



Recursive Networks

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Internet Architecture

Accused of ossification, but:

- Ossification = stability
- Flexibility is abundant:
 - Shim layers:
 - HIP, SHIM6, IPsec, TLS
 - Muxing layers:
 - SCTP, RDDP, BEEP
 - Connections:
 - MPLS, GRE, IKE, BEEP, SCTP
 - Virtualization:
 - L2VPN, L3VPN/X-Bone/RON/Detour, L7-DHTs



Motivation

- Layers of a stack becoming more similar
 - Security, soft-state, pacing, retransmission
- Desire to support new capabilities
 - Interlayer cooperation, dynamic layer selection
- Desire to support emerging abstractions
 - Overlay layers don't map to 1-7
 - Support for recursive nodes (BARP, LISP, TRILL)

Is layering more than a coding artifact?



Net Arch - Assumptions

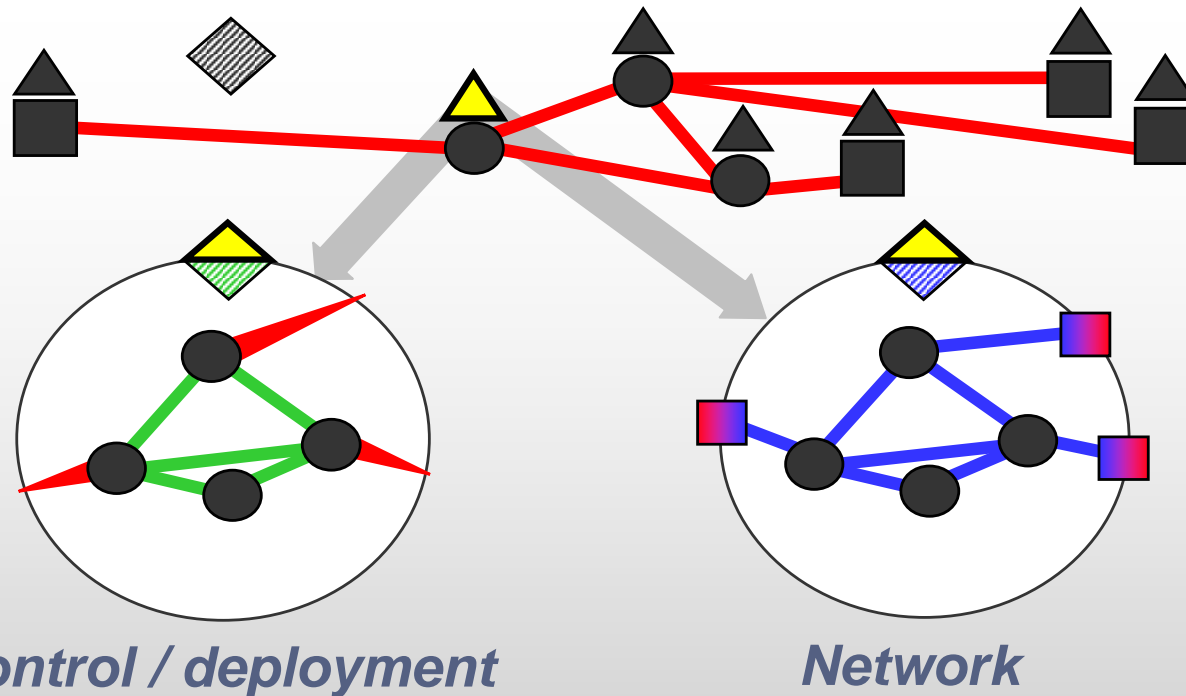
- **Internet-Compliant Architecture**
 - Hosts add/delete headers
 - Routers transit (constant # headers)
- **Supports New Capabilities**
 - Concurrence (multiprocessing)
 - Revisitation (multiple roles in one net)
 - Recursion (to hide topology and/or mgt.)



