has no notable differences from the one for editing a hub (see Section 2.3): only a *name*, an optional *label* (to be shown in the network graph) and the *number of ports* can be chosen.

2.5 Virtual router

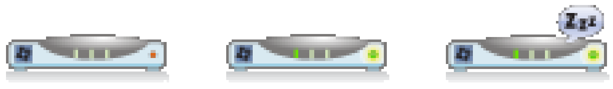
An IP *router* is a device directing packets from a local network to another local network. The main purpose of a router is to find the next node of a network through which a packet should be sent to reach its final destination in the minimum time. It is worth to emphasize that, differently from hubs and switches which operate at the *link* layer, routers work at the *network layer*, and their behavior is considerably more complex. *Routing tables* can be set either *statically* or *dynamically.*

Virtual routers are implemented with the *Quagga* software (see [10], [2]; Quagga is derived from the *Zebra* project: `http://www.zebra.org/`) *running on a UML virtual machine.* Quagga allows both static and dynamic routing (in the latest case supporting different protocols such as RIP, OSF, BGP and ISIS).

Each router port can be configured from the Marionnet *Interface* pane.

Once it is started, a virtual router can also be set up with the *telnet* protocol.

Virtual routers are identified by the following icons in the network graph:



Parameters

Router interfaces can be configured from the *Interfaces* pane.

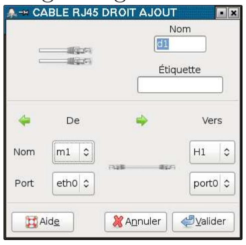
The dialog window allowing to setup or modify routers is similar to the ones for hubs and switches.

2.6 Virtual cable

Ethernet cables allow to physically connect nodes in the network. Marionnet simulates the most common sort of cables deployed today, twisted pair with "RJ45" connectors. In any case we tend to abstract over such low-level details, which are typically not relevant at the high-level where Marionnet works.

Marionnet currently supports only fully *wired* virtual networks; support for wireless networks is planned for a future version. Some work in this direction using UML already exists: see [9]. Bandwitdh limitation (allowing for example to restrict bandwidth to 100Mb/s over some cables and

Figure 3:
"Straight" cable editing dialog



to 1000Mb/s on others) would be easy to implement[5], and is planned for the next version. The distinction between "straight" and crossover cables can be enforced[6] or ignored by setting a global option.

The control actions provided by the devices palette are limited to *connect* and *disconnect* in the case of cables[7]. Cables are always connected by default, but they can be disconnected and reconnected at will by the user, as it is common while making tests on the network at several different levels.

Cables are represented in the network graph as *solid* lines when connected, and as *dashed* lines when disconnected.

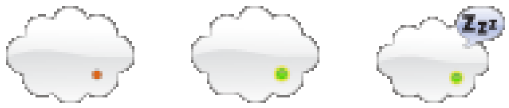
Parameters

The user can set the *name*, and optional *label* to be shown in the network graph, and *the identity of each endpoint* for each cable, as seen in Figure 3.

2.7 Virtual Ethernet "cloud"

An *cloud* represents an Ethernet network composed of hubs, switches and cables, with exactly two endpoints an unspecified internal structure. The only externally observable effects of a cloud consist in delays and other anomalies in the relaying of frames from one endpoint to the other.

This "device" is particularly useful for the simulation of dynamic routing (see Section 2.5).



Parameters

The cloud definition dialog is not particularly interesting, as it only allows to set a *name* and an optional *label* to be shown in the network graph.

[5]Of course the speed of the processor or processors would remain an artificial limit, but limiting the *maximum* bandwidth is easy with VDE.

[6]When this policy is enforced an "incorrect" cable, for example a crossover cable connecting a computer with a switch, simply does not trasmit any frames.

[7]There would be very little point in stretching the *startup/shutdown/poweroff/pause/resume* metaphore to also apply to cables, as the behavior associated to each of these actions would always exactly minic either the *connect* or *disconnect* action. Simply providing the means for temporarily disconnecting a cable is intuitive and covers all the useful cases.

Anomalies can be set from the *Defects* pane with a very fine level of detail: see Section 5.2.

2.8 Virtual external socket

Using the components presented up to this moment it is possible to build a virtual network made of computers, hubs, switches, routers and clouds connected by "straight" and crossover Ethernet cables. Such a virtual network is a possibly interesting and useful but completely *closed* system, isolated by the outside world[8].

