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From Shannon to Recursive Nets: Multihop/Multiparty Influences on Net Arch.

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Outline

- Background
- Principles of multihop/multiparty comms
- RNA
  - Concept
  - Design / Implementation
  - Related Work
- Conclusions

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Background

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What makes an architecture new?

- Shaking the Hourglass (CCW 08)
  - All exchanges are 1 packet
  - Collosograms > RTT*delay
  - No LANs? (all L2 was pt-pt)
- What defines success?
  - fixing what's 'broken'
  - doing something new/different
  - the Internet / circuits as a degenerate case

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Motivation

- Desire to support new capabilities
  - Interlayer cooperation, dynamic layer selection, layering created by virtualization
- Desire to support emerging abstractions
  - Overlay layers don't map to 1-7
  - Support for recursive nodes (BARP, LISP, TRILL)
- Desire to coordinate services in diff. places
  - Security, soft-state, pacing, retransmission

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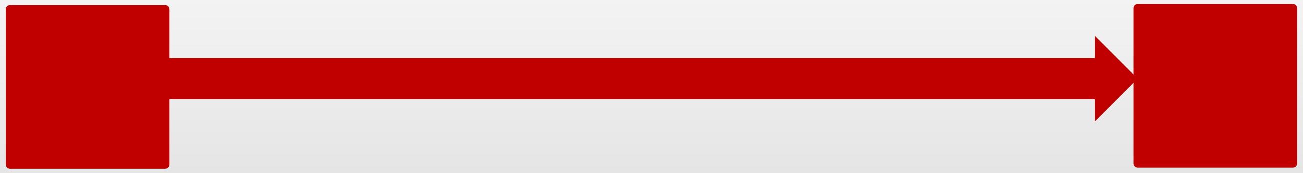
Shannon Channel

- Two preselected parties
  - Homogenous endpoints



- Unidirectional channel
  - Preselected sender, preselected receiver

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What is communication?

- Shannon: shared bits
  - Between fixed endpoints, known *a priori*

- Shared bits between two parties
  - How do we find the party to talk to?

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What SCs Ignore

- What if you're not directly connected?
  - A) multihop
  - B) multilayer
- Why are multihop/multilayer interesting?
  - Scalable = multihop
  - Ubiquitous = multilayer
  - I.e., all scalable, ubiquitous comms!

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Exploring Invariants

- Networking is *groups of interacting parties*
  - Groups are heterogeneous
  - All members want to interact
  - Groupings are dynamic (*i.e.*, virtual)
- Thus, need an architecture that supports:
  - Heterogeneity
  - Interaction
  - Virtualization

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Principles of comm.

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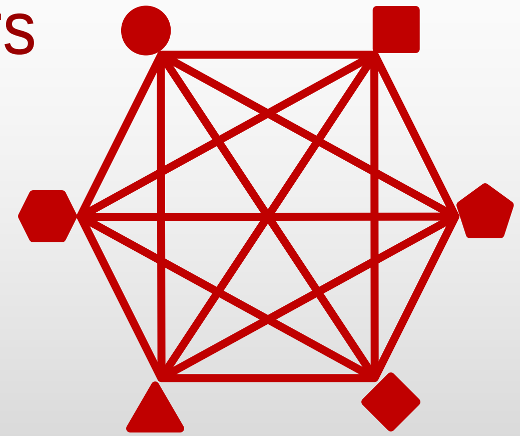
Heterogeneity leads to layering

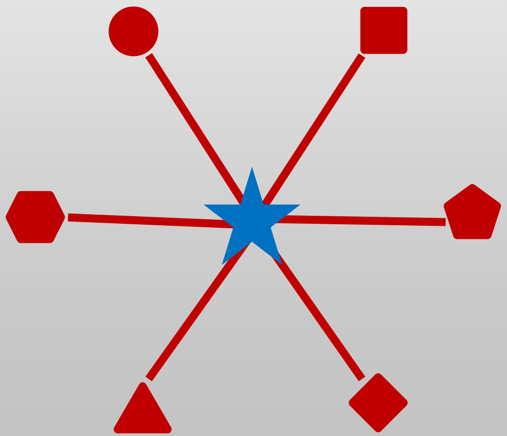
- M different interacting parties need
  - M^2 translators



or

  - M translators + common format

... *i.e.*, a layer



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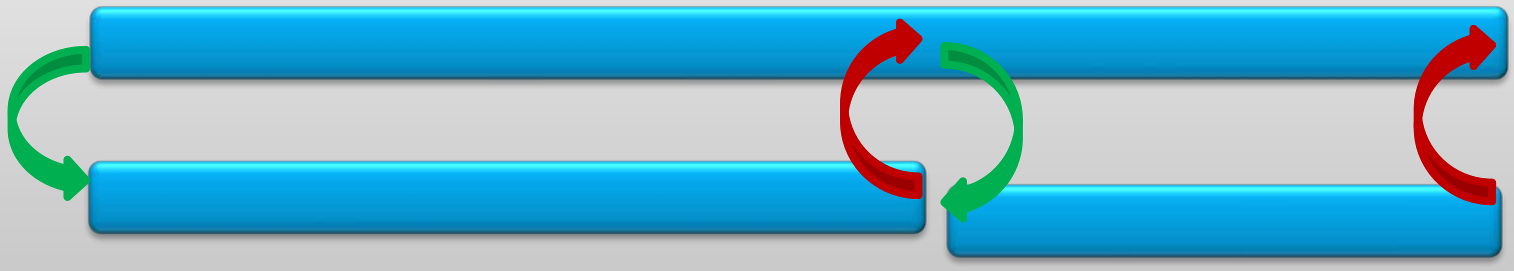
Layering leads to resolution

- IDs are local to a layer
  - Whether names, paths, locations
- Need to resolve IDs between layers
  - Google, DNS, ARP, LISP encap tables



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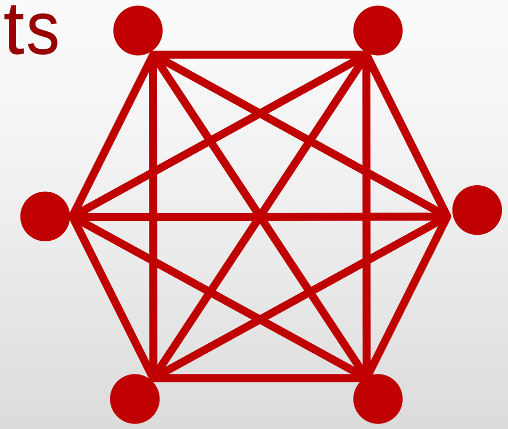
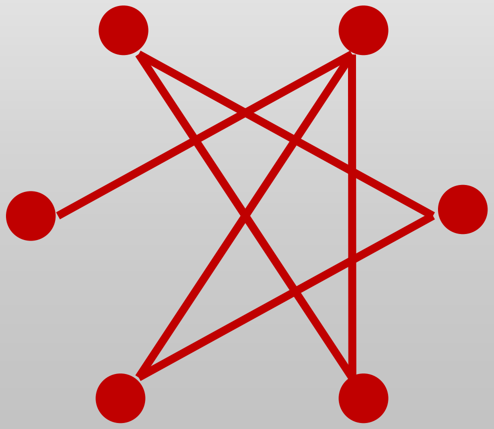
Interaction leads to forwarding

