Iris: Expressive Traffic Analysis for the Modern Internet

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Empirical Security Research Group

Network Traffic Analysis is Critical

Strengthen security and privacy

Improve performance and QoS

Build and evaluate new systems

Measure Internet phenomena

Demands on Traffic Analysis Systems are Increasing

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High Traffic Volumes (100Gbps+)

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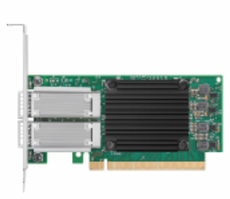

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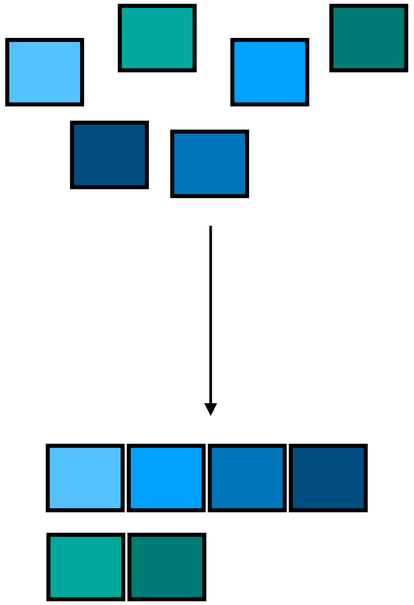
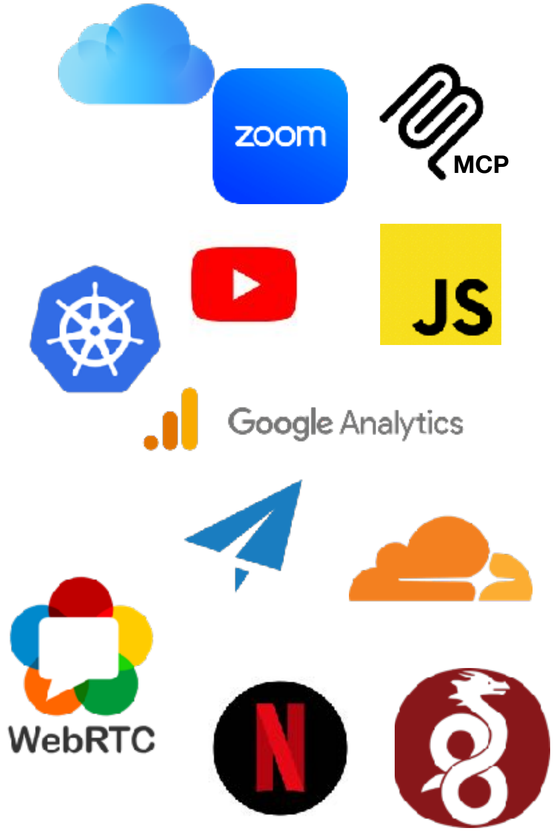




Complex Applications and Questions

Two Choices Today

Option 1
Build an experiment-specific system from scratch

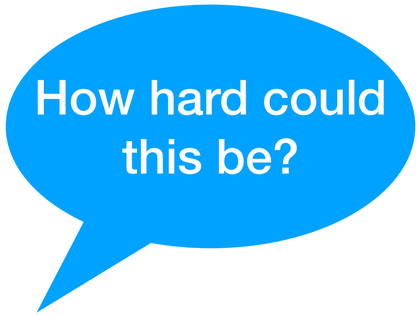
AF_PACKET

Option 2
Try to use an existing tool, which may not meet needs

Pigasus

Traffic Refinery

Two Choices Today



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Motivating Example: Video Resolution

Seemingly simple questions require **thousands of lines of code** to implement.

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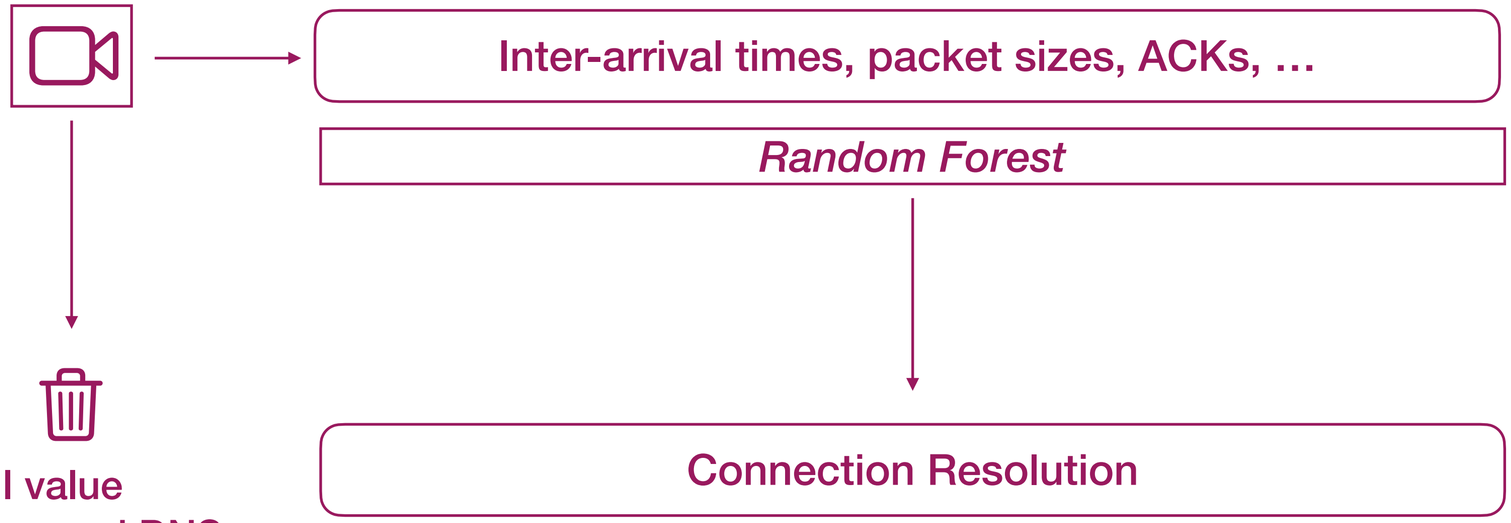

