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Raising the Datagram API to Support Transport Protocol Evolution

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Problem: Transport Ossification

- Existing transport protocols are globally deployed:
  - Can’t expect quick evolution of a network used by billions
  - TCP and UDP will be strongly conserved

- But – desire to change transport, to better meet application needs

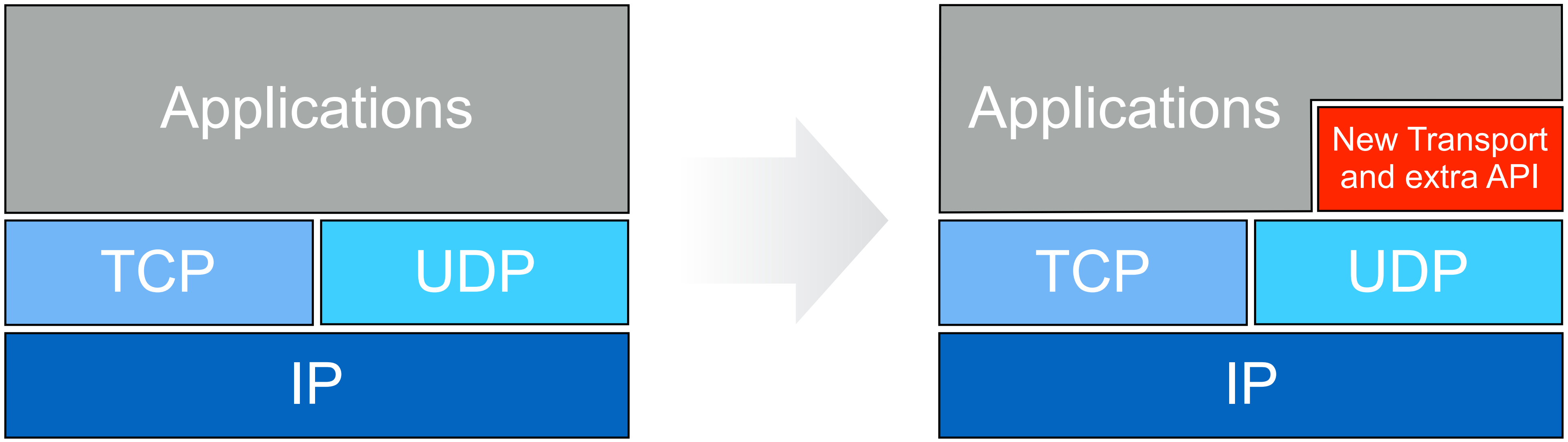
The TCP Straightjacket

- Compatible evolution of TCP significantly constrained – too much infrastructure “understands” TCP protocol to permit changes

- UDP provides minimal services – but offers few constraints
- Alternative protocols not deployable

- For the transport to evolve in ways that differ from the TCP model, must tunnel over UDP

Enabling a UDP Substrate



- Layering new transport sub-layer over UDP is conceptually straight-forward
- Complexity is not in the layering, it's in defining the new transport protocols; enabling flexible composition of transport services under a coherent API

Enabling Future Transport Services (1)

- Goal → raise the datagram API to support transport service composition and reduce implementation complexity

- What transport services to support in future protocols?
  - End-to-end security – while maintaining ease of management
  - NAT traversal and connection racing → as a generic service
  - Lower latency, avoiding HoL blocking
    - Alternative congestion control algorithms and ECN
    - Quality of service, active queue management, partial reliability

Enabling Future Transport Services (2)

- Goal → raise the datagram API to support transport service composition and reduce implementation complexity

- How to compose services and develop new systems?
  - Correctness of implementation → security and robustness
  - Ease of transport service composition, validation against specification, clean specification of policy
  - Integrate with higher-level systems languages → Go, Rust, Swift, …