- N parties need
  - N^2 circuits



or

  - O(N) links + forwarding

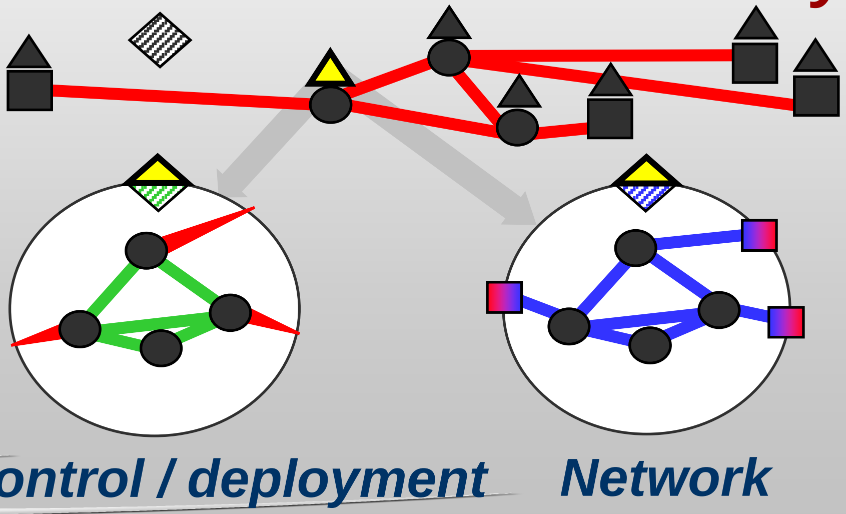


Virtualization leads to recursion

- N parties want to group in arbitrary, dynamic ways.

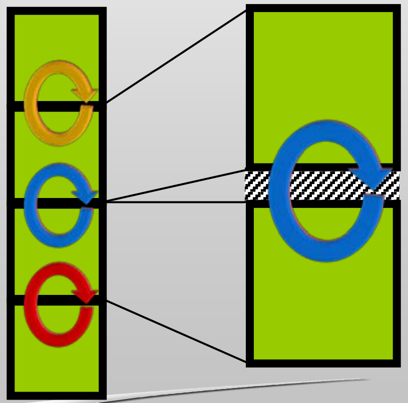
  ... such groups are inherently virtual

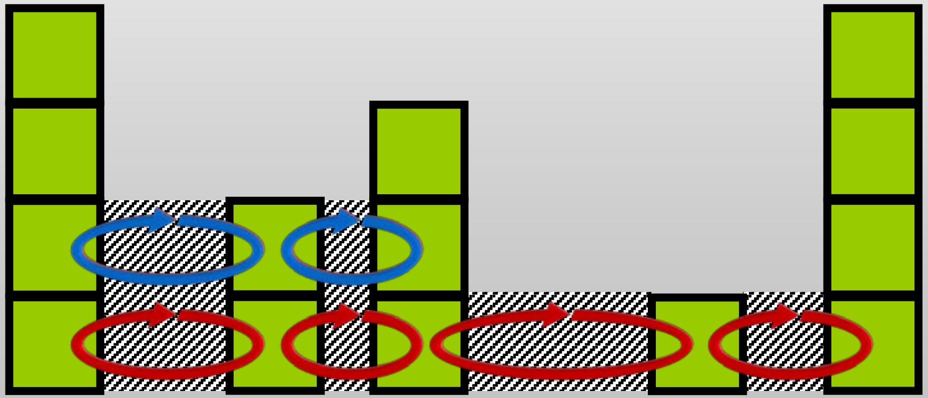
... and virtualization is inherently recursive



Recursion unifies layering, forwarding, & resolution

- Layering (left)
  - Heterogeneity via O(N) translators
  - *Supported by successive recursive <u>resolution</u>*
- Forwarding (right)
  - N^2 connectivity via O(N) links
  - *Supported by successive iterative <u>resolution</u> (tail recursion)*





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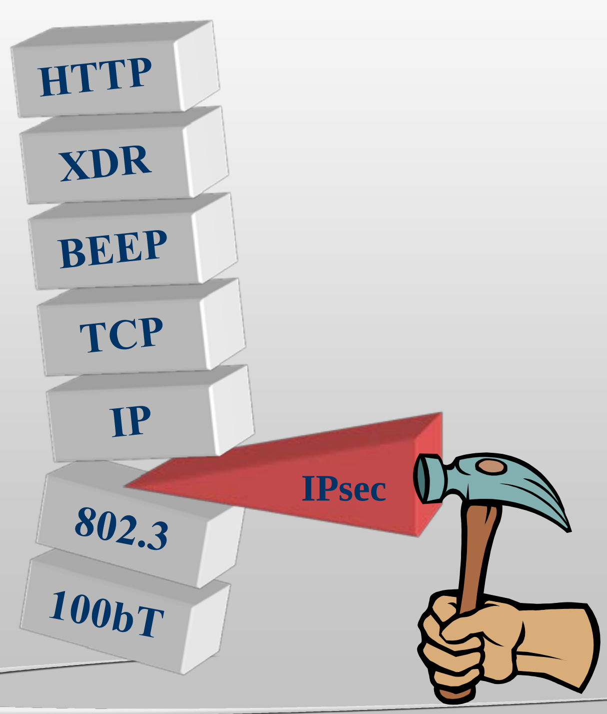
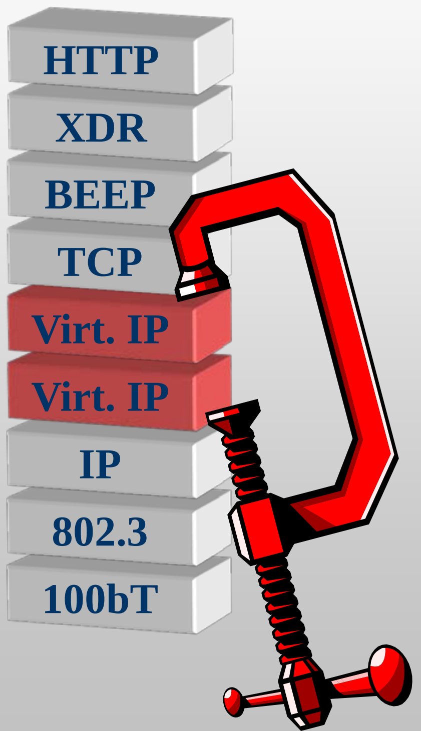
Recursion requires new layers – where? Why?