The *external socket* device represents a "female Ethernet wall socket", opening a breach in this apparent closure: when connected to an external socket other compoenents can access the *same* (non-virtual) network to which the *host belongs*.

External sockets provide several useful opportunities:

- connecting virtual computers to the Internet
- easily installing additional software on virtual machines, for example using `apt-get install` on a *debian* distribution
- making virtual computers *clients* of services offered by the host or its network: some examples include DHCP, DNS, NFS, and NTP

It is also possible to use external sockets to connect *several virtual networks*, possibly running on different hosts.

The implementation depends on the *bridging* functionality in Linux.

Parameters

The user can only specify a *name* and an optional *label*.

3. NETWORK GRAPH

When any virtual device changes state or a Marionnet project is opened the *network graph* image is regenerated[9] to reflect the current situation.

The configuration parameters settable by the user from the palette next to the graph image in the *Hardware* pane are divided into four categories.

[8]There is a hidden communication channel from each virtual computer to the host system, used for making virtual machines exchange messages with the host X server (be it "native" or *Xnest*). The implementation of this feature is discussed in [12]. Nonetheless this communication is not directly accessible to the user and definitely not "general-purpose".

[9]This functionality is implemented with runtime calls to `dot`, from the free sofware package *Graphviz* ([1]). `dot` can generate an image by placing icons in the two-dimensional space in a completely automatic way, but it also supports many "hints" to tune the picture apparence. All the user settings described in this section are implemented with (often quite complex) *dot* commands.

