
# Recursive Networks

Joe Touch
USC/ISI

With: Yu-Shun Wang
Lars Eggert
Venkata Pingali

Information Sciences Institute

# 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

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# 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?***

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# 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.)

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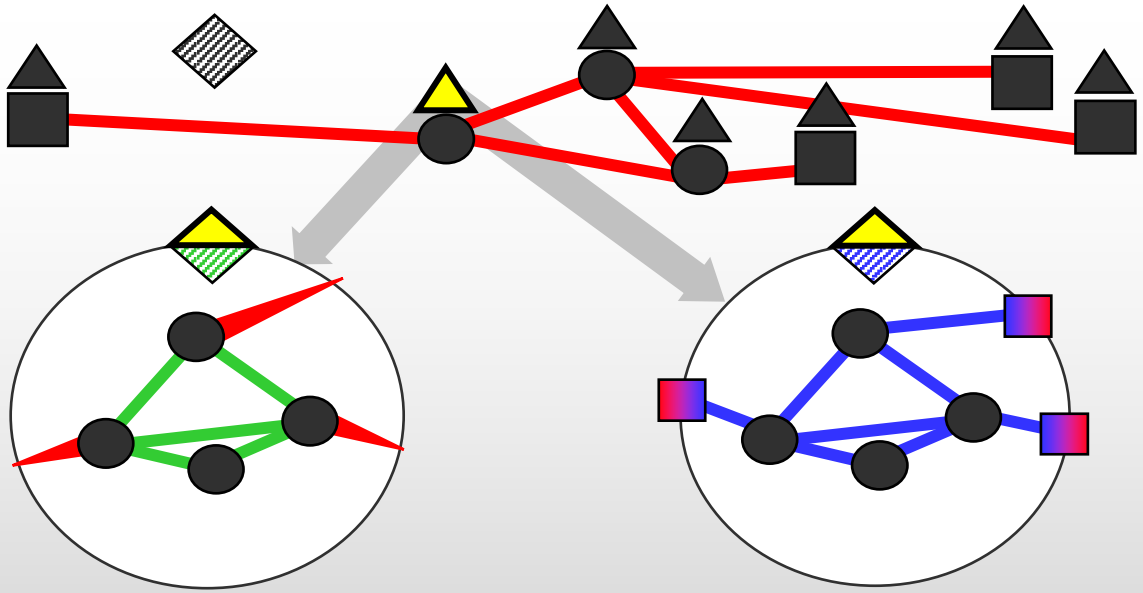
# Virtual Networks

- ***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)