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





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What if…

- Über-protocols are the right idea…
  - A single configurable protocol with
    - Hard/soft state management
    - Congestion control, error management
    - Security
  - *E.g.*, XTP, TP++
- But they went too far…
  - Keep layering – because of first principles

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RNA – concept

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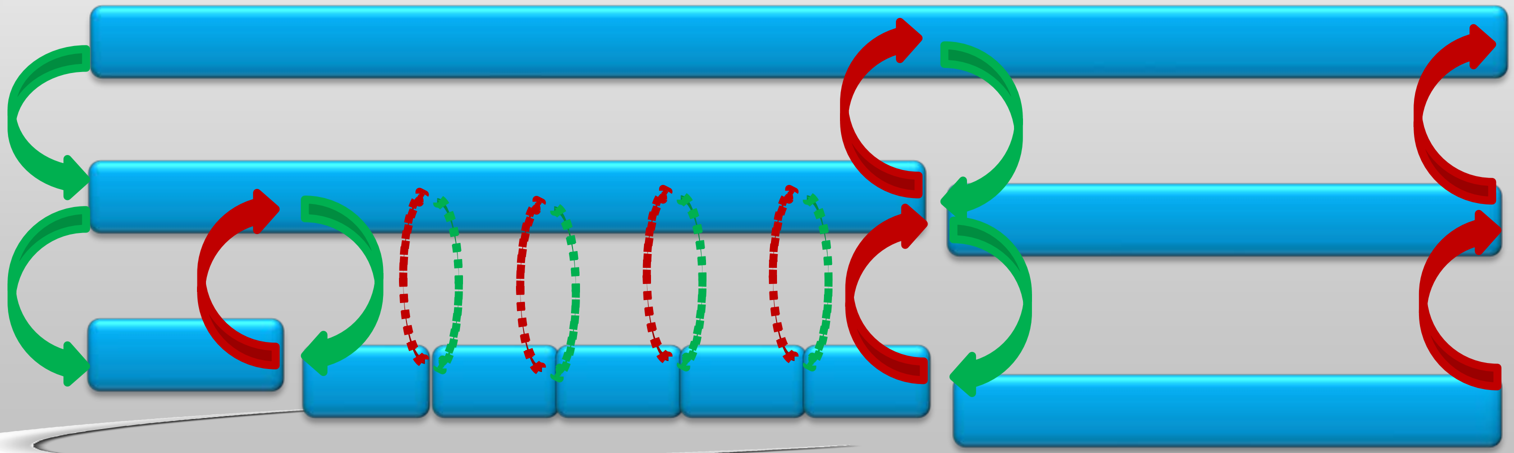
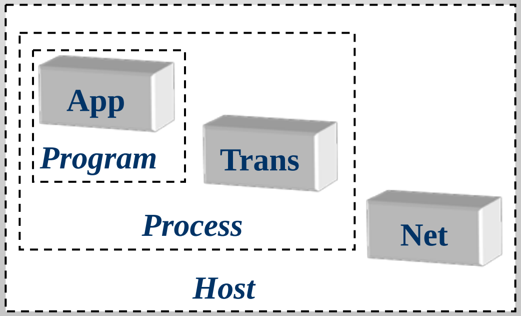
RNA

- One metaprotocol, many instances
  - Needed layers, with needed services
  - Layers limit scope, enable context sensitivity
  - Scope defined by reach, layer above, layer below
  - Resolution connects the layers (red/green)



Scope defines a layer

- Its endpoints
  - A “hop” @layer N = E2E extent of layer N-1
- The layer above
  - What services this layer provides
- The layer below
  - What services this layer requires
- E.g.: Shared state at diff. layers for diff. services
  - Application binding
  - Transport delivery
  - Net security



The difference is scope

What makes this an architecture?

- General template (metaprotocol + MDCM)
  - Instantiates as different layers or forwarding
- Abstraction for virtualization
  - Tunnel as link
  - Partitioned router as virtual router
  - Partitioned host + internal router as virtual host
- Abstraction for recursion
  - Recursive router implemented as a network of vrouters with vhosts at the router interfaces

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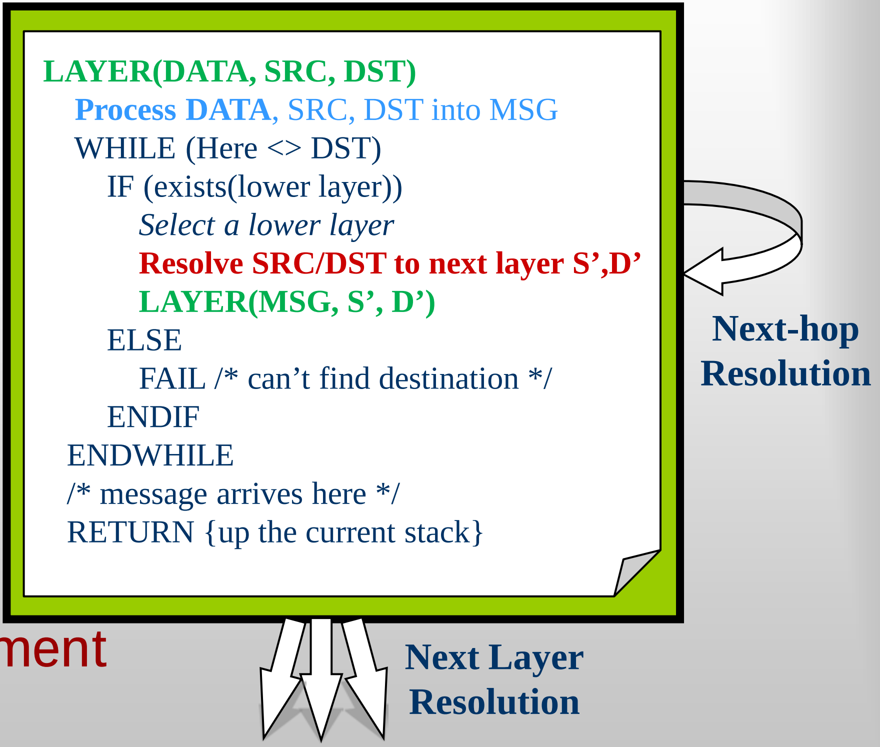
RNA MP Unifies...