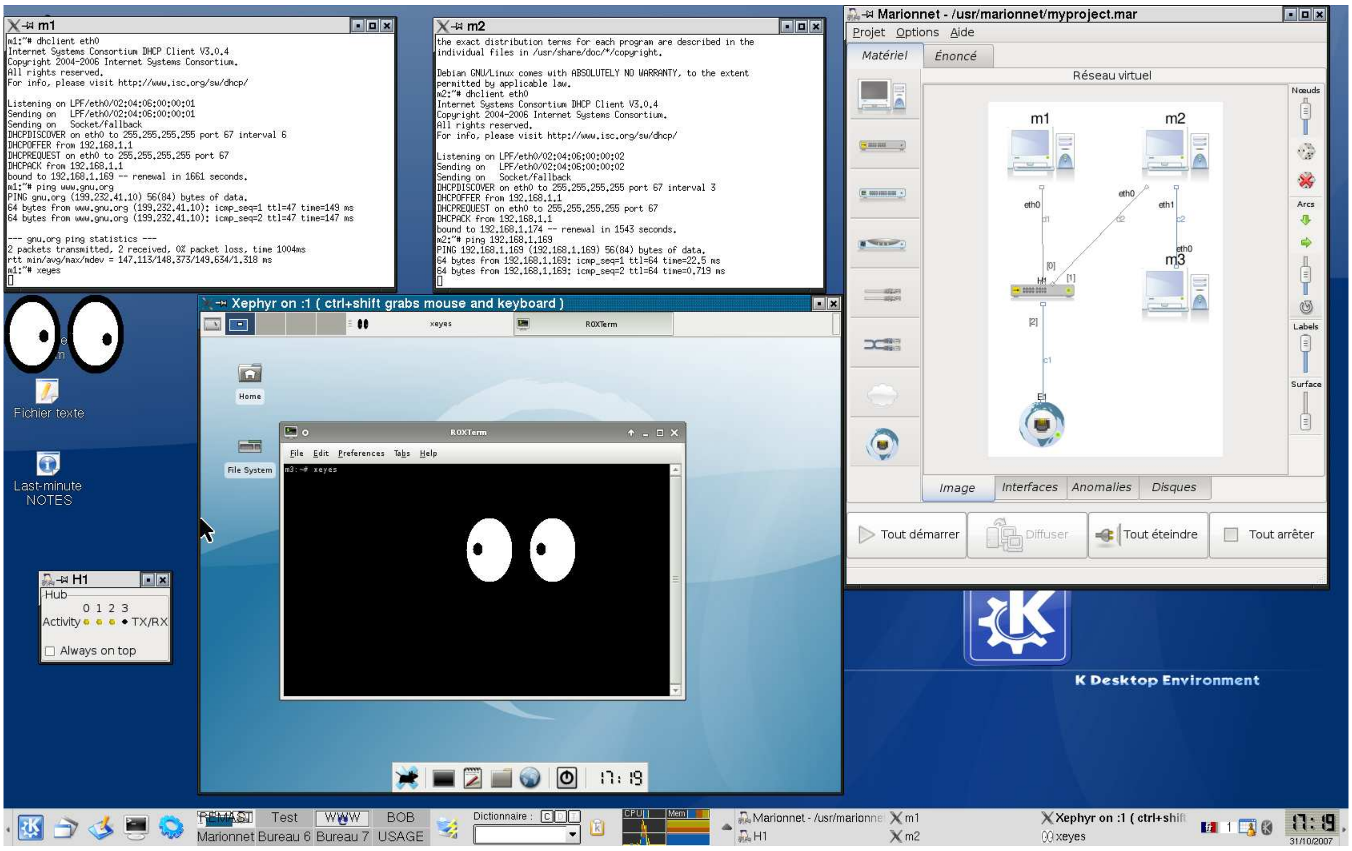


Figure 4:
A typical example of simulation with a very simple network. *m2* is `ping`ing a remote machine reachable through the *external socket*. *m3* has an *Xnest* interface; instead *m1* has a terminal interface, and its `xeyes` is shown by the host X server.

```
m1:~# dhclient eth0
Internet Systems Consortium DHCP Client V3.0.4
Copyright 2004-2006 Internet Systems Consortium.
All rights reserved.
For info, please visit http://www.isc.org/sw/dhcp/

Listening on LPF/eth0/02:04:06:00:00:01
Sending on   LPF/eth0/02:04:06:00:00:01
Sending on   Socket/fallback
DHCPDISCOVER on eth0 to 255.255.255.255 port 67 interval 6
DHCPOFFER from 192.168.1.1
DHCPREQUEST on eth0 to 255.255.255.255 port 67
DHCPACK from 192.168.1.1
bound to 192.168.1.169 -- renewal in 1661 seconds.
m1:~# ping www.gnu.org
PING gnu.org (199.232.41.10) 56(84) bytes of data.
64 bytes from www.gnu.org (199.232.41.10): icmp_seq=1 ttl=47 time=149 ms
64 bytes from www.gnu.org (199.232.41.10): icmp_seq=2 ttl=47 time=147 ms

--- gnu.org ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1004ms
rtt min/avg/max/mdev = 147.113/148.373/149.634/1.318 ms
m1:~# xeyes
```

```
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
m2:~# dhclient eth0
Internet Systems Consortium DHCP Client V3.0.4
Copyright 2004-2006 Internet Systems Consortium.
All rights reserved.
For info, please visit http://www.isc.org/sw/dhcp/

Listening on LPF/eth0/02:04:06:00:00:02
Sending on   LPF/eth0/02:04:06:00:00:02
Sending on   Socket/fallback
DHCPDISCOVER on eth0 to 255.255.255.255 port 67 interval 3
DHCPOFFER from 192.168.1.1
DHCPREQUEST on eth0 to 255.255.255.255 port 67
DHCPACK from 192.168.1.1
bound to 192.168.1.174 -- renewal in 1543 seconds.
m2:~# ping 192.168.1.169
PING 192.168.1.169 (192.168.1.169) 56(84) bytes of data.
64 bytes from 192.168.1.169: icmp_seq=1 ttl=64 time=22.5 ms
64 bytes from 192.168.1.169: icmp_seq=2 ttl=64 time=0.719 ms
```

Nodes

Three settings are available:

1. a slider allows to tune the icons' *size*
2. pressing the "dice" button randomly rearranges nodes
3. pressing the "slashed dice" button resets the nodes arrangement to the initial state

Edges

Four settings:

1. pressing the "right arrow" button regenerates the image so that its main spine is drawn horizontally
2. pressing the "down arrow" button redraws the image with a vertical main spine
3. a slider allows to set the *minimum edge length*
4. pressing the "circular arrow" button pops up a menu allowing to swap the ends of an edge in the network graph image

Labels

A slider allows to set the *distance* between a label and the icon representing the node it describes.

Surface

A slider allows to set the *size of the canvas* containing the whole image.

