XORP: An eXtensible Open Router Platform

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Outline

1. Motivations

2. XORP introduction

3. XORP IPC mechanism

4. What does it take to implement a routing protocol?

5. Dependency tracking mechanism

6. Conclusions

Networking research: divorced from reality?

- Gap between research and practice
- Most of the important Internet protocols originated in research
- It used to be that researchers designed systems, *build implementations*, *tried them out*, and standardized the ones that *survived and proved useful*.
- What happened?

Networking research: why the divorce?

- The commercial Internet
  - Network stability is critical, so experimentation is difficult
  - Major infrastructure vendors not motivated to support experimentation
- Network simulators
  - Nice tool, but usually too abstract from reality

Simulation is not a substitute for experimentation

- Many questions require real-world traffic and/or routing information

- Many people:
  - Give up, implement their protocol in *ns*
  - Set *ns* parameters based on guesses, existing scripts
  - Write a paper that may or may not bear any relationship to reality

- We need to be able to run experiments when required!

Options

- Option 1:
  - Persuade Cisco to implement your protocol;
  - Persuade ISPs that your protocol won't destabilize their networks;
  - Conduct experiment.

Options (cont.)

- Option 2:
  - Implement routing protocol part in MRTd, GateD, or Zebra;
  - Implement forwarding part in FreeBSD, Linux, Click, etc;
  - Persuade network operators to replace their Ciscos with your PC;
  - Conduct experiment.

Likelihood of success?

Possible solutions

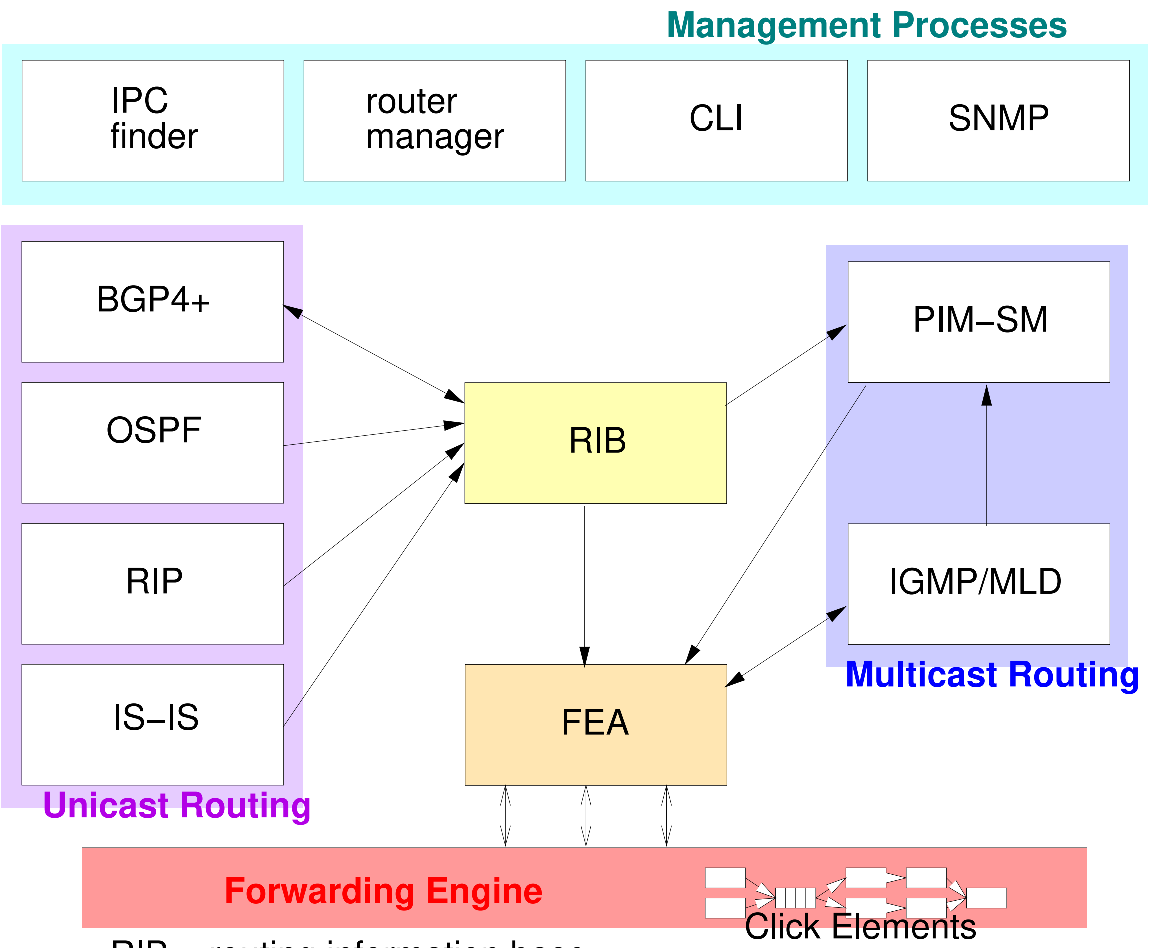
- Solution 1: A router vendor opens their development environment and APIs:
  - Third-party router applications
  - Basic router functionality cannot be changed
- Solution 2: Someone (*hint, hint*) builds a complete open-source router software stack explicitly designed for **extensibility** and **robustness**:
  - Adventurous network operators deploy this router on their networks
  - Result: a fully extensible platform suitable for **research** and **deployment**