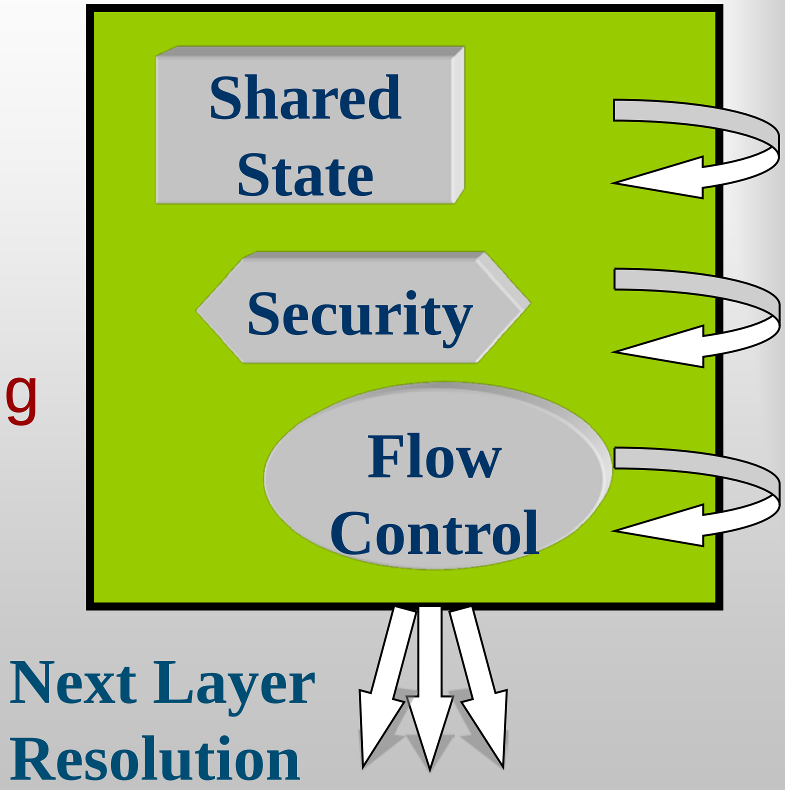
- "Resolve" unifies:
  - Layer address translate/resolution
    - ARP, IP forwarding lookup
    - BARP/LISP/TRILL lookup
  - Layer alternates selection
    - IPv4/IPv6, TCP/SCTP/DCCP/UDP
  - Iterative forwarding
    - IP hop-by-hop, DNS recursive queries
- "Process data" unifies:
  - Shared state, security, management
  - Flow control, error control



```
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}
```

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



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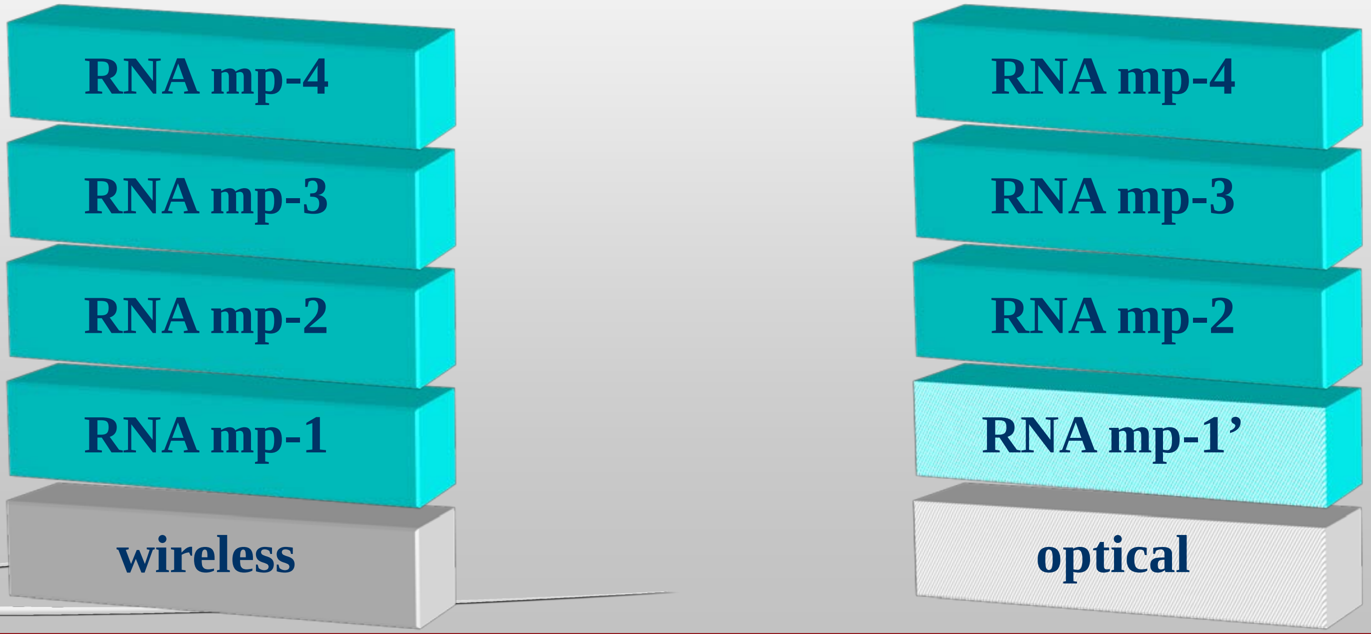
RNA Stack

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



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What does RNA enable?

- Explains and details invariants
  - Layering as more than a SW Engr. artifact
- Integrate current architecture
  - ‘stack’ (IP, TCP) *vs.* ‘glue’ (ARP, DNS)
- Support needed improvements
  - Recursion (AS-level LISP, L3 BARP, L2 TRILL)
  - Revisitation (X-Bone)
  - Concurrence (VPNs, multipath TCP)
- Supports “old horse” challenges natively
  - Dynamic ‘dual-stack’ (or more)