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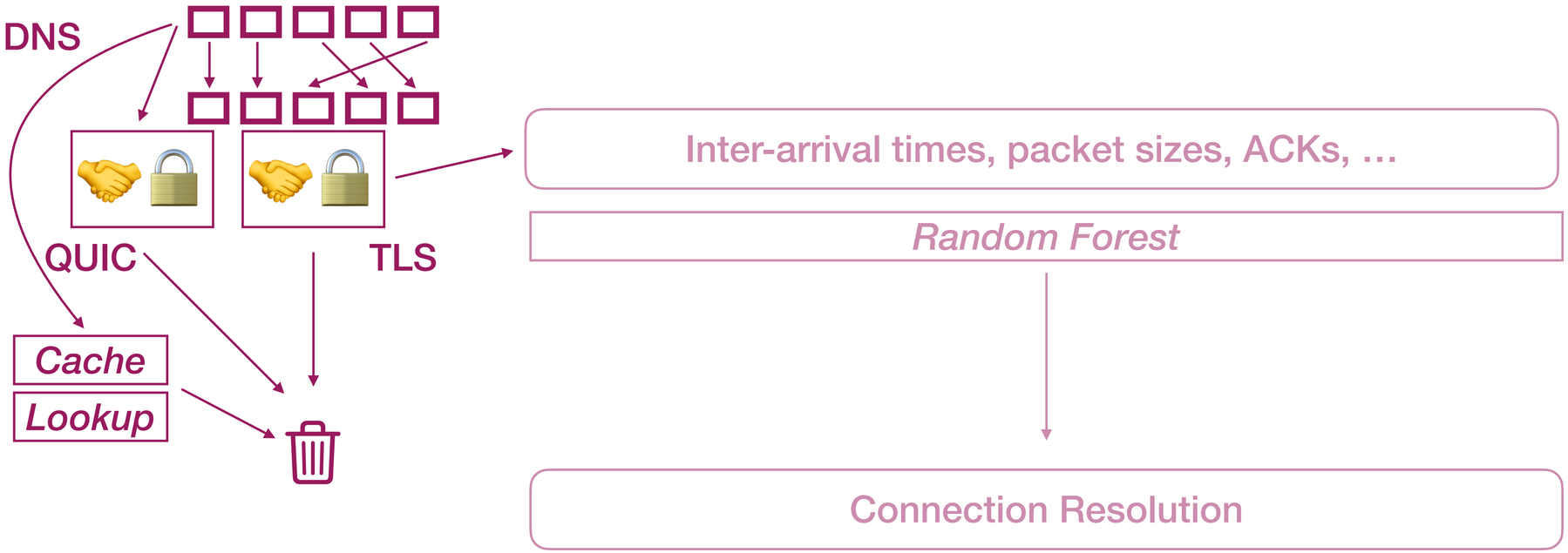

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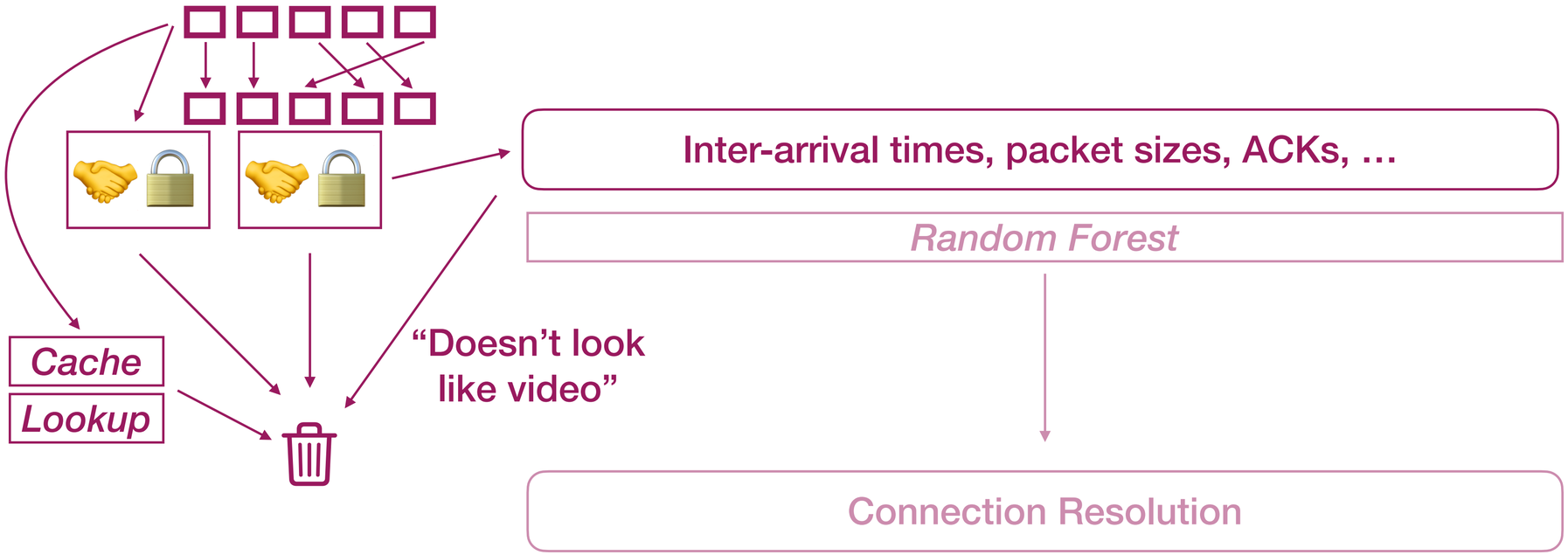