XORP: eXtensible Open Router Platform

Complete software stack for an IP router:

- Routing protocols: unicast and multicast
  - Protocols can be run in simulation-like environment
- Management Interfaces
- Forwarding path

XORP Architecture



RIB = routing information base
FEA = forwarding engine abstraction

Challenges

- **Features**: real-world routers support a long feature list
- **Extensibility**:
  - Every aspect of the router should be extensible
  - Multiple extensions should be able to coexist
- **Performance**: raw forwarding performance; routing table size (not core routers; even edge routing is hard enough)
- **Robustness**: must not crash or misroute packets

XORP Features

- IPv4 and IPv6

- Unicast routing protocols: BGP4+, OSPF, RIPv2/RIPng, IS-IS

- Multicast: PIM-SM/SSM, IGMPv1,2,3/MLDv1,2

- DHCP, PPP

- Management: CLI, SNMP, WWW

- Forwarding path: UNIX (native), Click

Extensibility: Intra-router APIs

Separate abstract request (API) from concrete request (which process? which arguments? which version?)

In particular, the caller:

- Should not care about IPC mechanism
- Should not know in advance which process is relevant
  . . . unless required

Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

- Library marshals arguments, implements transport, handles responses
- Redirection into a single XRL or an XRL sequence
- Programmer explicitly handles failure

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XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

IPC mechanism: `finder`, `xudp`, `snmp`, . . .

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Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

Module/process name: `fea`, `rib`, `bgp`, ...

- Library marshals arguments, implements transport, handles responses

- Redirection into a single XRL or an XRL sequence

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Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

Interface name: `fea`, `routing-process`, ...

- Library marshals arguments, implements transport, handles responses
- Redirection into a single XRL or an XRL sequence
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Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

Version number

- Library marshals arguments, implements transport, handles responses

- Redirection into a single XRL or an XRL sequence

- Programmer explicitly handles failure

Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

```
finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1
```

Method name: `delete_address4`, `get_mtu`, ...

- Library marshals arguments, implements transport, handles responses
- Redirection into a single XRL or an XRL sequence
- Programmer explicitly handles failure

Extensibility: XRLs (XORP Resource Locators)

XORP IPC mechanism (like URLs for IPC):

`finder://fea/fea/1.0/add_address4?vif:txt=fxp0&addr:ipv4=10.0.0.1`

Arguments

- Library marshals arguments, implements transport, handles responses
- Redirection into a single XRL or an XRL sequence
- Programmer explicitly handles failure

Defining XRL interface

XRL interface is defined in XRL-specific files:

```
interface pim/0.1 {
/**
 * Enable a PIM virtual interface.
 *
 * @param vif_name the name of the vif to enable.
 * @param fail true if failure has occurred.
 * @param reason contains failure reason if it occurred.
 */
enable_vif ? vif_name:txt -> fail:bool & reason:txt

...
}
```

Using XRLs: C++

All header files are auto-generated; developer implements only XRL handlers:

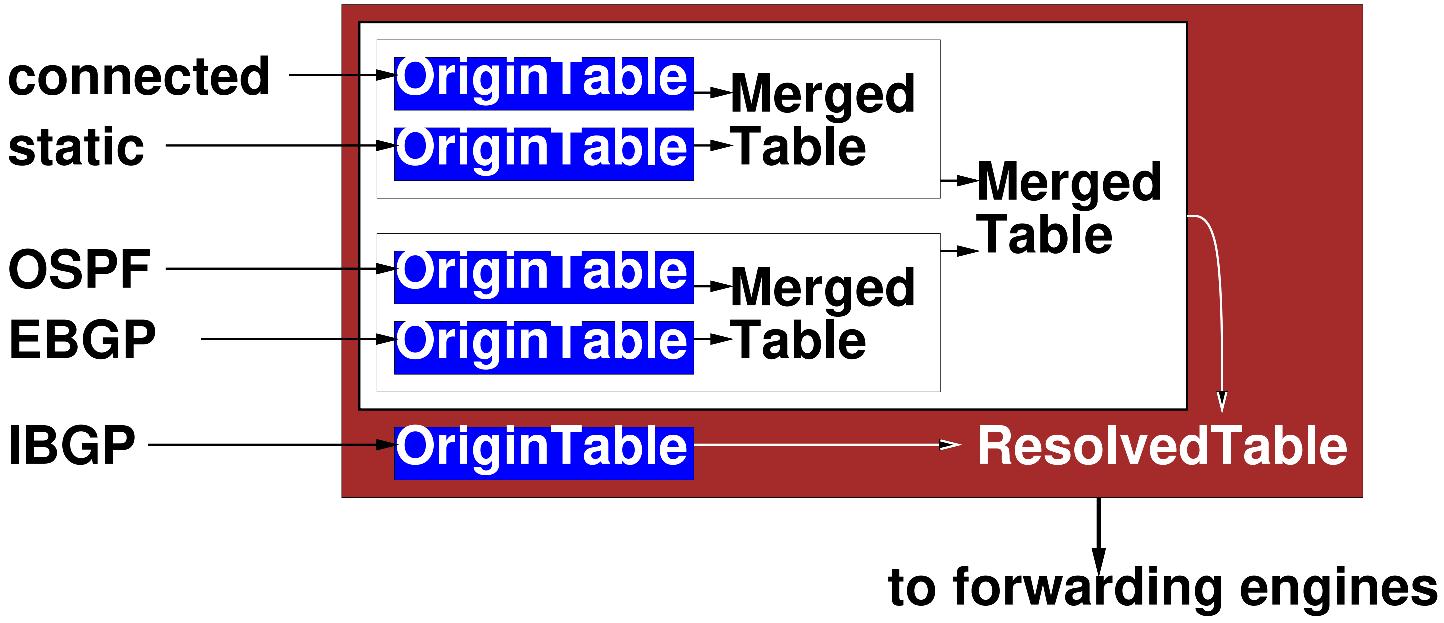
```
XrlCmdError XrlPimNode::pim_0_1_enable_vif(
    // Input values,
    const string&        vif_name,
    // Output values,
    bool&                fail,
    string&              reason)
{
    fail = enable_vif(vif_name, reason);
    return XrlCmdError::OKAY();
}
```