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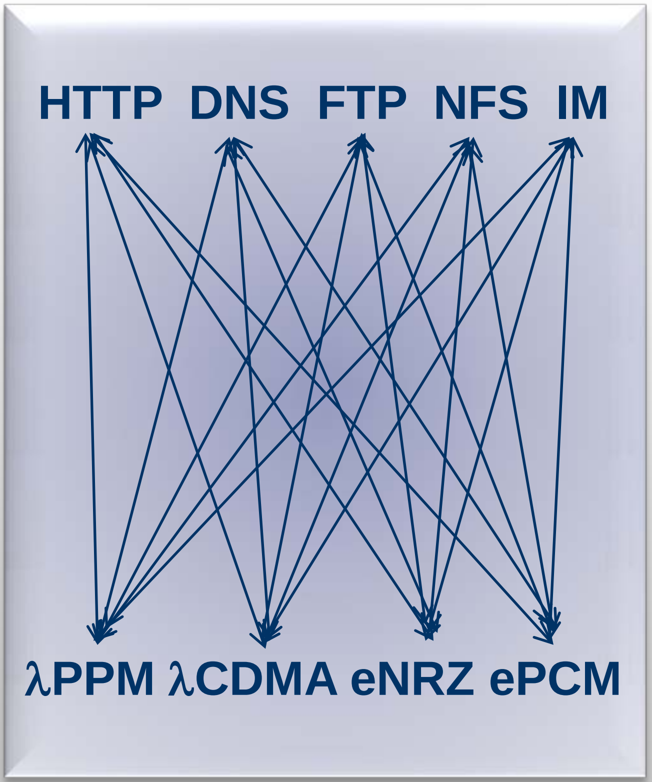
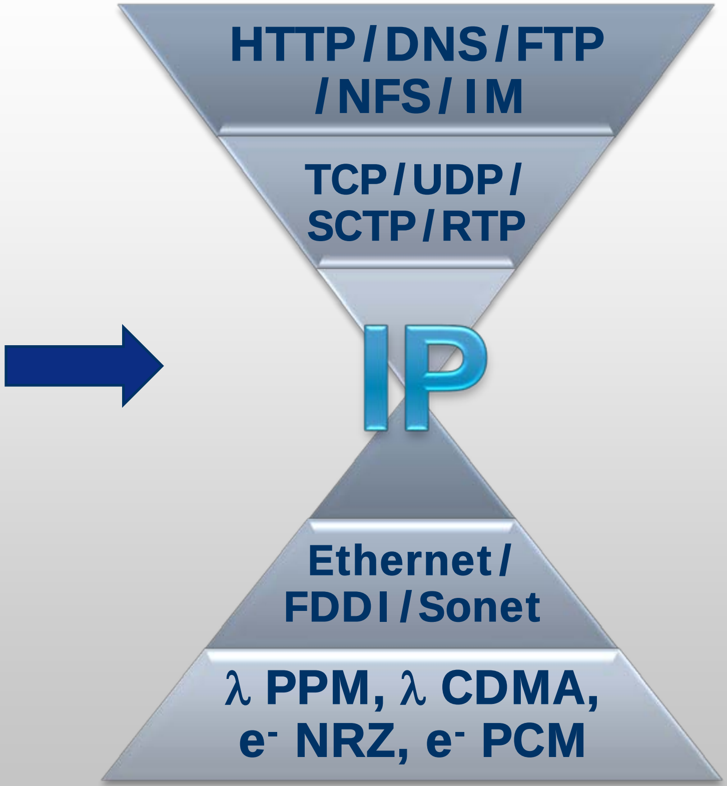
The Hourglass Principle

- Common interchange format between layers





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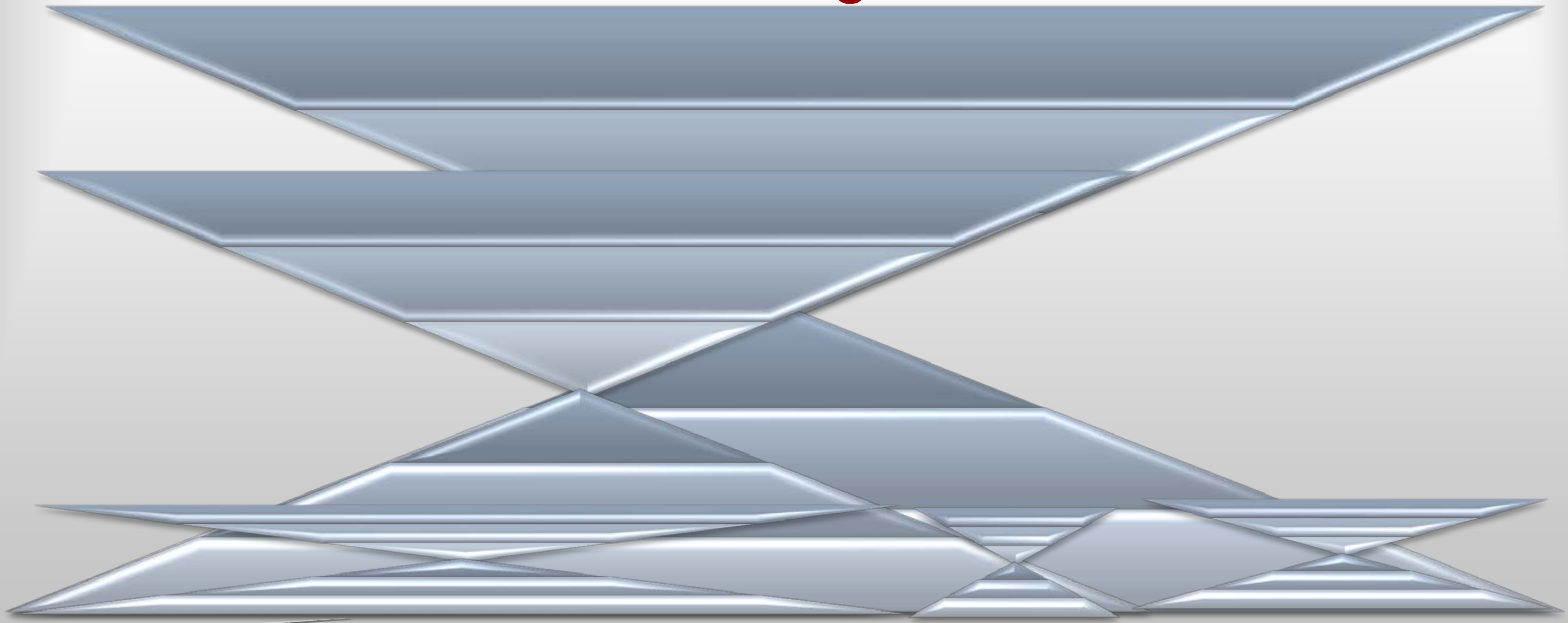
Multiple hourglasses

- "Waist" is relative
  - The common interchange = the waist



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RNA – design & impl.