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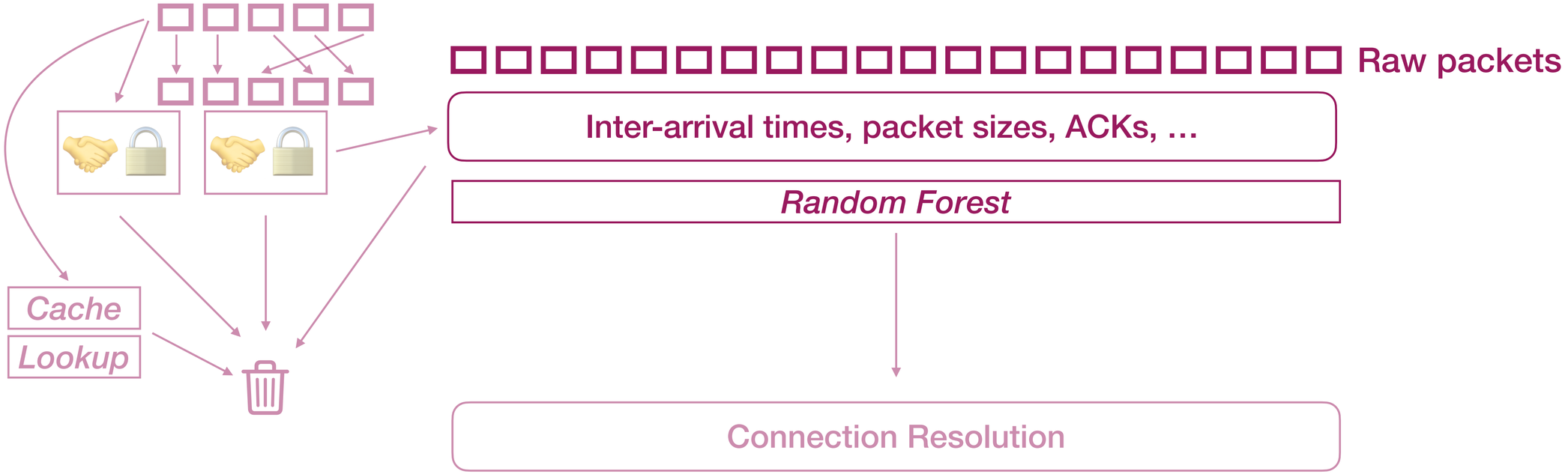

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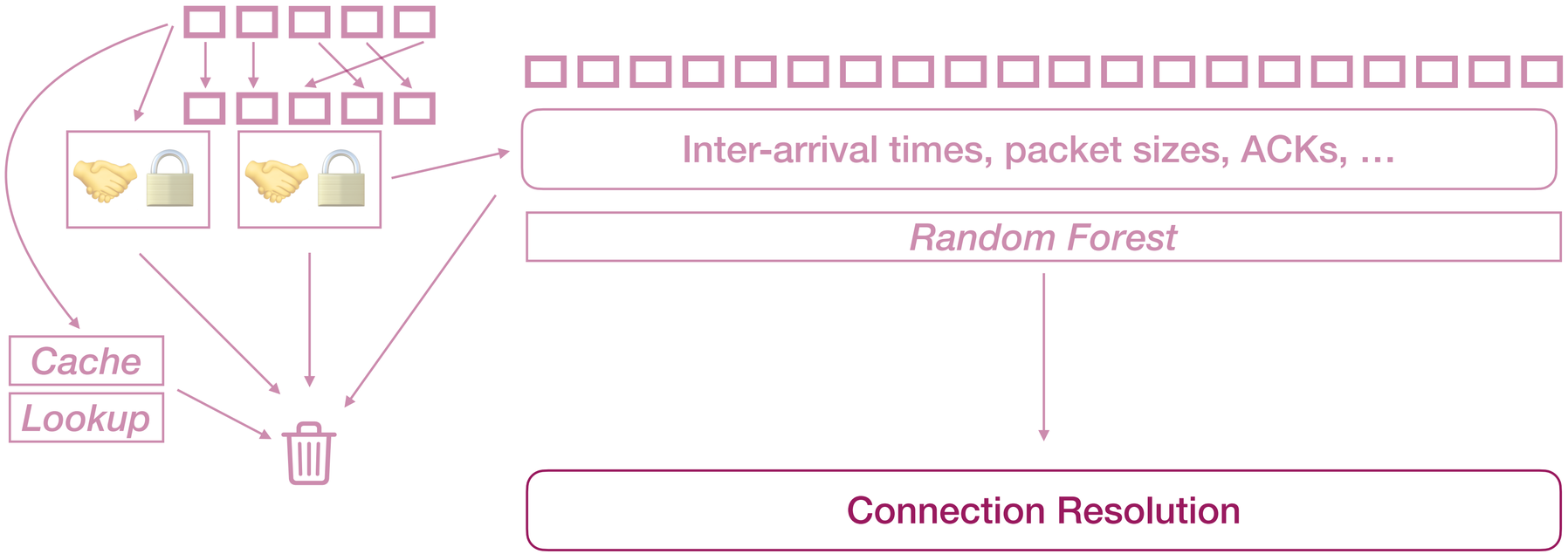