***Control / deployment*** ***Network***

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

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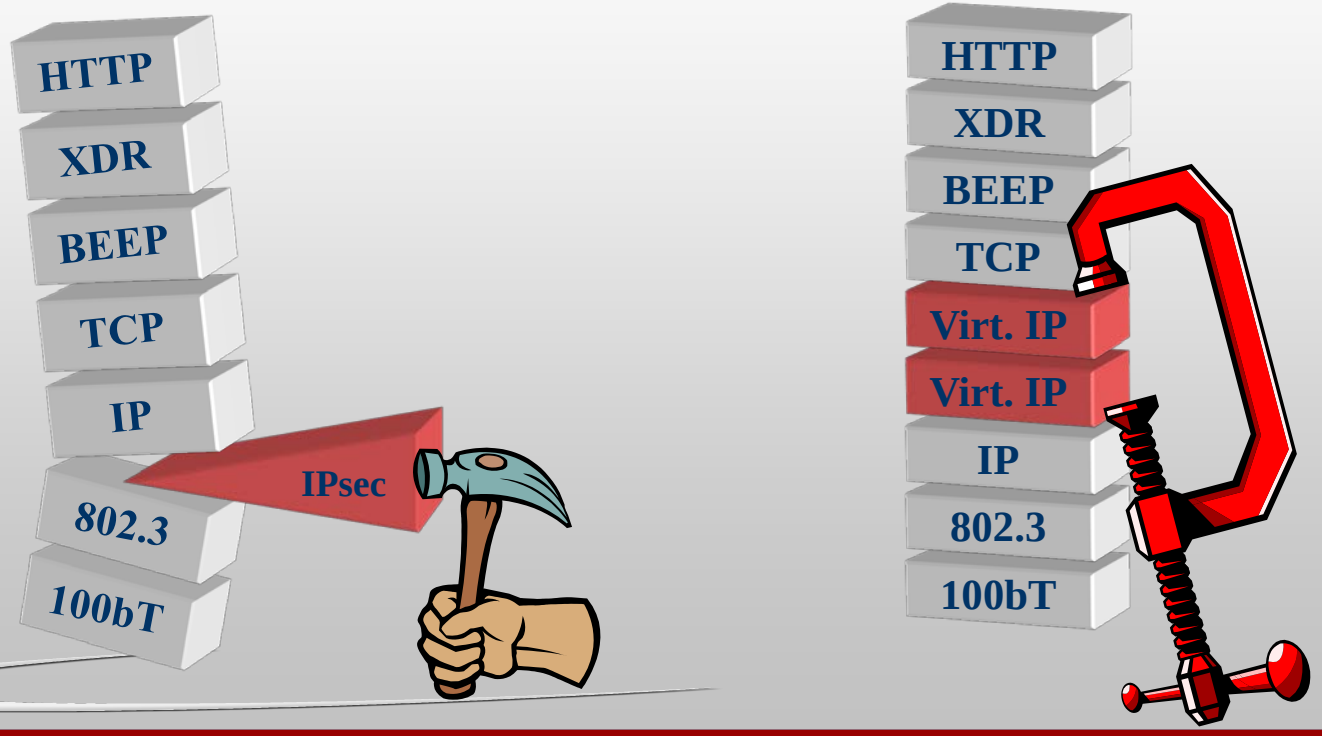
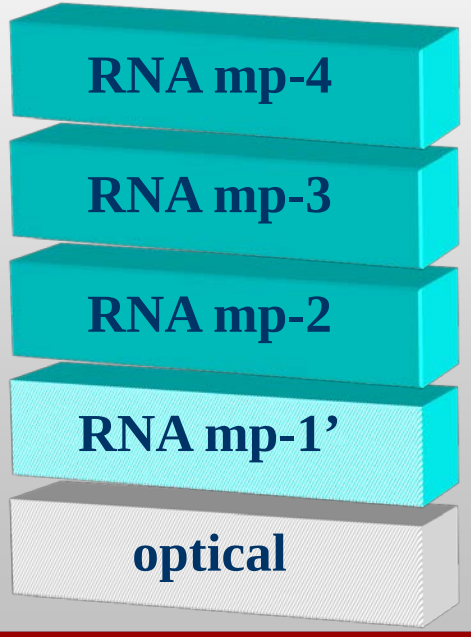
# Recursion requires new layers – where? Why?

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



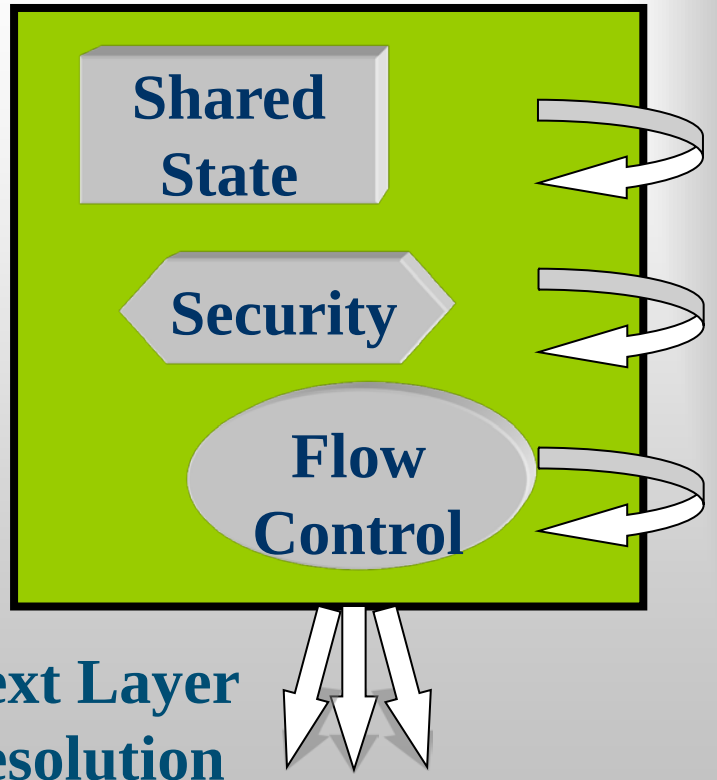
# RNA Stack (2006)