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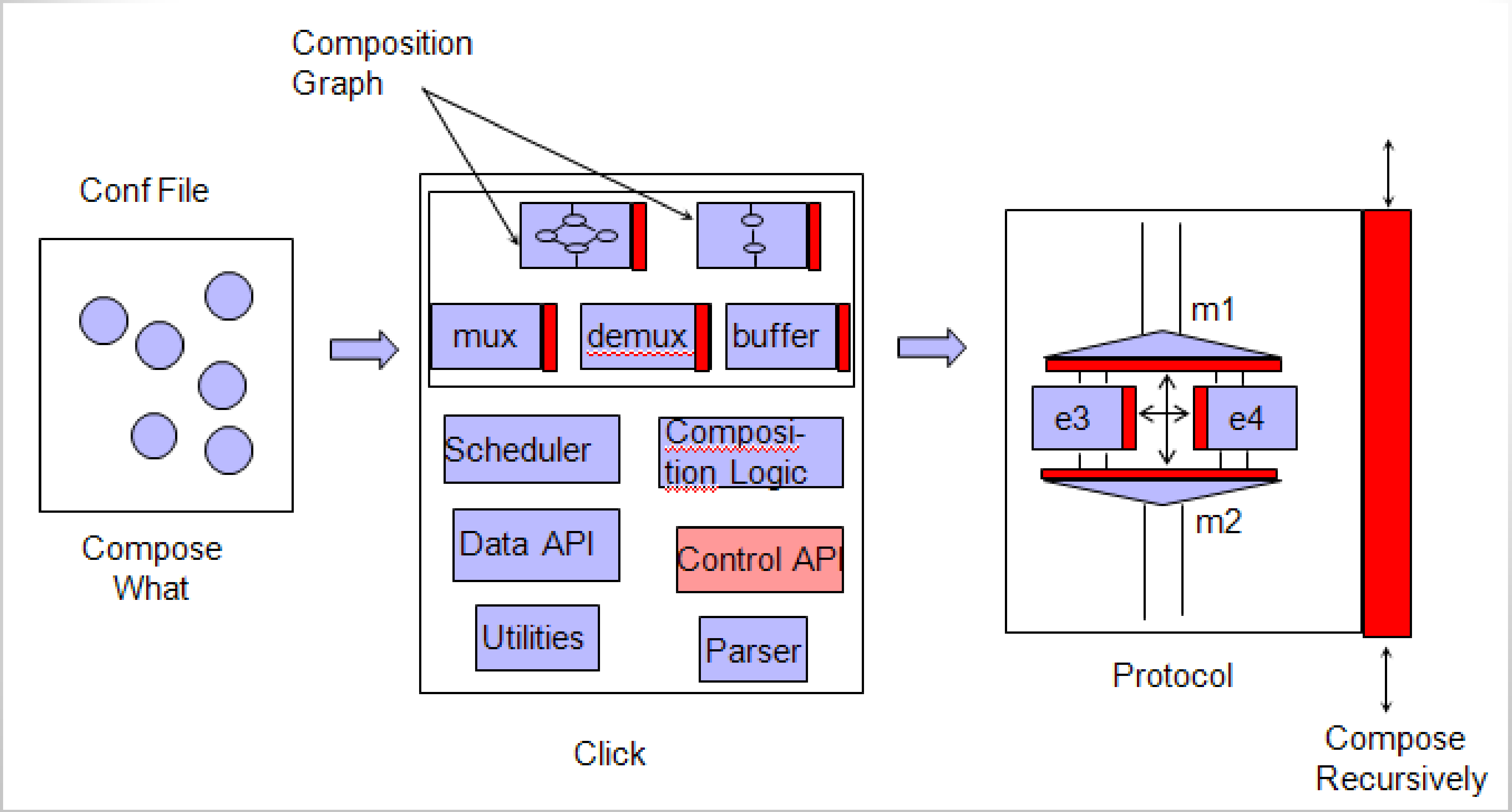
Click Implementation



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RNA MP Template

```
START PATTERN MIN

# This simply specifies a buffer. no reodering etc.
PATTERN MIN
    REQ MUST BUFFER 1
    ARG BUFFER 1 VAR size 1000
    LINK ADD SELF 0 BUFFER 1
   ...
# Next use this pattern if MIN is successful
PATTERN ORDERED_DELIVERY
    FOLLOWS MIN
    REQ MUST REORDERING 1
    LINK DEL ….
    LINK ADD ….
…
# If reordering successful, try more stuff…
PATTERN ENCRYPTED_ORDERED_DELIVERY
    FOLLOWS ORDERED_DELIVERY
    REQ MUST ENCRYPTION 1
    ARG ENCRYPTION 1 VAR algo des
    ARG ENCRYPTION 1 VAR keysize 512
    ....
```

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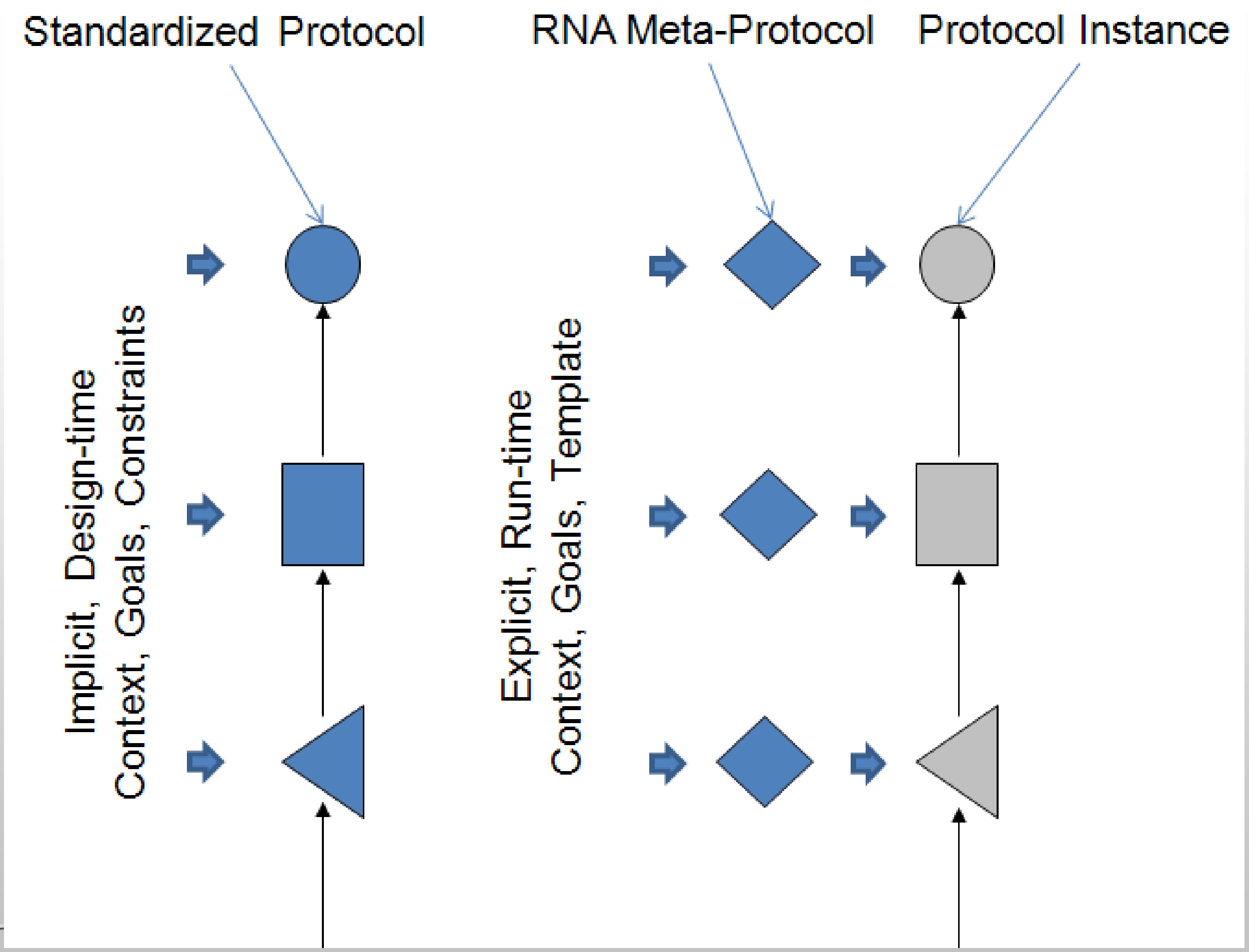
Instantiation