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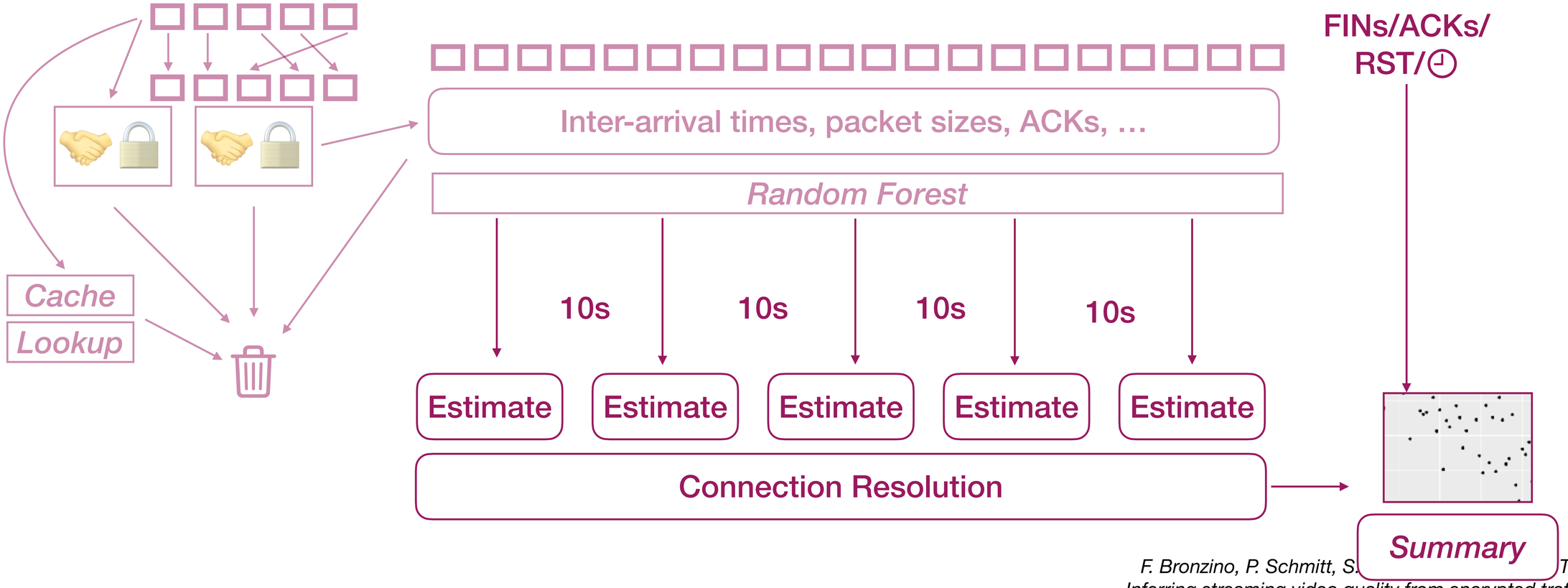