Using XRLs: Shell Script

Everything is ASCII text:

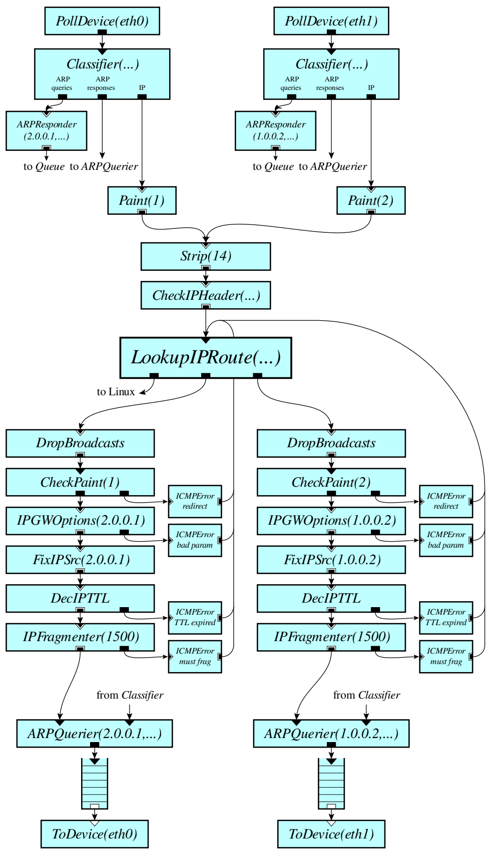
```
pim_enable_vif()
{
    vif_name=$1
    XRL="finder://$PIM_TARGET/pim/0.1/enable_vif"
    XRL_ARGS="?vif_name:txt=$vif_name"
    call_xrl $XRL$XRL_ARGS
}
```

Extensibility: RIB



- Object-oriented routing table design
- Add new merged tables implementing new merging policies, . . .