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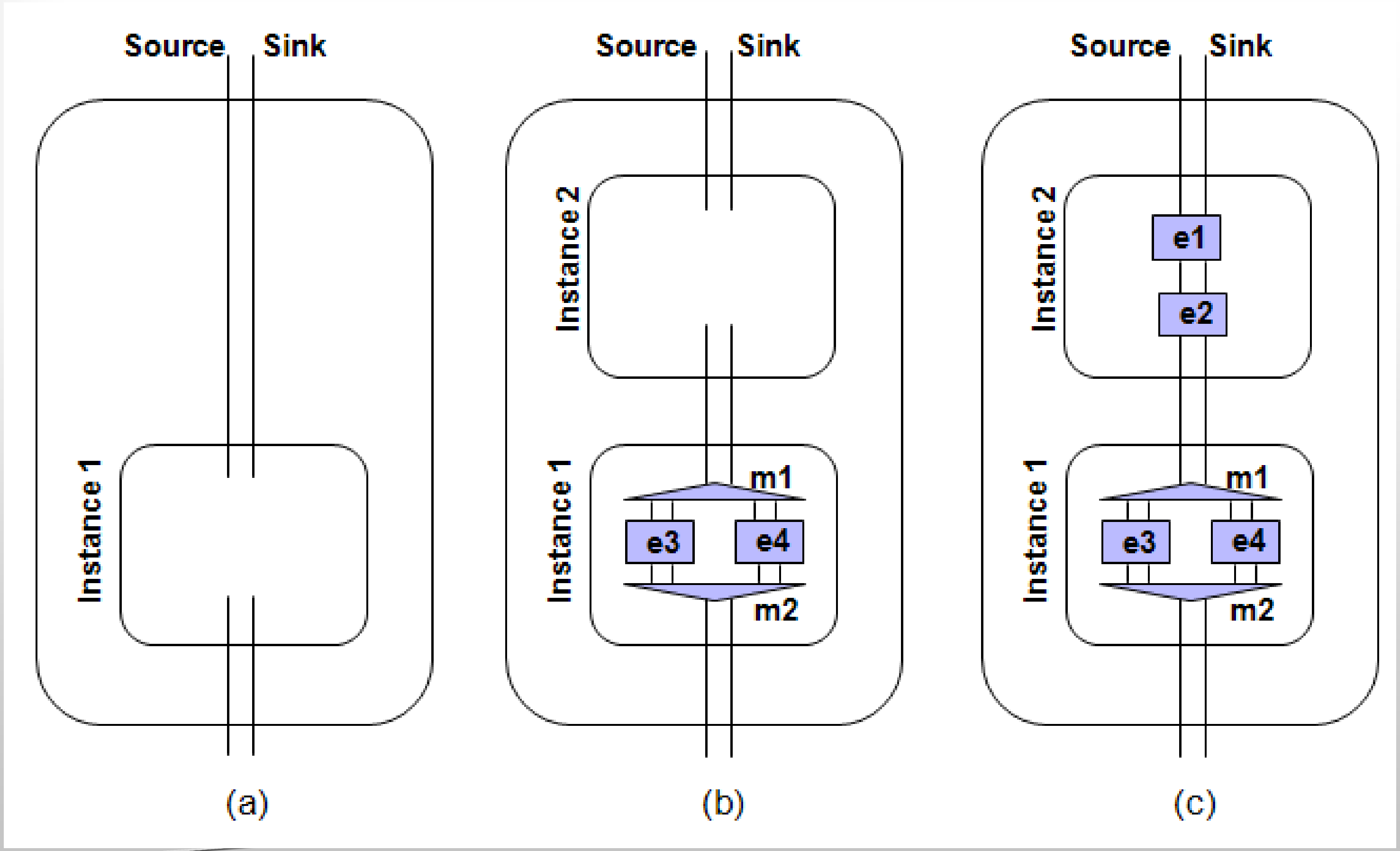
Building a Stack



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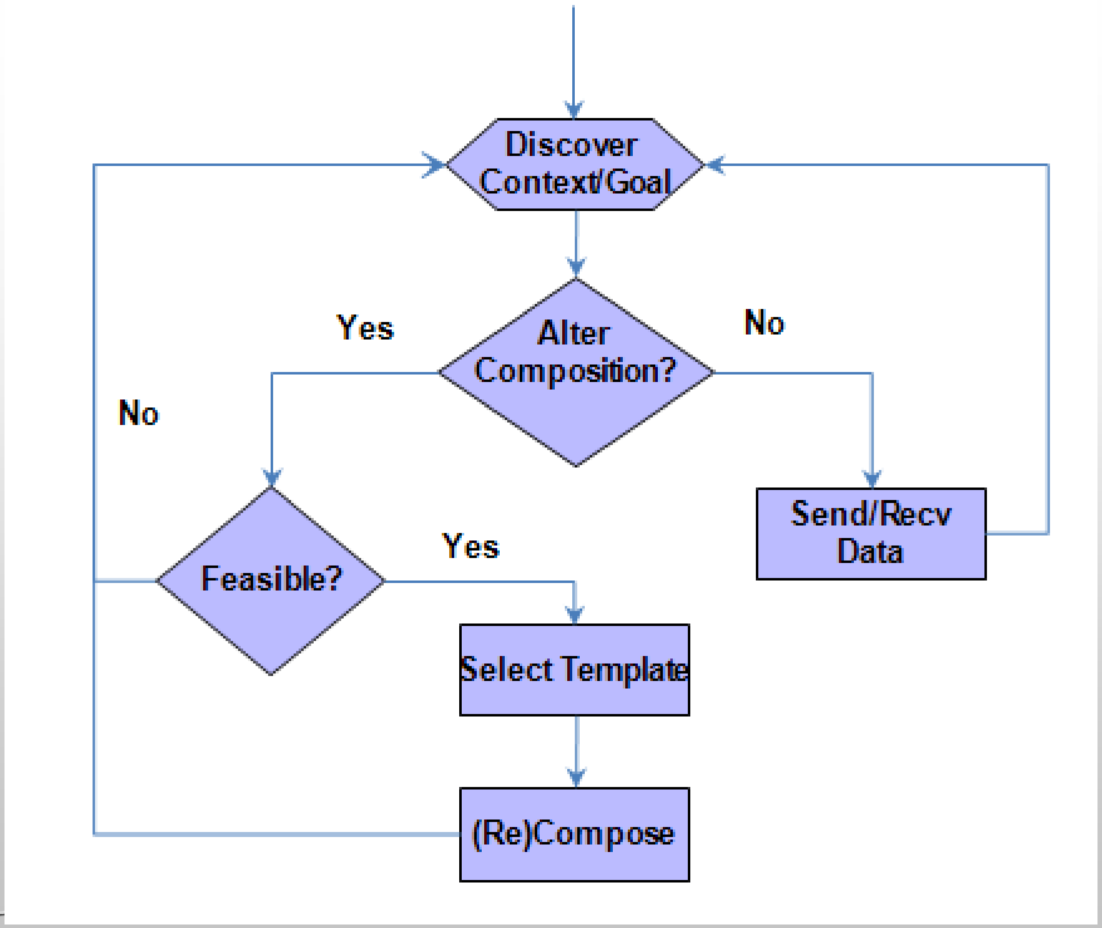
Composition Process