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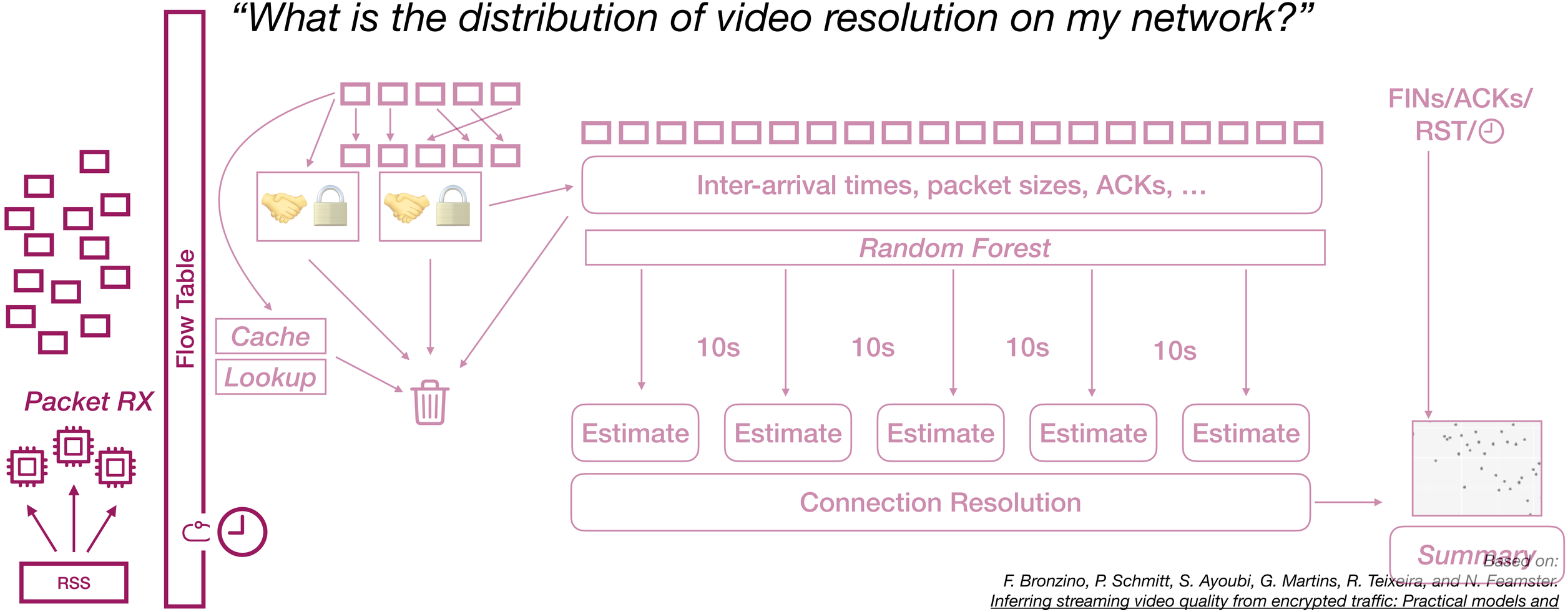

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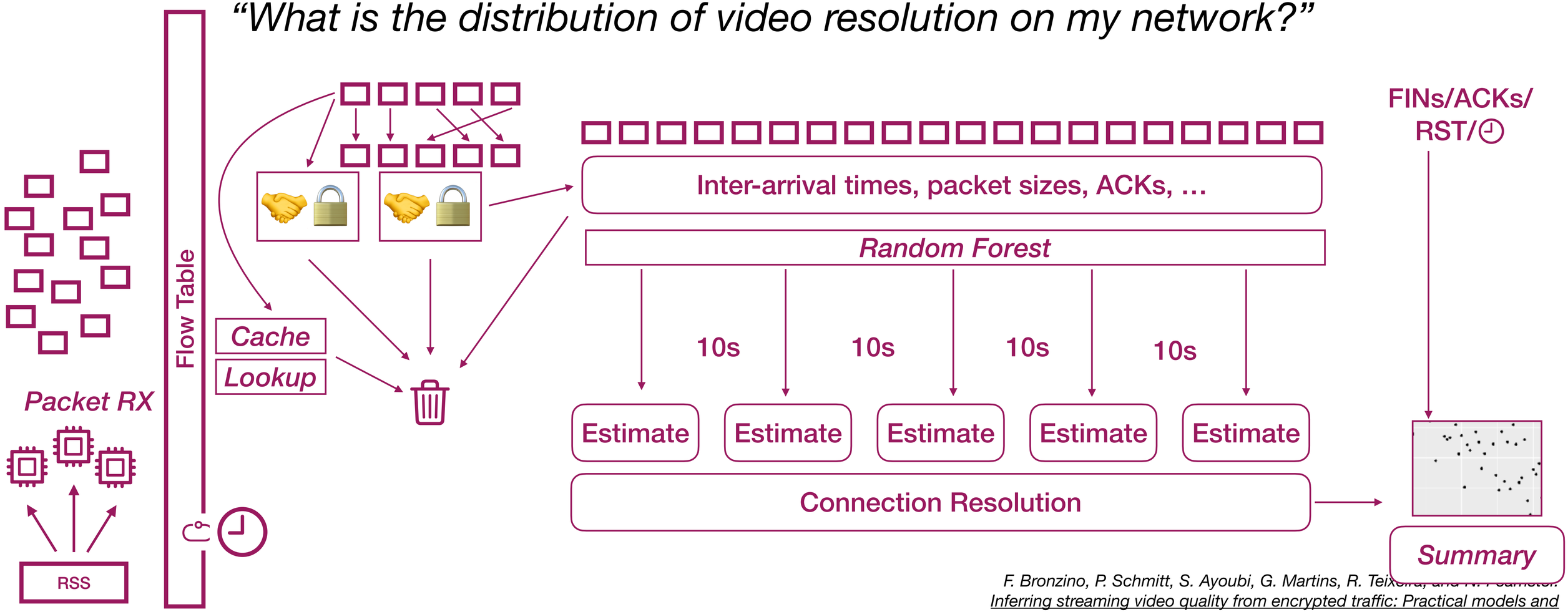