- 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

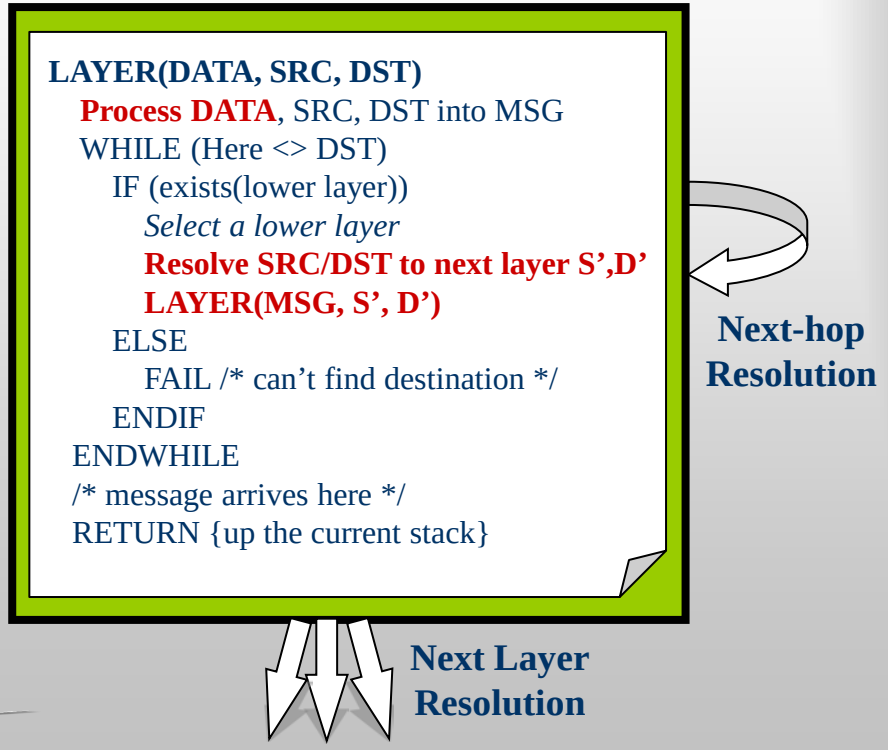
- Template of basic protocol service:
  - Establish / refresh state
  - Encrypt / decrypt message
  - Apply filtering
  - Pace output via flow control
  - Pace input to allow reordering
  - Multiplex/demultiplex
    - includes switching/forwarding