Extensibility/performance: Click forwarding path



Fast kernel forwarding; easy to write extensions

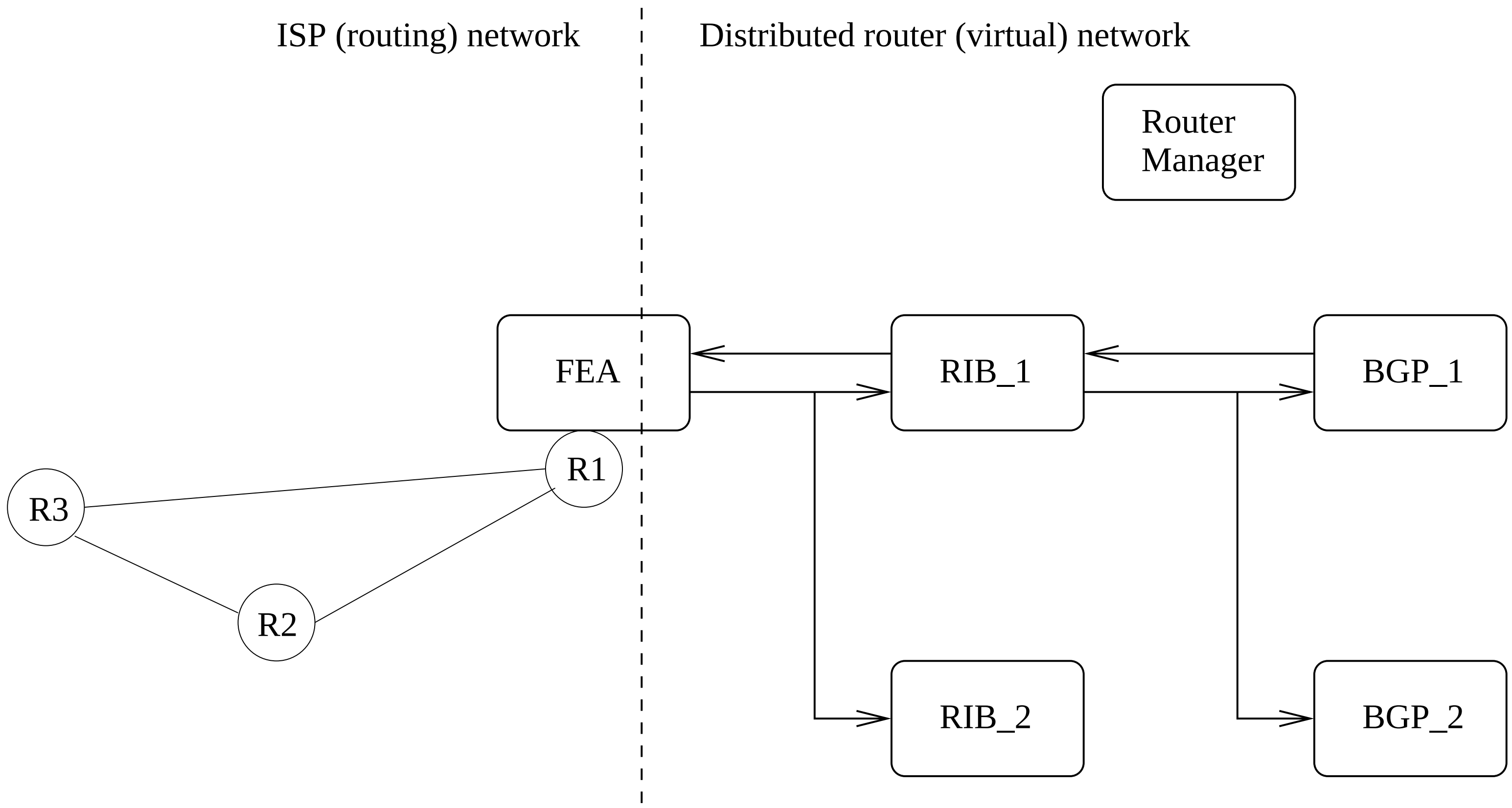
Robustness

- Policy decision: Strong robustness for user-level processes
  - Difficult to get performance, robustness, and extensibility simultaneously
- Facilitated by multi-process design
  - Automatically restart processes that crash
- XRL sandboxes
  - All interaction with router through XRLs
  - Redirect XRLs to run new protocols in a sandbox

Improving robustness and performance: distributed router

- XRLs can be sent across network
- Each routing process can run on a separate machine
- Only the FEA must run on the machine with the forwarding engine:
  - The memory and the CPU are not the bottleneck
  - Improved robustness through hot-swapping of routing modules

Example of a distributed router



Distributed router (cont.)

- The Router Manager coordinates the modules and the interaction among them.

- A routing protocol instance doesn't care whether it is part of a distributed router, or whether it is running as a backup

- Potential issues:
  - Communication latency
  - Bandwidth overhead
  - Synchronization

What does it take to implement a routing protocol?

PIM-SM (Protocol Independent Multicast-Sparse Mode): case-study

- Fairly complicated protocol (protocol specification is 100 + 25 pages), full of tiny details:
  - Early specifications (two RFCs) easy to read, difficult to decode and implement
  - Lastest spec is much more "implementor-friendly"
- Lots of routing state and state dependency

0. Get yourself into the right mindset

Think SIMPLICITY and CONSISTENCY:

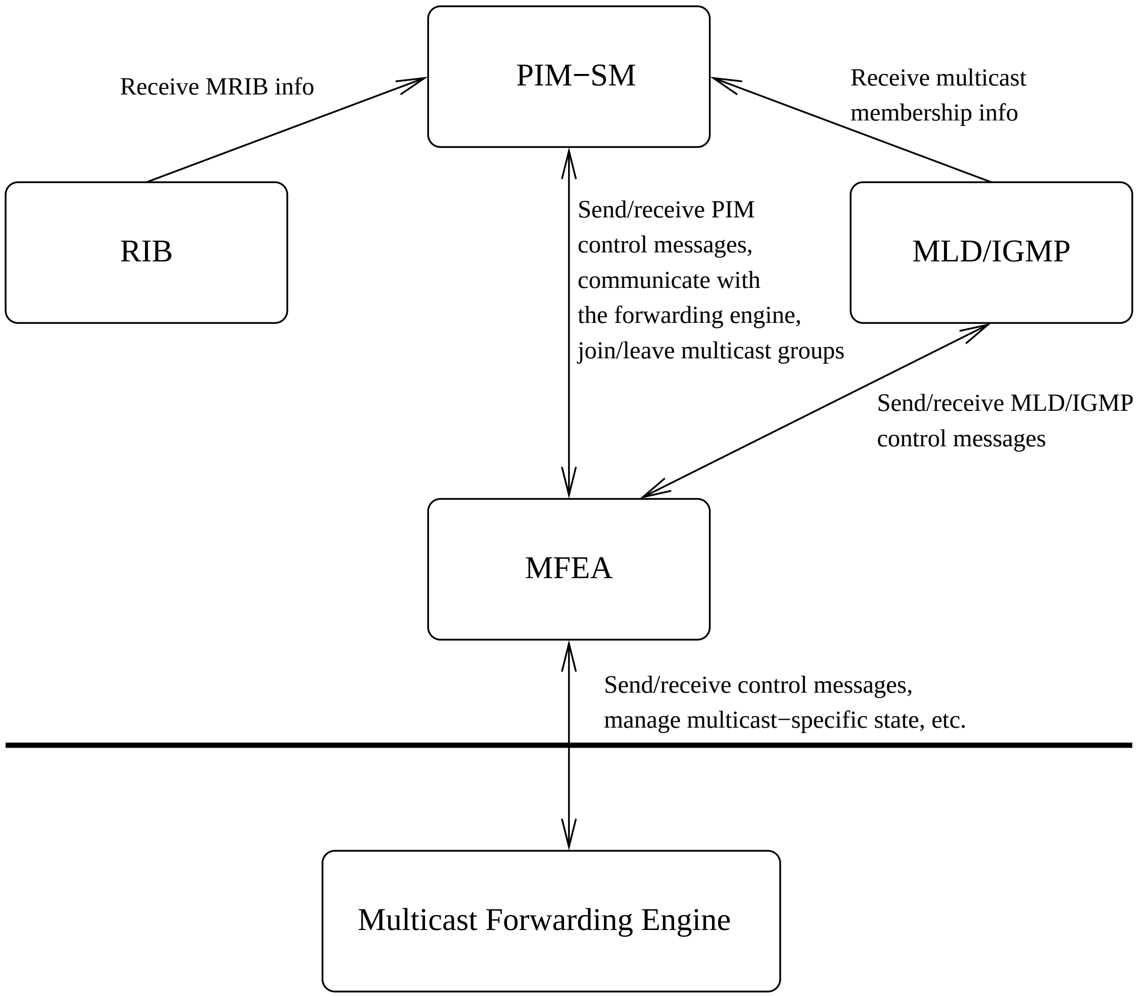
- Simplicity gives you lots of space for maneuvers
- Consistency (*e.g.*, in variables naming): things don't get into your way when you shuffle them around
- Which one comes first would be a trade-off
- Don't go into extremes