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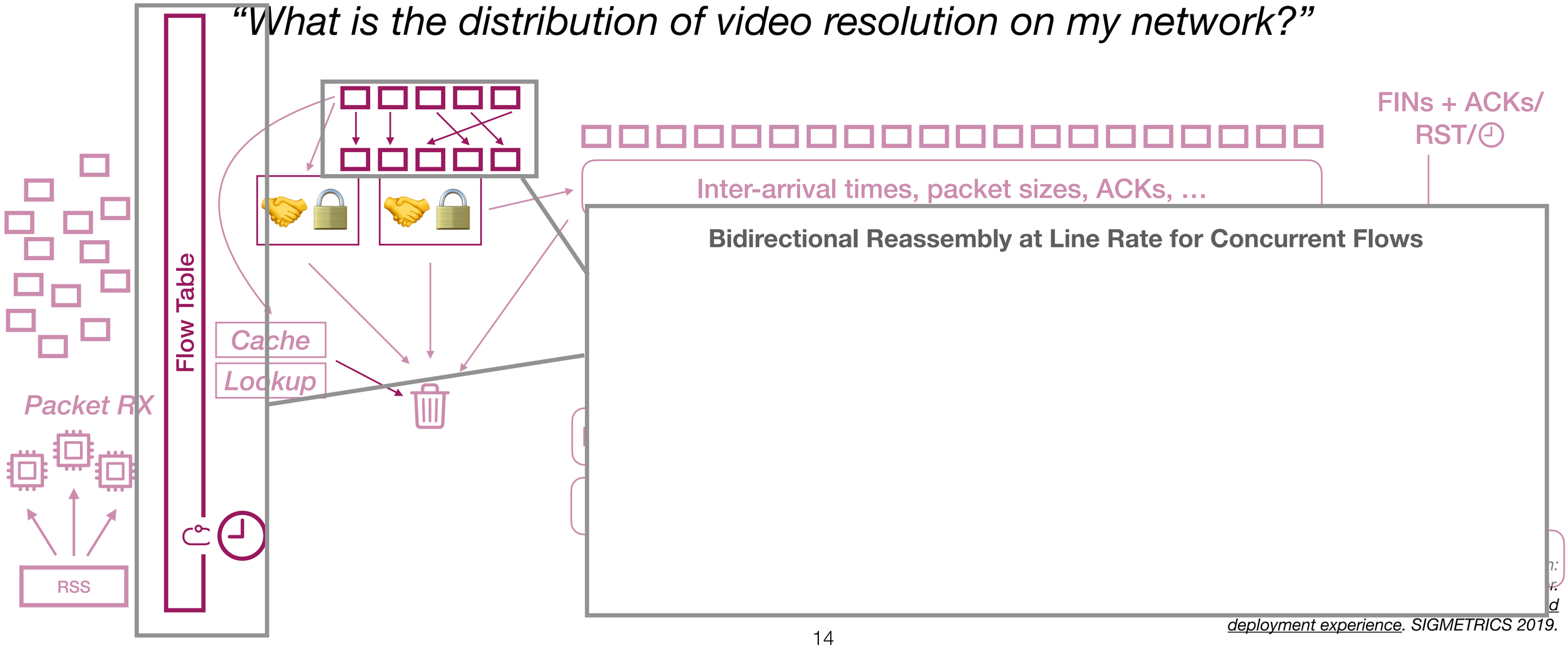

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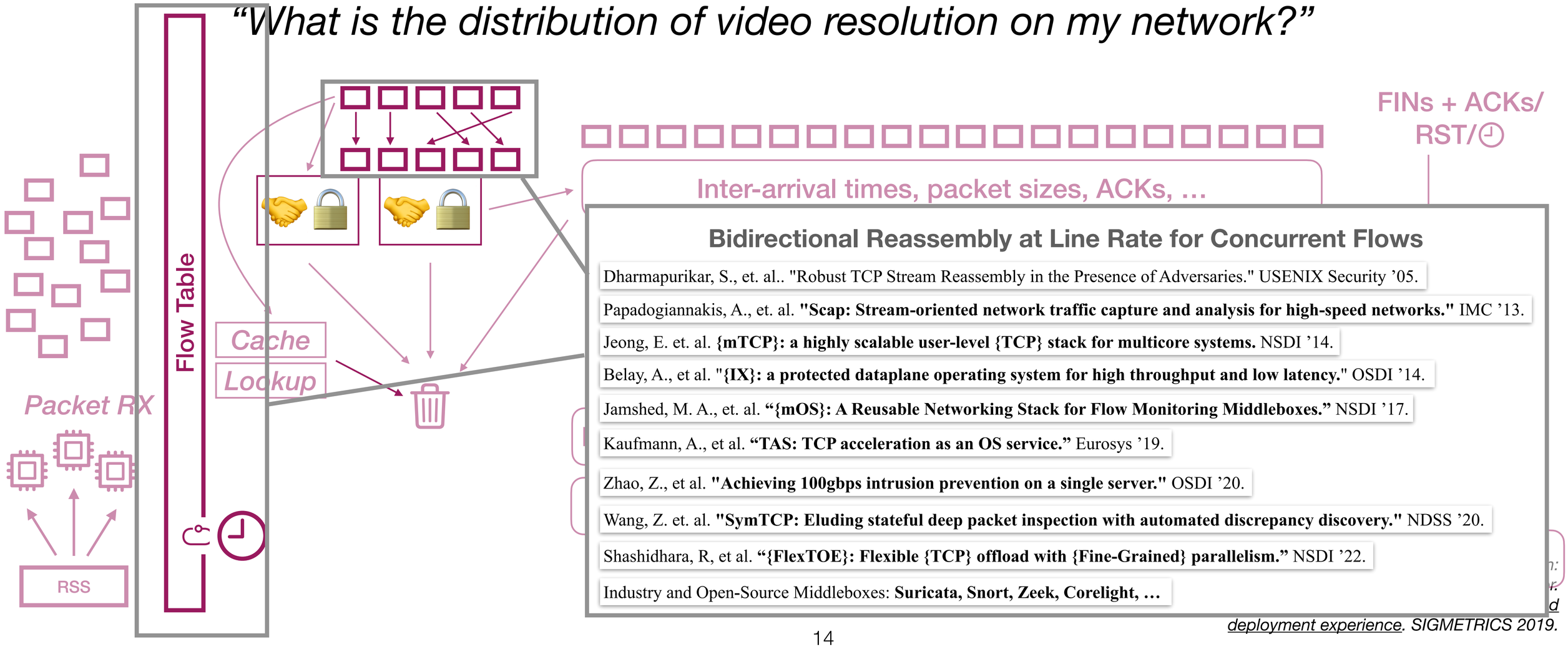