4. EXECUTION AND CONTROL

The Marionnet user interface provides two different styles of controlling simulation: the device-oriented *local style* and the network-oriented *global style.*

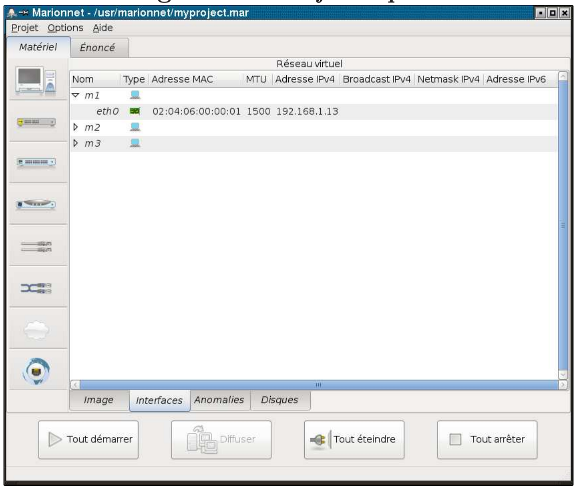
4.1 Local vs. global control

The device palette provides for *local control*: the user first chooses a *device type* (e.g. the router); then a popup menu appears displaying the possible *actions*. When the user chooses one (e.g. "power-off"), a sub-menu pops up displaying the list of *device name* of the selected type on which the selected action is currently possible. The action is performed as soon as the user clicks on a device name.

All menus are *dynamically generated* according to the current simulation state: for example the "resume" action is only possible on currently "paused" devices; and of course the possibility of creating and destroying devices *even during the simulation* implies that the list of existing devices itself varies through time.

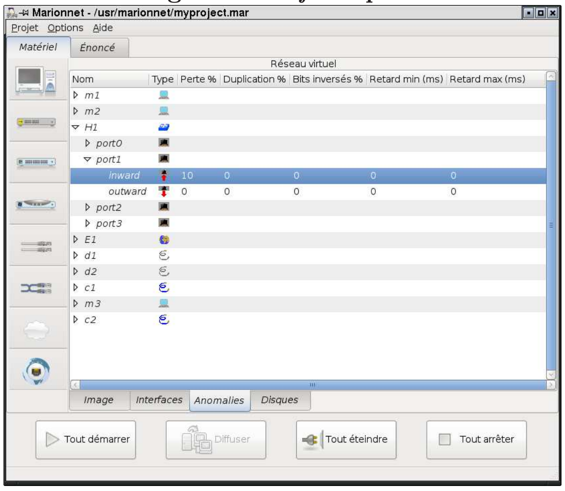
By contrast, the large buttons always visible on the bot-

Figure 5: *Interfaces* pane



Nom	Type	Adresse MAC	MTU	Adresse IPv4	Broadcast IPv4	Netmask IPv4	Adresse IPv6
m1							
eth0		02:04:06:00:00:01	1500	192.168.1.13			
m2							
m3							

Figure 6: *Defects* pane



Nom	Type	Perte %	Duplication %	Bits inversés %	Retard min (ms)	Retard max (ms)
m1						
m2						
H1						
port0						
port1						
inward		10	0	0	0	0
outward		0	0	0	0	0
port2						
port3						
E1						
d1						
d2						
c1						
m3						
c2						

tom pane permit a form of global control: pressing one of them executes the same action on all the devices which are currently in a state allowing it; the possible global actions are *startup everything*, *shutdown everything*, and *power-off everything*.

4.2 "Shutdown" vs. "power-off"

Within Marionnet the term "power-off" means brusquely unplugging the "power cord" of a virtual device[10]. By contrast the term "shutdown" refers to the action of "gracefully" terminating the activity of a device before turning it off.

The difference between *power-off* and *shutdown* is relevant for "stateful" virtual devices which contain some kind of disk which supports asynchronous writes, like computers and routers; just like for physical devices, a brusque power-off can leave filesystems in an inconsistent state[11].

5. ADVANCED USAGE

Marionnet also provides several advanced functionalities, the most important of which we now enumerate:

5.1 Interface pre-configuration

In the *Interfaces* pane (see Figure 5) the user can configure the network interfaces of virtual computers and routers by setting the following parameters:

- MAC address
- MTU
- IPv4 address
- IPv4 broadcast address
- IPv4 netmask
- IPv6 address[12]

Although all these parameters can also be set after startup by logging in the virtual computer or router and invoking `ifconfig`, this interface provides a conventient shortcut. By setting a global option IPv4 and IPv6 addresses can also be automatically generated by the application upon the creation of a port.