Virtual Networks

- ***Internet-like***
 - Internet = routers + hosts + links
 - VIs = VRs + VHs + tunnels
 - Full architecture (vs. VPNs, PP-VPNs, etc.)
- ***All-Virtual***
 - Supports VNs on VNs
 - “Reality” is undecidable
- ***Recursion-as-router***
 - Some of VRs are VI networks
- ***See Globecom 1998 (running code 2000)***
 - 15 layers deep, 800 wide, app. deploy, P2P integration

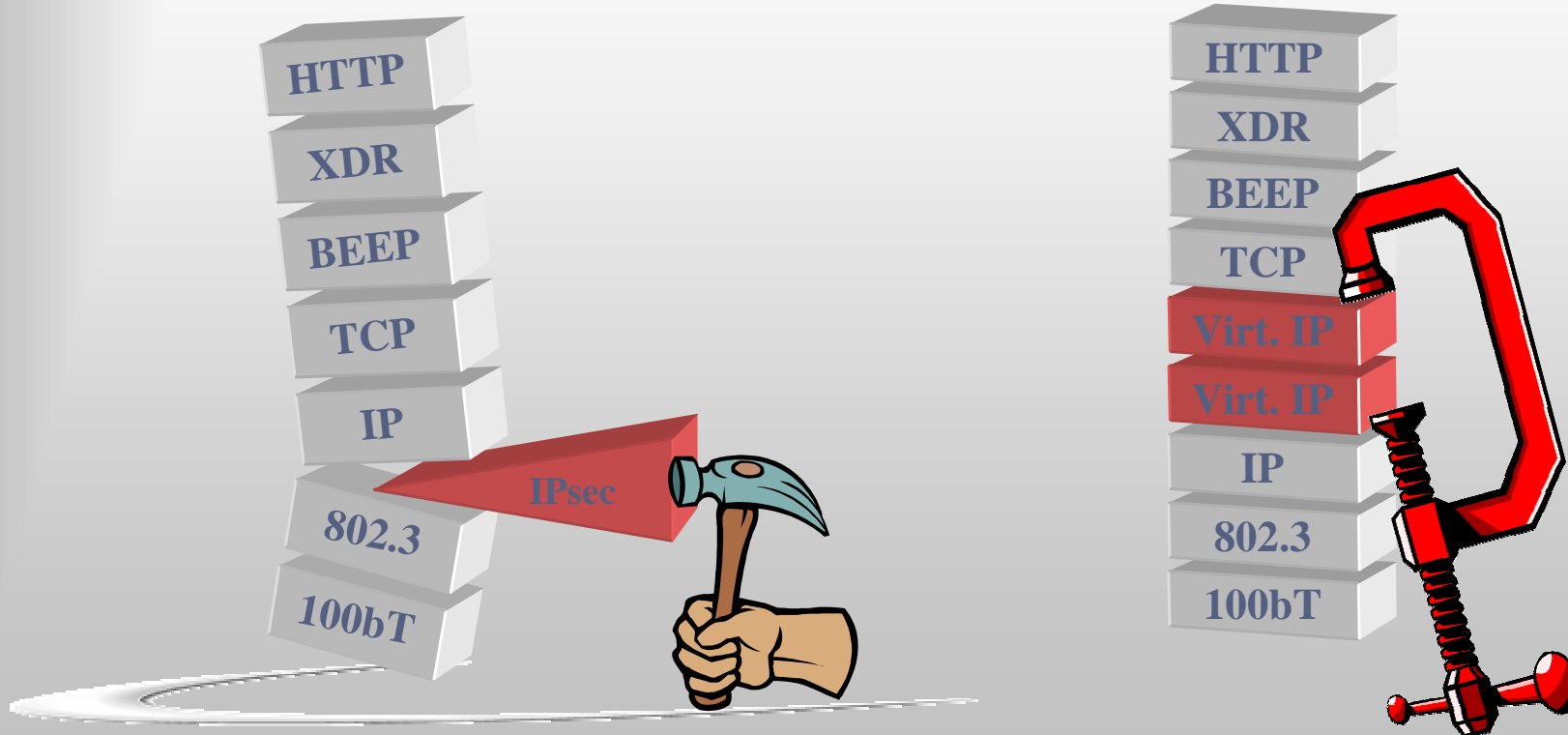
Recursive Internet (2003)



- Recursion as a router
 - L3 = BARP (X-Bone), LISP (IRTF)
 - L2 = Rbridges/TRILL

Recursion requires new layers – where? Why?