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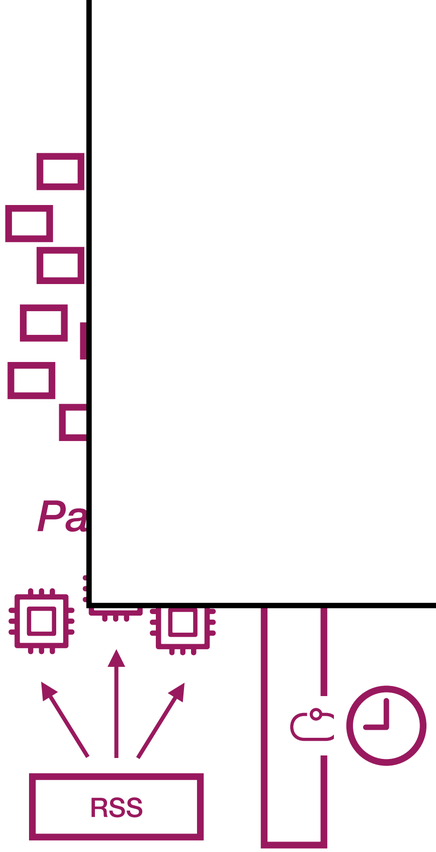

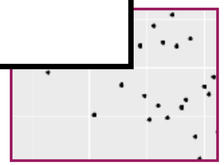

Summary

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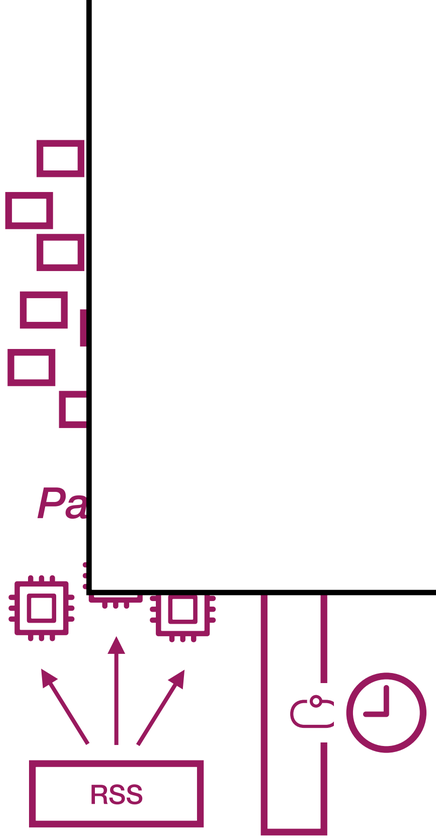

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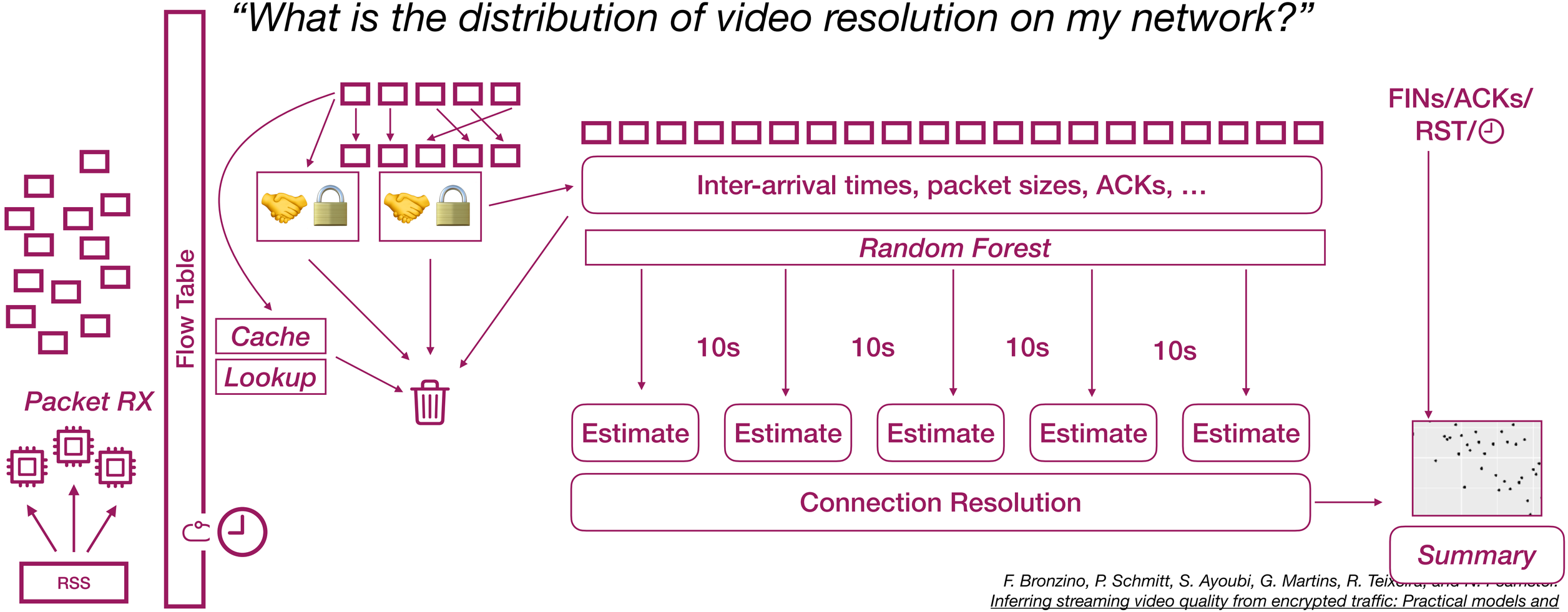