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Related Work

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Related Work

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

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RNA and Network IPC

- Similarities
  - Recursive protocol stack
  - Unified communication mechanism
  - Focus on process-to-process interaction
- Differences
  - RNA uses MDCM to define IPC as combining a Shannon-style channel with namespace coordination
  - RNA provides a detailed (and demonstrated) mechanism that achieves unification and recursion
  - RNA supports both recursion and forwarding in a single mechanism

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Other Components

- Dynamic negotiation protocol
  - Cross-layer negotiation, IETF TAE
- Composable/recursive extensions
  - Network management/SLAs
  - Security (user/infrastructure)
  - Non-comm services (storage, computation)
- Integrated optimization
  - Caching, precompute/prefetch
  - Pinning, dampening

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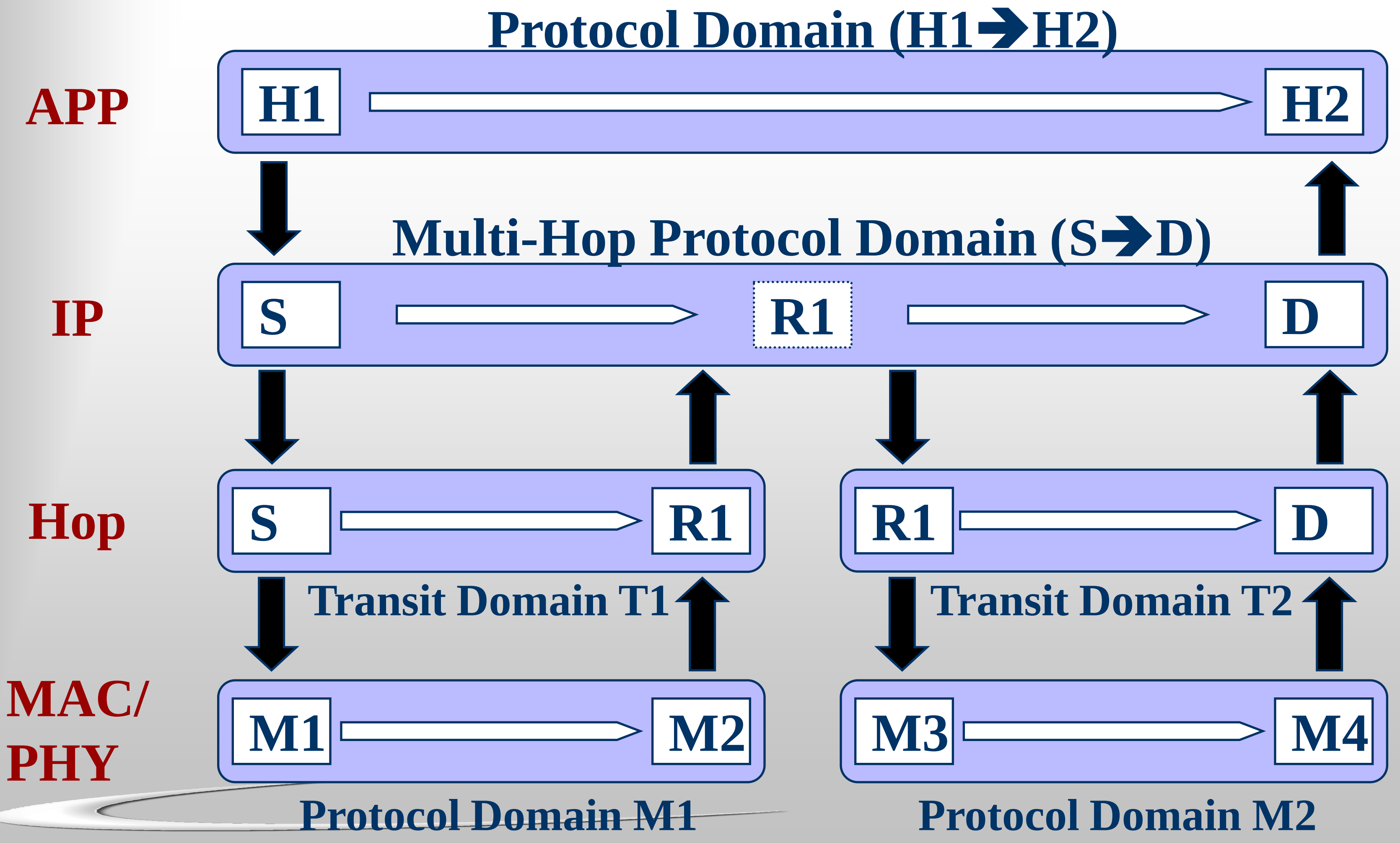
Protocol & Transit Domains



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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**

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Discussion Questions

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Define a "science of networking“ (SON)

- Informally:
  - Principles we’d teach to besides “here’s an artifact we built”
- Formally:
  - Abstract principles and fundamentals of multiparty communication

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Fundamental of a SON

- State coordination
  - 3-way handshake, soft state, delta-T
  - *All as "convergence of shared state"*
- Error control and recovery
  - FEC, ACK/NAK, sliding window
  - *All as "refinement of shared state"*
- Flow and policy control
  - Pacing, SLA enforcement, authorization, window scale
  - *All as "maintenance of shared state"*

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Contributions to SON

- Latency management
  - Trading information structure, predictability, and capacity for delay
- Virtualization
  - Unifying strong/weak models of addressing
- Recursion
  - Unifying forwarding, layering, recursion, resolution

Ignored SON Aspects

- Almost everything...
  - Most comm work is artifact, not architecture
  - Teaching focuses on tools, not principles
- Foundational principles missing
  - Lack of generalized concepts
- Expand Shannon
  - Shared state as more than symbol sequence
  - Extend shared state to determining endpoints

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SON Changes What?

- Teaching
  - See current textbooks to see why
- Tools
  - Start to build reusable components based on key concepts, not forced playgrounds
- Testbeds
  - Helps us focus effort on shared utility
- Architectures and Protocols
  - Won’t confuse artifacts with approaches