What does the Sockets API do?

```
int main()
{
  int sockfd, rv, numbytes;
  struct addrinfo hints, *servinfo, *p;

  hints.ai_family = AF_UNSPEC;
  hints.ai_socktype = SOCK_DGRAM;
  if ((rv = getaddrinfo(argv[1], SPORT, &hints, &
      servinfo)) != 0) {
    fprintf(stderr, "getaddrinfo: %s\n",
        gai_strerror(rv));
    return 1;
  }
  while (true) {
    if ((numbytes = sendto(sockfd, "hello",
        strlen("hello"), 0,
      p->ai_addr, p->ai_addrlen)) == -1) {
      perror("talker: sendto");
      exit(1);
    }
    if ((numbytes = recvfrom(sockfd, buf,
        MAXBUFLEN-1 , 0,
               (struct sockaddr *)&their_addr, &
                   addr_len)) == -1) {
      perror("recvfrom");
      exit(1);
    }
  }
  close(sockfd);
  return 0;
}
```

Listing 1. Example of a client application using the UDP Socket API. (The example client, looks up the remote host, chooses an IP address and settles into a loop of sending and receiving data until the application completes.)

- Datagram API in Berkeley sockets:
  - Create socket
  - Bind to local port; "connect" remote
    No on-the-wire effect from connection – locks destination address and enables receipt of ICMP responses on the socket
  - Send and receive datagrams
  - Set and get options
  - Resolve DNS names to IP addresses
- Limited consistency in option usage between different systems
  - Ad-hoc addition of features – different options to enable the same feature
  - Inconsistent feature implementation
  - Use of options to trigger actions
    setsockopt(socket, IPPROTO_IP, IP_ADD_MEMBERSHIP, …)

What Transport Services are Missing?

Datagram API lacks critical features needed for new protocols

- Establishing connectivity
- Support for multiple interfaces
- Control over QoS and reliability
- Congestion control

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- `connect()`, `listen()`, `accept()` suitable for connection-oriented client-server protocols
- Unsuitable for peer-to-peer NAT traversal
  - No support for probing connectivity via STUN, TURN, ICE
- No connection racing
  - No support happy eyeballs IPv6 transition strategy
- Generically, no *path layer* features
  - No help discovering, probing, and gaining consent for use of path(s) from source to receiver

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- Interfaces can have radically different properties
  - Present API doesn't make these easy to discover; applications must probe to determine what works
  - No way to determine if information gathered on an interface is valid on any other interface (e.g., DNS lookup results)
- Hard to portably determine valid interfaces, and changes to interface availability
  - Complicates NAT traversal, connection racing
- No systems support for migrating traffic flows between network interfaces

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- TCP provides a reliable, ordered, byte-stream subject to HoL blocking – no flexibility in API
- Datagram API exposes best effort IP service, but no help with (partial) reliability, ordering, or framing
  - Limited support for ECN use with datagrams
  - Limited support for QoS use with datagrams –how to determine what code points work?

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- TCP assumes congestion control occurs below API, and doesn't expose behaviour or offer any controls
- Datagram service requires congestion control be implemented above the API, with no support and no visibility into send/receive queues
  - No support for cooperation between congestion controller, transport, and application – needed to ensure low-latency

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Clear the current API is too low level – doesn't meet needs of applications or help implementors of new transport protocol layers

Principles for Raising the Datagram API

- Follow four principles when revising the API:
  - An application using the new API that does nothing new should receive similar service to that of the Sockets API
  - Commonly needed functions should be placed below the API when these can be automated – do not require application decisions
  - Functions where the preference can be expressed as a policy can also be placed below the API
  - Functions that rely on application algorithms or detailed knowledge of trade-offs related to data should be implemented above the API

- Ensures continuity of behaviour, avoids surprises, while allowing transport evolution

Below the Datagram API – Policies and State

- Higher-layers pass abstract policy information through the API – map onto transport services rather than concrete protocol features

- Per-interface information base:
  - MTU, line rate, IP address, DNS name cache, supported QoS features, …
- Per-path information base:
  - Credentials for crypto session resumption, key continuity, opportunistic encryption, …
  - Last achieved congestion control state
  - Destination feature support

- Policy specifies what is needed, not how accomplished

```
{
    "transport": [
    {
      "value": "Datagram", "precedence": 1
    },
  ],
  "qos": [
    {
      "value": "Interactive Video", "precedence":
           1
    },
    {
      "value": "Live Video", "precedence": 2
    }
  ]
  "network": [
    {
      "value": "cost", "precedence": 1
    },
    {
      "value": "capacity", "precedence": 2
    }
  ]
}
```