5.2 Defects

The communication infrastructure can manifest several kinds of "faulty" behavior:

- frame loss
- frame duplication
- flipped bits
- trasmission delay[13]

As shown in Figure 6 defects can be set up in the *Anomalies* pane, with the granularity of the single *electric line*, i.e. the *direction* (*in-to-out* or *out-to-in* for ports and *left-to-right* or *right-to-left* for cables).

For each direction of each cable or port of each device the user can individually set any defect, by entering a probability or, in the case of delays, a time in millieconds.

Defects settings can be updated "hot", i.e. while the network is running: the behavior is immediately affected.

5.3 Filesystem history

For each virtual computer or router, a complete history of the disk states is available (see Figure 7): each state is saved just before startup.

A machine or router can be started up in the most recent state (which is the default behavior), or in any previously

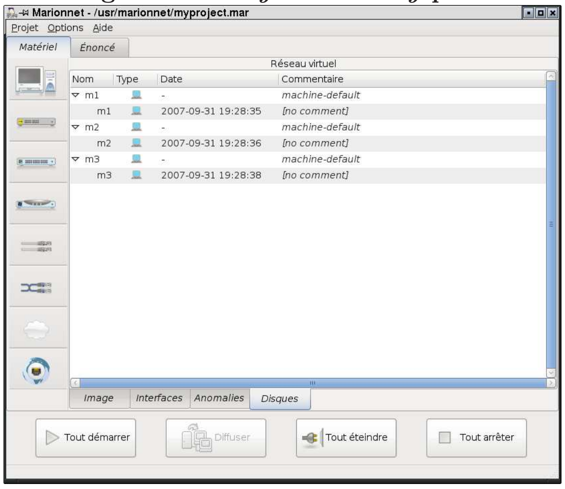
[10]This is implemented by sending a `SIGKILL` signal to all the processes simulating a virtual device, for most devices.

[11]But damages are typically very limited with modern filesystems: since UML is a complete port of Linux it includes support for journaled filesystem like *ext3* and *raiserfs*, which of course can also be used in virtual computers and routers.

[12]IPv6 addresses also contain information about the netmask and broadcast; there is no need for three distinct paramters in the case of IPv6.

[13]The delay follows a normal distribution in the current implementation. The parameters "min" and "max", settable by the user, represent $\mu - 3\sigma$ and $\mu + 3\sigma$.

Figure 7: *Filesystem history* pane



Nom	Type	Date	Commentaire
▽ m1		-	*machine-default*
m1		2007-09-31 19:28:35	*[no comment]*
▽ m2		-	*machine-default*
m2		2007-09-31 19:28:36	*[no comment]*
▽ m3		-	*machine-default*
m3		2007-09-31 19:28:38	*[no comment]*

saved state. This allows users to freely experiment with potentially "dangerous" filesystem modifications, as each change is reversible.

For each machine or router the *filesystem history* displays a tree structure keeping track of the "parent-child" derivation relation of states.

States can also be *deleted* or exported as *variants*, to be used for new machines or routers in the same or even in different projects: see subsection 2.1 and Figure 2 for some details about variants.

6. FILE FORMAT

The Marionnet project file format is a `tar` archive containing some OCaml marshalled objects and UML *cow* files.

The format has been very carefully designed to be back- *and forward*-compatible: newer versions of Marionnet can read project saved by older versions and vice-versa: when Marionnet finds some information which it doesn't "understand", the system simply ignores it. If instead some needed field is lacking then a default value is generated.

We hope this to become a conventional exchange format for people who desidred to share projects and "prepackaged" networks.

7. A POSSIBLE USAGE EXAMPLE

As one example of a usage scenario for Marionnet being employed in the industry we outline the development of a peer-to-peer application-level protocol, using a simulated network.

7.1 Scenario

We assume the protocol to be based on an existing *transport* layer, so that its implementation does not need to reside in the kernel[14]; a reasonable choice for the transport is, of course, UDP.