Forget (for now) the word "optimization"!!

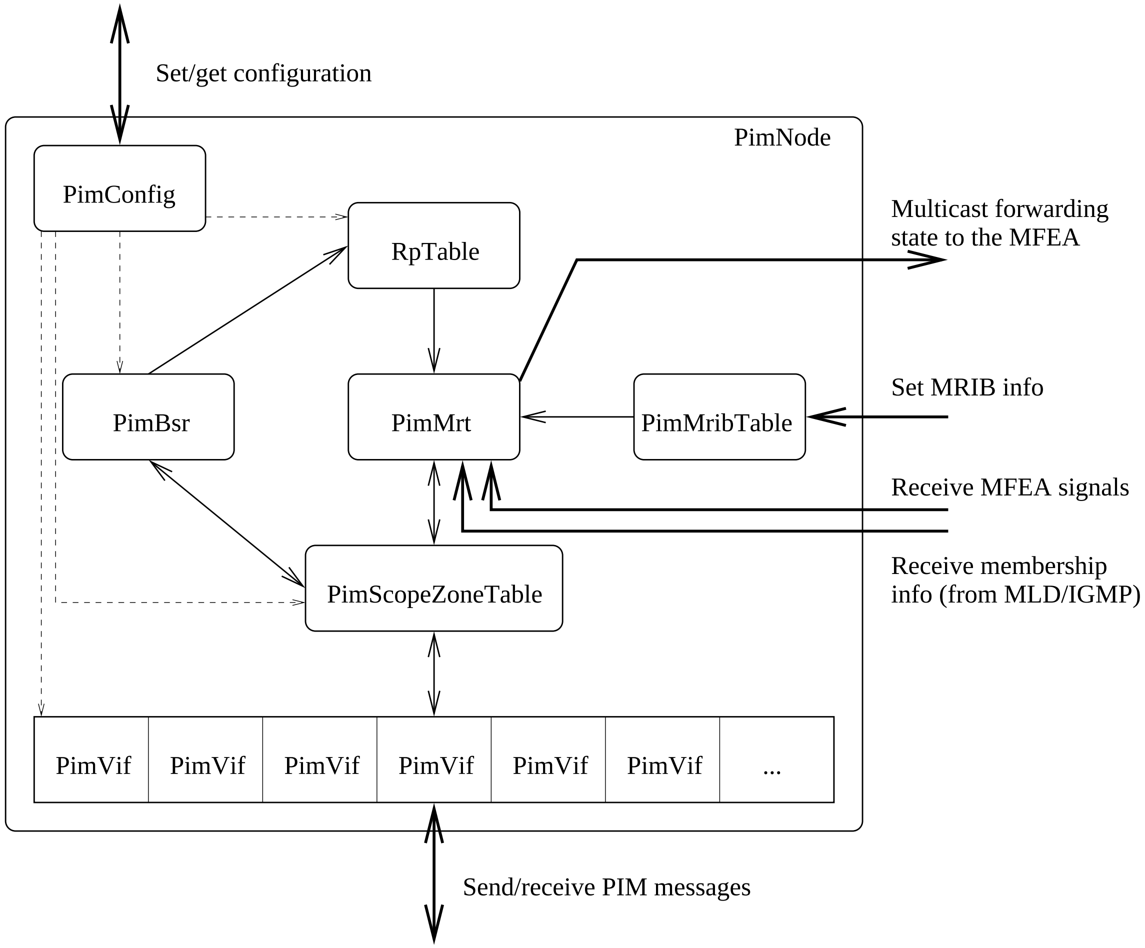
PIM-SM may have lots of routing state:

- So what, by the time the implementation is ready for prime-time, the price of memory will fall in half!
- Premature optimization results in complicated design, which is a sure sign for disaster!
- Solve performance issues when you do testing and profiling (*i.e.*, after the implementation is completed)

1. Design and understand the interaction with other modules



2. Break-down the protocol into semi-independent units



Protocol units break-down

- Probably the most difficult part
- There is no way you will get it right the first time!
- Simplicity comes first!