# 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



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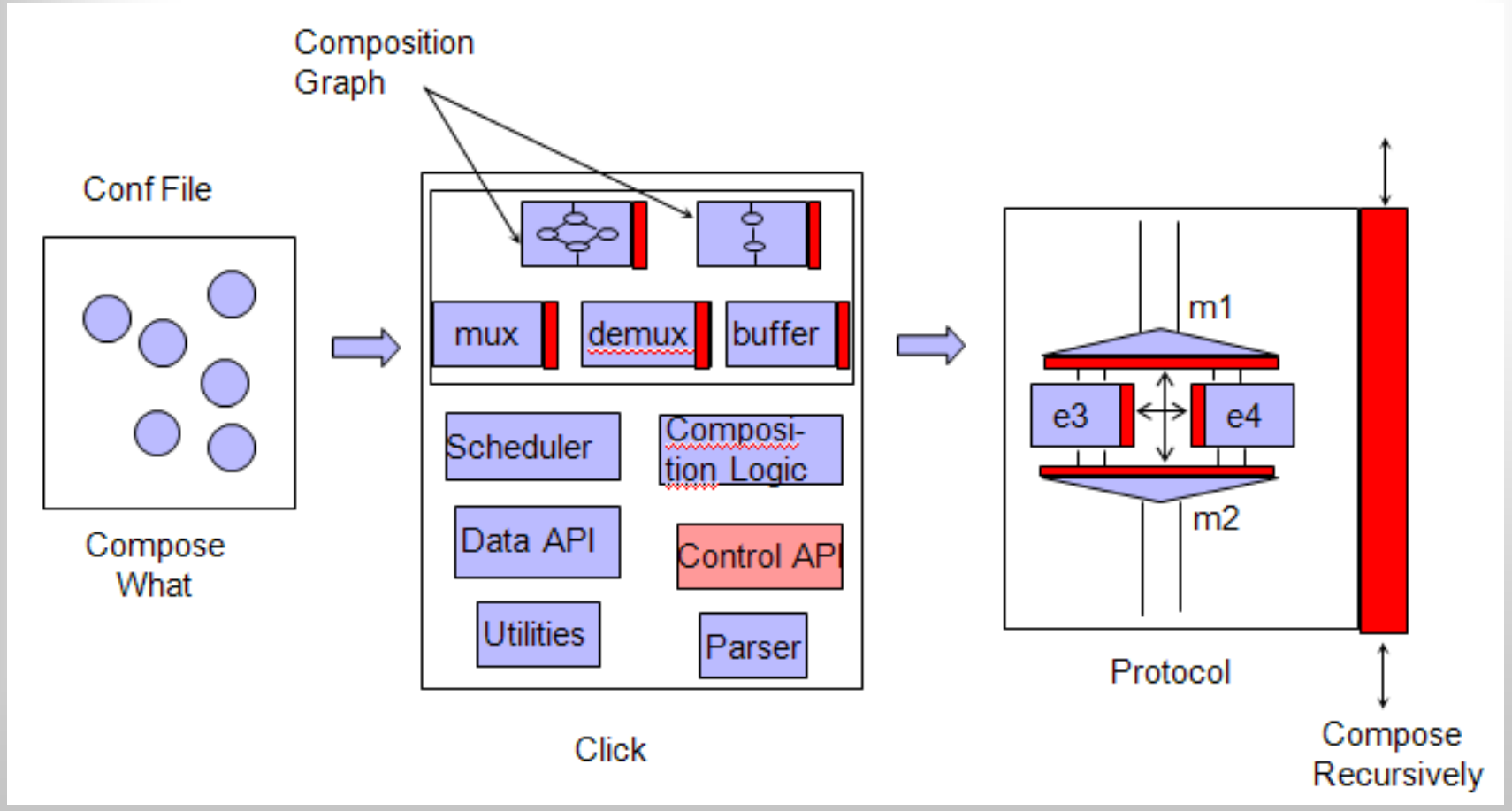
# Click Implementation



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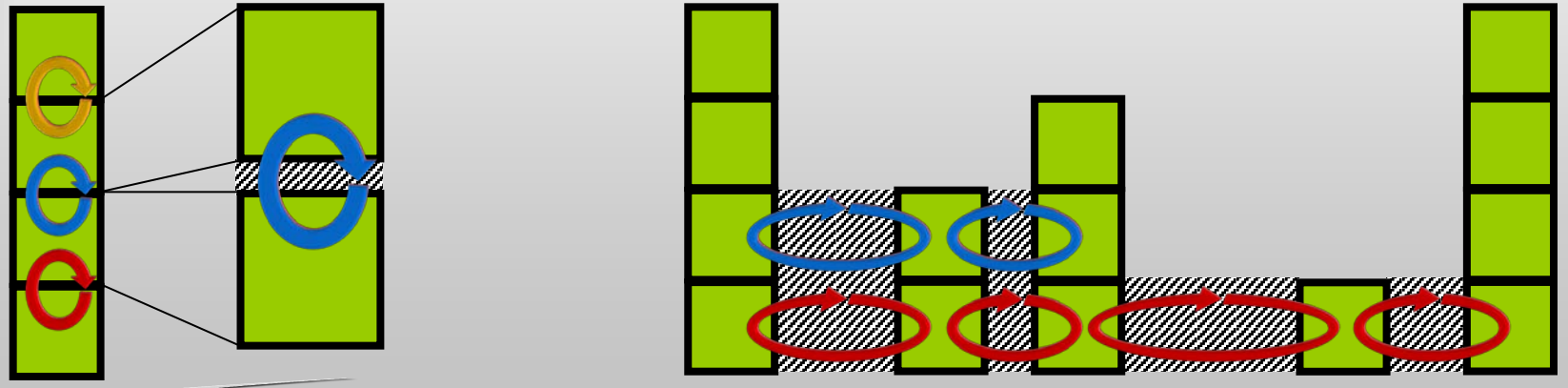
# Recursion supports Layering and Forwarding

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



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# 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.*

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# 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**