7.2 Development

Setting up a development environment in which programmers can be productive and at ease may involve a considerable investiment of time and energy; our proposal is explicitly aimed at *not disrupting* this environment. In particular the *devlopment* itself, intended as editing and compiling, can continue to happen on the phyisical machines already employed by programmers.

We assume the adoption of a typical modern infrastructure for development, in particular the availability of a network file system like NFS or SMB[15].

A shared directory on the network file system will host the compiled, executable files, so that they are available to all *virtual* computers through an *Ethernet socket device* (see Subsection 2.8).

One virtual computer should be configured *as a peer machine*, installing on its virtual filesystem all the needed software, including external serivices and libraries; the packaging system of the GNU/Linux distribution can be used for this. This setup should then be made easily *reusable* by saving the machine's filesystem state as a variant: in this way other identical peer virtual machines can be later created, at will.

7.2.1 *Discovery*

The first task in this project would probabaly consist in developing some strategy to *discover* new peer machines joining the network. This is easy to test by creating a virtual network with just three or four computers connected to a switch. Each of them will run the same executable from the shared directory.

7.2.2 *Fault tolerance*

Any reasonable peer-to-peer protocol should of course be fault-tolerant, and react in a correct way to the sudden disconnection of some machine. The *pause* and *power-off* actions can be employed on virtual computers in the same setup outlined above.

In order to stress the protocol's resilience to the lack of reliability of the network, one or more *cloud* devices (see Subsection 2.7) can be added to the virtual network. The application can be tested in arbitrarily adverse conditions, by tuning the defect probabilities[16] (see Subsection 5.2) at runtime, while the application is running.

If the application has also an *on-disk* state and its fault-tolerance needs to be tested, single virtual computers can be *powered-off* while running, just for this purpose. If some "interesting" inconsistent disk state is reached in this way the filesystem state can be saved as a variant (see Subsection 2.2) so that the problem can be studied and debugged *in repeatable conditions*.

7.2.3 *Firewalls, NATs and multicast*

If the peer-to-peer protocol needs to work across firewalls

[14]Marionnet could also be used for testing kernel-level implementations based on Linux, but this would limit its application to running virtual machines using experimental UML kernels. The kernel-level development itself could also be performed within Marionnet, but without particolar benefits: in particular (virtual) computer reboots would be still needed. Here we want to present, by constrast, a case of development with *rapid turnaround*.

[15]If not already available such a service can be installed on the Marionnet *host* computer, when the same machine is also used for development.

[16]Doing the same type of test with a loopback network device or on a physical network would be extremely hard, because the number of faults would be *too small* in practice, and however not directly modifiable.

and NAT subnetworks, the virtual network can be modified by adding *routers* (see Subsection 2.5), or different virtual computers configured as gateways: virtual computers can be equipped with the exact same firewall software which could run on physical networks.

A possible optimization of the protocol consists in supporting *multicast* to transmit the same message to multiple peers: such a feature, and its interaction with routing, is *much* easier to test in a virtual environment.

7.2.4 Interoperability among different versions

At some time in the application life time, the protocol will inevitably have to be modified. When interoperability among different versions is desired, tests can be prepared by setting up one virtual machine per released protocol version (not using the shared network direcory in this case), and making variants.

If this is desired, machines created from such variants can be added to *all future test cases*, and made interact with the new versions of the protocol.

If some older version which the developer desires to use for testing is not readily available, it can even be fetched from the revision control system and compiled *on the virtual machine itself*: the only requirements are, of course, the availability of a network-accessible revision control system on the *host* network, and the compiling (not necessarily editing) environemnt on *virtual* computers.

8. CONCLUSIONS

We implemented a general purpose interactive simulation system for computer networks, allowing to accurately simulate complete networks, including the software running on computers.

Marionnet is currently being employed with success for teaching computer networks to students at Université Paris 13. We believe its use can be profitable extended to other cases of simulation and debugging or networks and applications.

Some rough edges and "wishlist features" remain, like UI internationalization. The problem of supporting wireless networks, despite being nontrivial, has been tackled with success by others using UML: see [9].

Marionnet is free software, released under the GNU GPL ([8]): anyone is free to share and modify it.

Marionnet is written using the elegant functional language OCaml ([11]), and the implementation itself is quite interesting; we are trying to build a strong "community" around it, and we welcome contributions to expand it in new directions.

The Marionnet web site is `http://www.marionnet.org`.

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