3. Protocol units implementation

- If you got your design right, in this stage you need to concentrate only on the protocol detail
- Be consistent!
- Each unit must respond to common methods/commands. E.g.: start/stop/enable/disable.
- Try to avoid implementation-specific assumptions

4. Testing, testing, testing

- If you don't test it, it doesn't work!
- Detailed testing takes time
- If you can, build a testing framework that allows you to perform automated testing any time you change something
- Now you can profile and optimize

Dependency tracking mechanism

- For each input event, what are the operations to perform and their ordering

- If the protocol is simple, you can take care of this by hand

- Unfortunately, this is not the case with PIM-SM: total of 50 input events, and 70 output operations.

PIM-SM dependency tracking mechanism

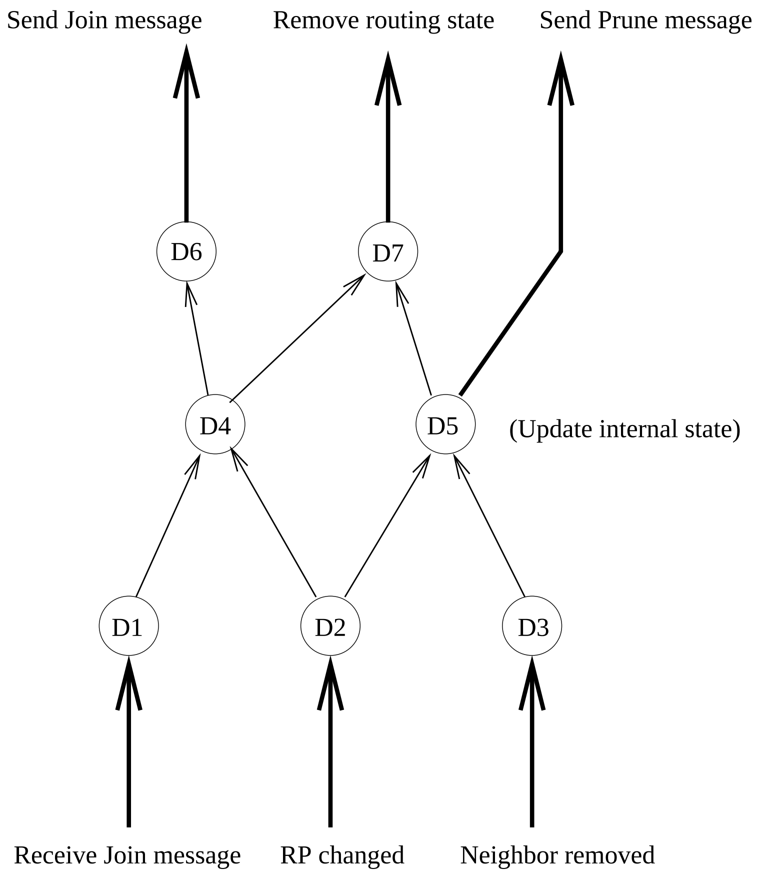
PIM-SM spec has tens of macros like:

```
pim_include(S,G) =
    { all interfaces I such that:
      ( (I_am_DR( I ) AND lost_assert(S,G,I) == FALSE )
        OR AssertWinner(S,G,I) == me )
       AND  local_receiver_include(S,G,I) }
```

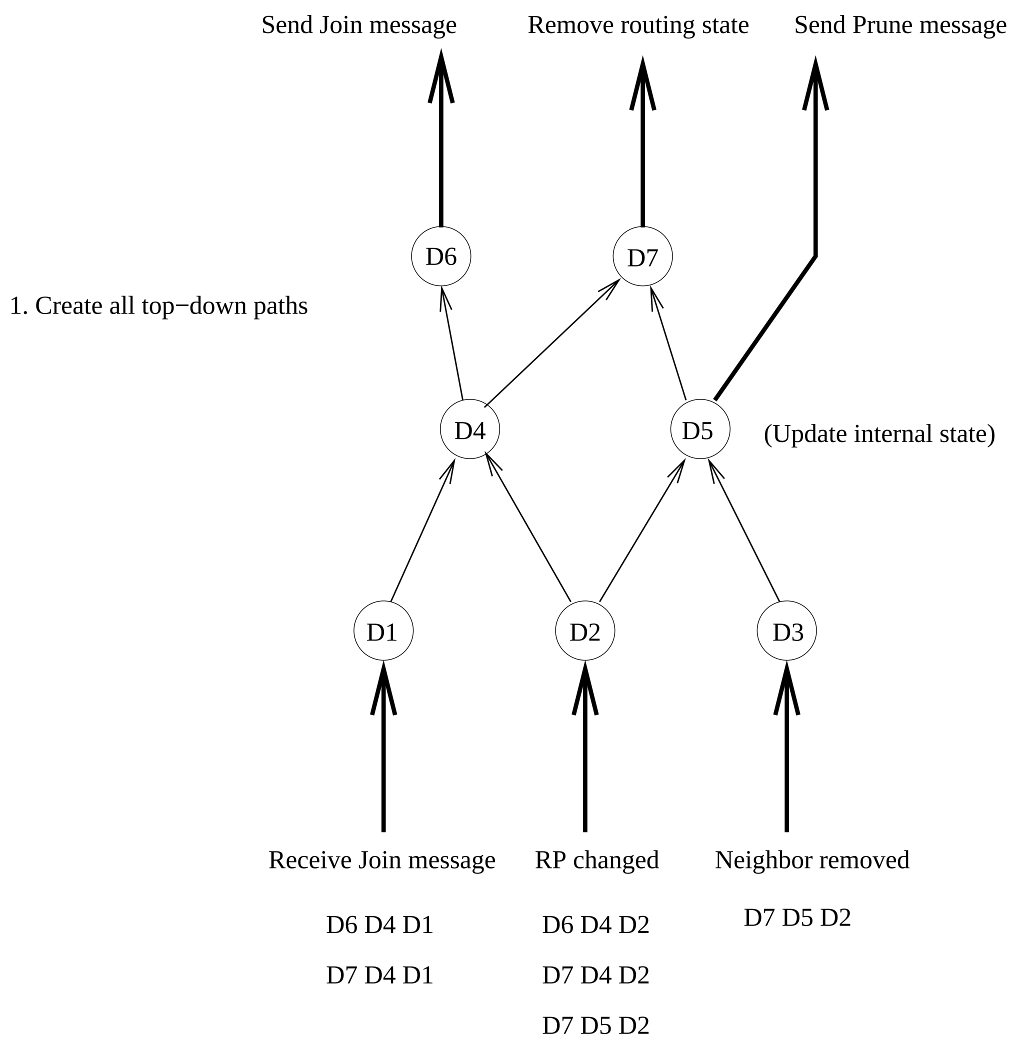
The corresponding state dependency rule is:

```
void
PimMreTrackState::track_state_pim_include_sg(list<PimMreAction> action_list)
{
    track_state_i_am_dr(action_list);
    track_state_lost_assert_sg(action_list);
    track_state_assert_winner_sg(action_list);
    track_state_local_receiver_include_sg(action_list);
}
```