Listing 2. Example JSON file describing a NEAT Abstract Policy

Below the Datagram API – Mechanisms

- Policies bind to concrete protocol features and transports
    - DSCP, ECN, IP addresses, network interfaces, congestion controllers, etc.
    - TCP, UDP, SCTP, …
- Push new transport implementations below the API – UDP as transport demultiplex
    - Congestion control algorithms
    - Reliability – retransmission, FEC
    - Reordering
    - PDU parsing and serialisation, framing
    - Connection racing, probing for NAT traversal – driven by high level policy
- Asynchronous and event driven

Implementation Approach

- Asynchronous, to match network behaviour
- Rich sharing of data across the API
  - Application policies and preferences
  - Queries of interface/path management data
  - Jointly managed send and receive queues

- A higher-level API for applications… and, below that, a richer API framework for transport services

Example: The NEAT API

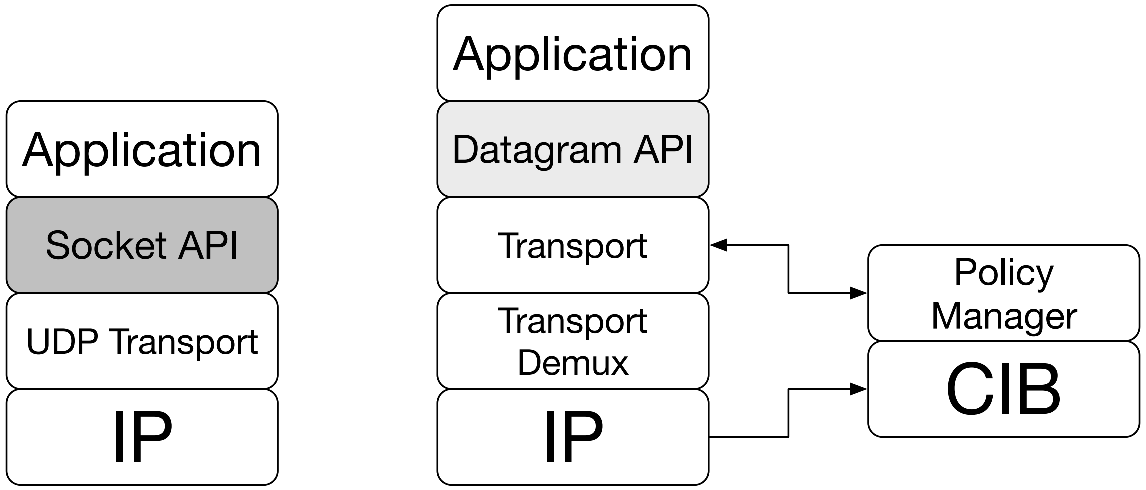
- An example of the application API:
  - JSON policy specification – policy manager component below API
  - Asynchronous event loop – callback driven
  - Allows transport behaviour to be chosen by the stack – e.g., happy eyeballs connection racing

```
static struct neat_flow_operations ops;
static struct neat_ctx *ctx = NULL;
static struct neat_flow *flow = NULL;

ctx = neat_init_ctx()
flow = neat_new_flow(ctx)
prop = "(see Listing 2)";
neat_set_property(ctx, flow, &prop)
ops.on_writable = on_writable;
ops.on_readable = on_readable;
ops.on_error = on_error;

neat_set_operations(ctx, flow, &ops)
neat_open(ctx, flow, hostname, port)
neat_start_event_loop(ctx, NEAT_RUN_DEFAULT);

static neat_error_code
on_writable( struct neat_flow_operations *opCB)
{
    neat_write(opCB->ctx, opCB->flow, buf)
  return NEAT_OK;
}

static neat_error_code
on_readable( struct neat_flow_operations *opCB)
{
    neat_read(opCB->ctx, opCB->flow, buf)
  return NEAT_OK;
}
```

Listing 3. NEAT Example Application listing

Raising the Datagram API to Support Protocol Evolution

- We propose raising the datagram API to allow specification of policy and transport services
- Give the protocol stack flexibility to fulfil application needs via different transports



- Post Sockets APIs must raise the level of abstraction and enable composition of transport services – raising the datagram API is but a first essential step