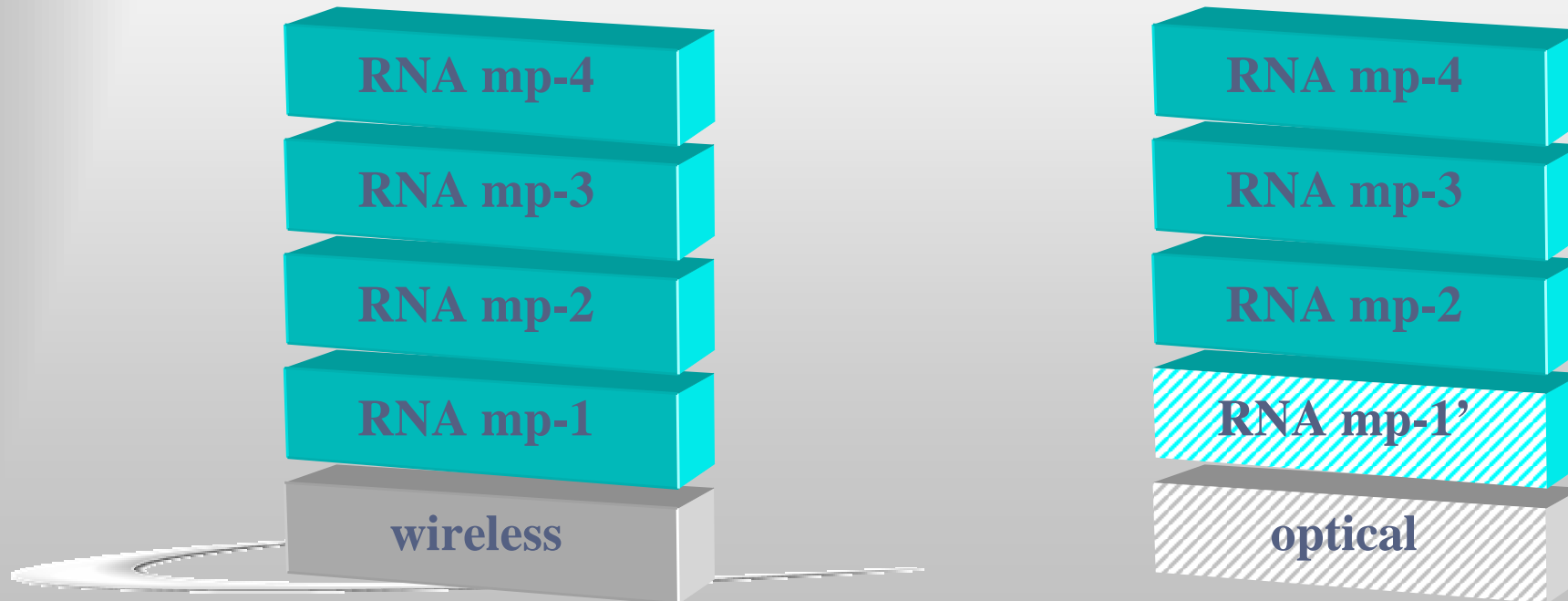
- Wedge between (IPsec, left) or replicate (virtualization, right)





RNA Stack (2006)

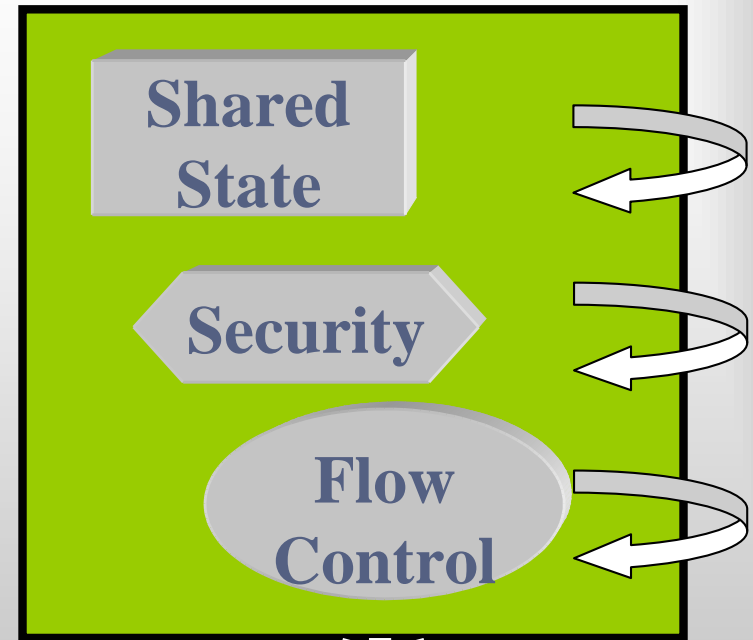
- One MP, many instances
 - Needed layers, with needed services
 - Layers limit scope, enable context sensitivity
 - Scope defined by reach, layer above, layer below