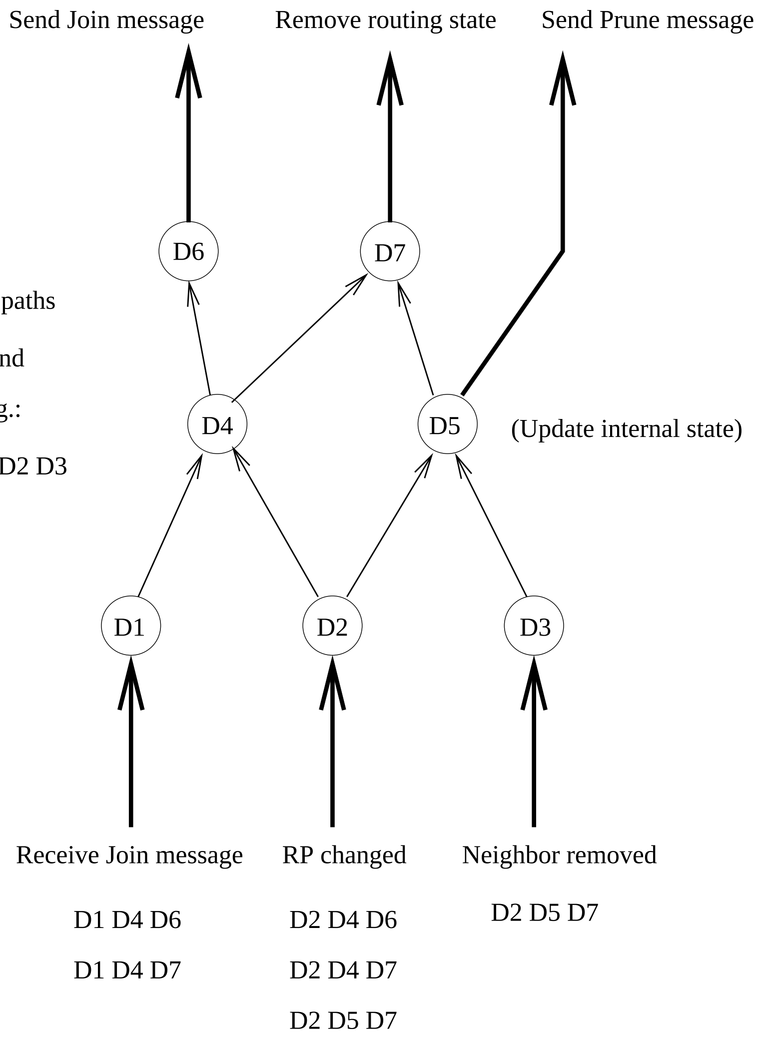
Dependency tracking



Dependency tracking (2)



Dependency tracking (3)



1. Create all top−down paths

2. Remove duplicates and reverse the paths. E.g.:

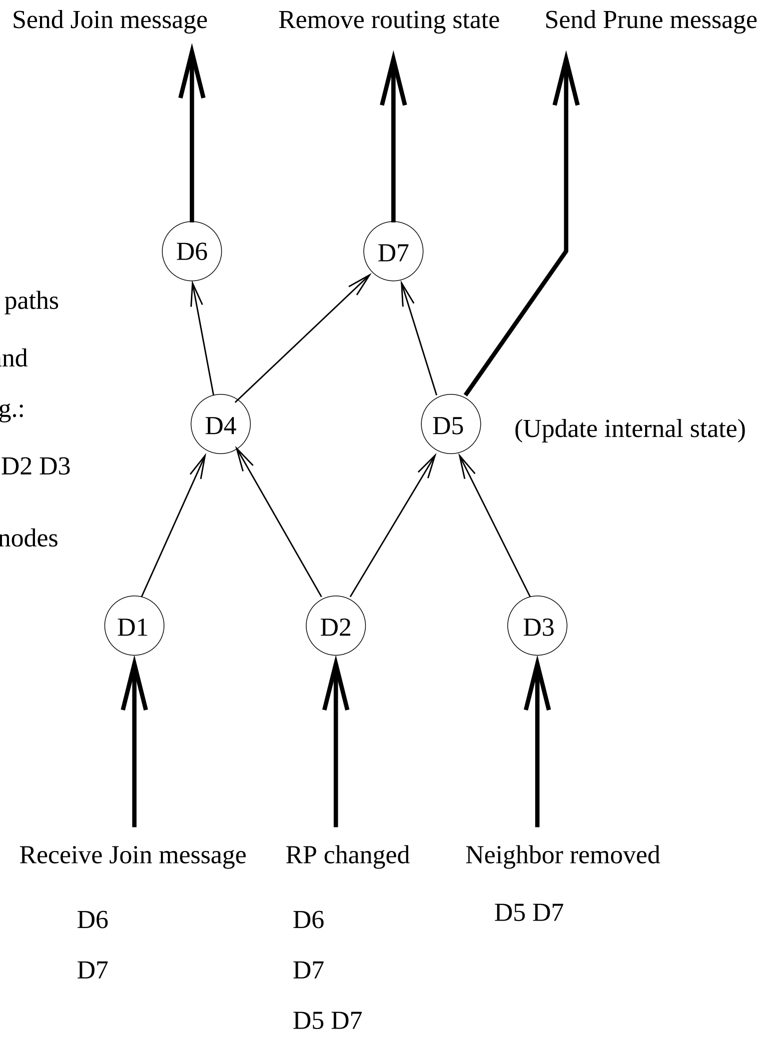
D3 D2 D2 D1 −> D1 D2 D3

Dependency tracking (4)

1. Create all top−down paths
2. Remove duplicates and
   reverse the paths. E.g.:

   D3 D2 D2 D1 −> D1 D2 D3

3. Remove non−output nodes
   from each list



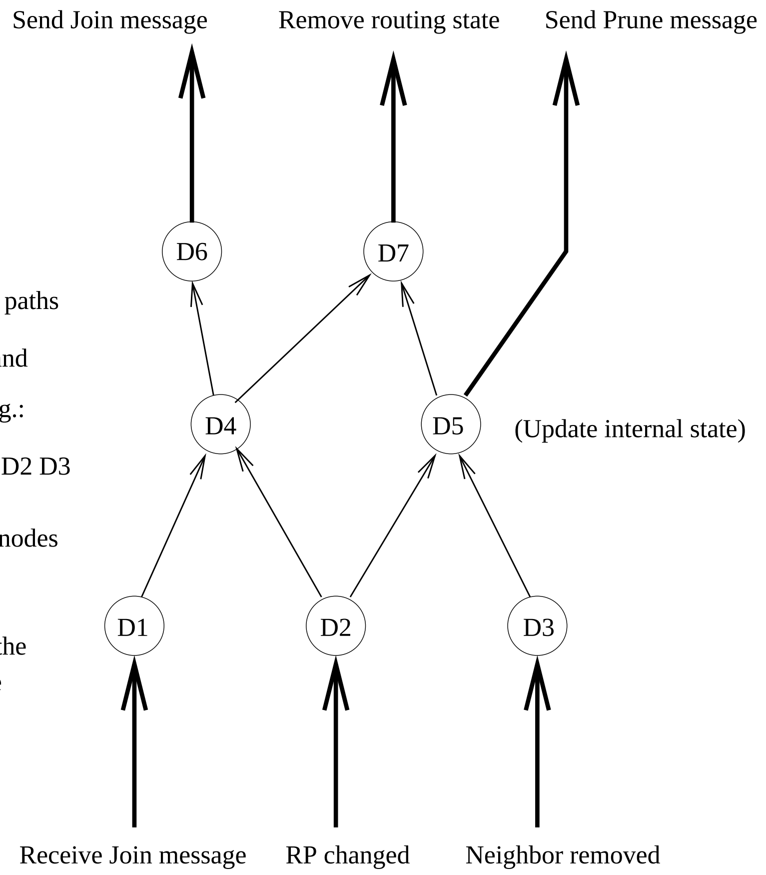
Dependency tracking (5)

1. Create all top−down paths
2. Remove duplicates and
   reverse the paths. E.g.:

   D3 D2 D2 D1 −> D1 D2 D3

3. Remove non−output nodes
   from each list

4. Recursively pop−up the
   actions that are at the
   head of a list only



Receive Join message	RP changed	Neighbor removed
D6	D6	D5 D7
D7	D7	
	D5 D7	
D6 D7	D6 D5 D7	D5 D7

Dependency tracking usage

- The unidirectional "graph" is semi-defined by the state computation macros

- For each macro, write the corresponding state dependency rule

- All state dependency is pre-computed once on start-up

- If the spec changes, the rules are easy to update

- If the spec does not use macros for state computation, write your own macros

Status

- Completed: core design, IPC, RIB, BGP, PIM-SM, IGMP, FEA

- In progress: OSPF, RIP adaptation, IPv6, Click integration,

- Future work: create XORP simulation environment

- First preliminary release early December: **http://www.xorp.org/**

Summary

- XORP tries to close the gap between **research** and **practice**

- Routing architecture designed for **extensibility** and **robustness**.

- Can be used to build distributed routers

- XORP simulation environment can facilitate protocol development: the simulation and the real-world prototype use exactly same code