RNA Metaprotocol

- Template of basic protocol service:
 - Establish / refresh state
 - Encrypt / decrypt message
 - Apply filtering
 - Pace output via flow control
 - Pace input to allow reordering
 - Multiplex/demultiplex
 - includes switching/forwarding



Next Layer
Resolution

MDCM from *Choices*

Structured template w/plug-in functions

- Layer address translate/resolution
 - ARP, IP forwarding lookup
 - BARP/LISP/TRILL lookup
- Layer alternates selection
 - IPv4/IPv6,
TCP/SCTP/DCCP/UDP
- Iterative forwarding
 - IP hop-by-hop,
DNS recursive queries

```
LAYER(DATA, SRC, DST)
```

```
Process DATA, SRC, DST into MSG
```

```
WHILE (Here <> DST)
```

```
IF (exists(lower layer))
```

```
Select a lower layer
```

```
Resolve SRC/DST to next layer
```

```
S',D'
```

```
LAYER(MSG, S', D')
```

```
ELSE
```

```
FAIL /* can't find destination */
```

```
ENDIF
```

```
ENDWHILE
```

```
/* message arrives here */
```

```
RETURN {up the current stack}
```

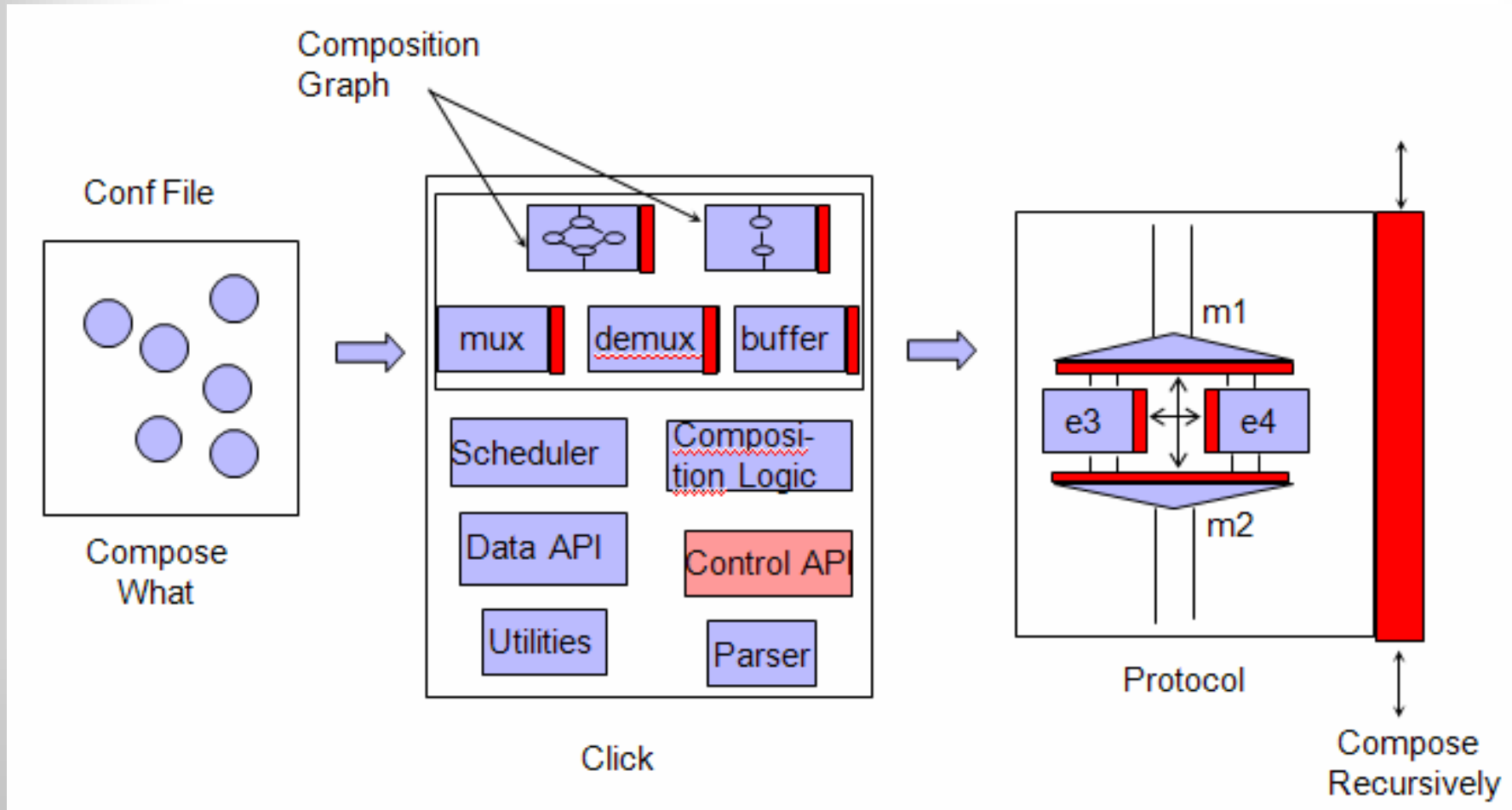


**Next-hop
Resolution**



**Next Layer
Resolution**

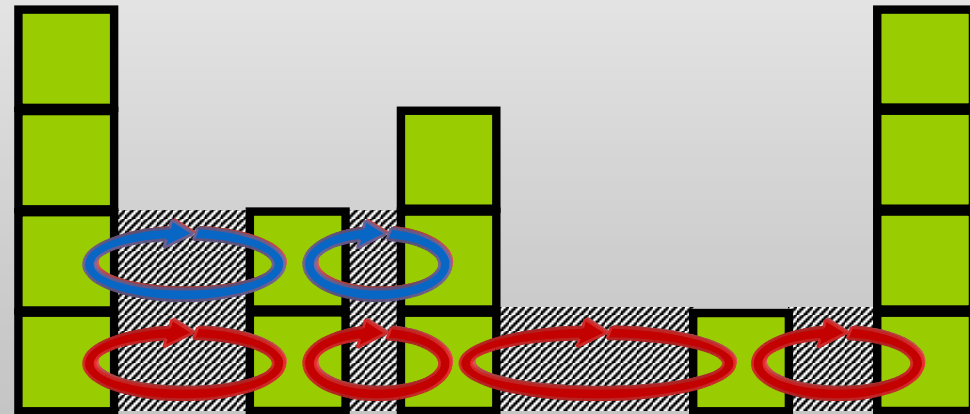
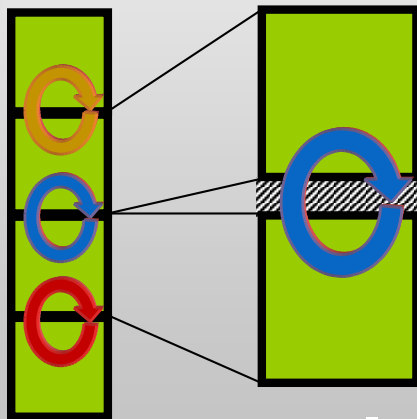
Click Implementation





Recursion supports Layering and Forwarding

- Layering (left)
 - Heterogeneity via $O(N)$ translators
 - *Requires successive recursive discovery*
- Forwarding (right)
 - N^2 connectivity via $O(N)$ links
 - *Requires successive iterative discovery*





Related Work

- Recursion in networking
 - X-Bone/Virtual Nets, Spawning Nets, TRILL, Network IPC, LISP
 - *RNs natively include resolution and discovery*
- Protocol environments
 - Modular systems: Click, x-Kernel, Netgraph, Flexible Stacks
 - Template models: RBA, MDCM
 - *RNs adds a constrained template with structured services*
- Context-sensitive components
 - PEPs, Shims, intermediate overlay layers, etc.
 - *RNs incorporates this into the stack directly*
- Configurable über-protocols
 - XTP, TP++, SCTP
 - *RNs make every layer configurable, but keeps multiple layers.*



Conclusions

- Virtualization requires recursion
- Recursion supports layering
- Recursion supports forwarding

One recurrence to bind them all...

- ***Recursion is a native network property***
 - Integrates and virtualization, forwarding and layering
in a single mechanism