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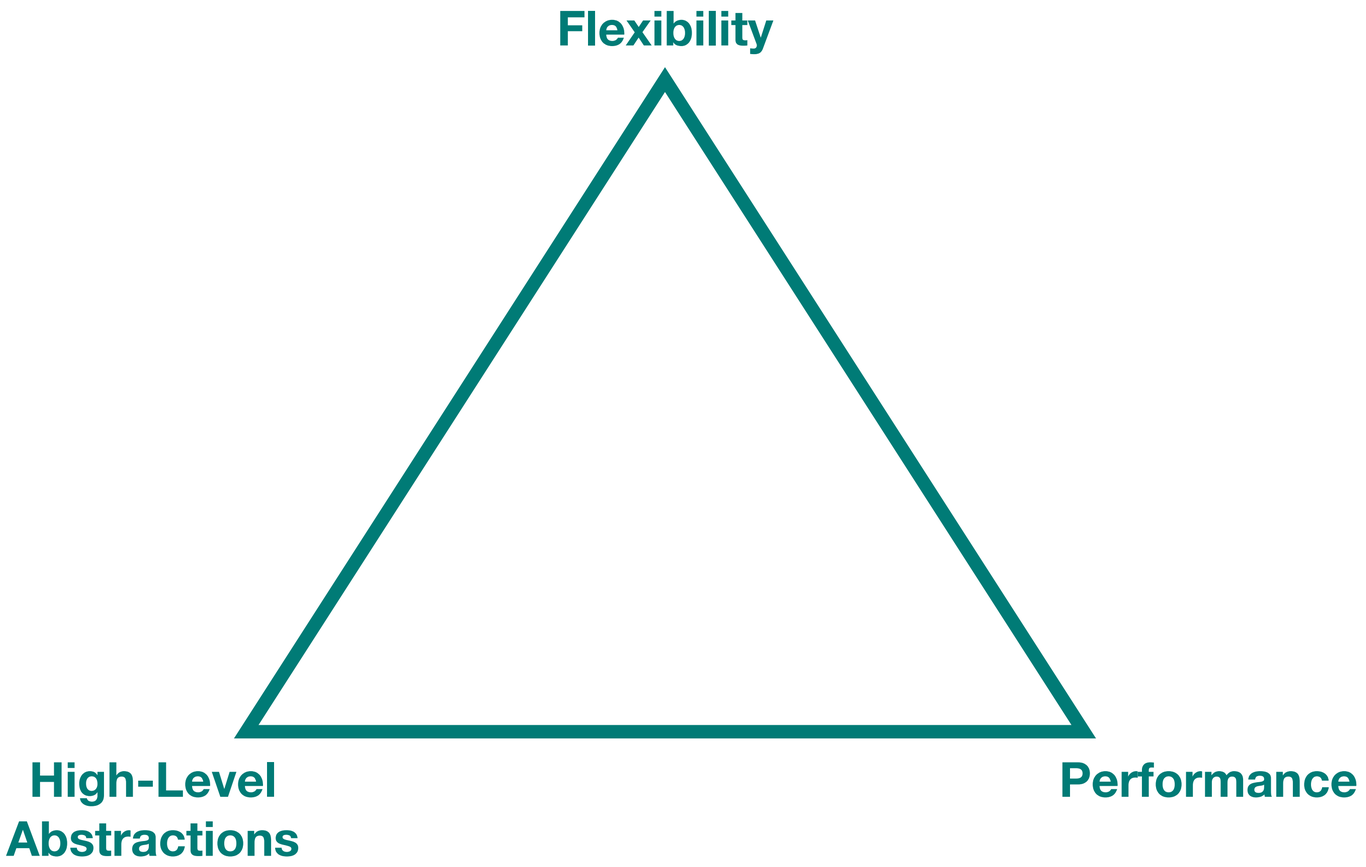
Access to common, connection- and application-layer types

3. Performance

100Gbps+ on commodity hardware for concurrent analysis tasks

No Current System Provides all Three



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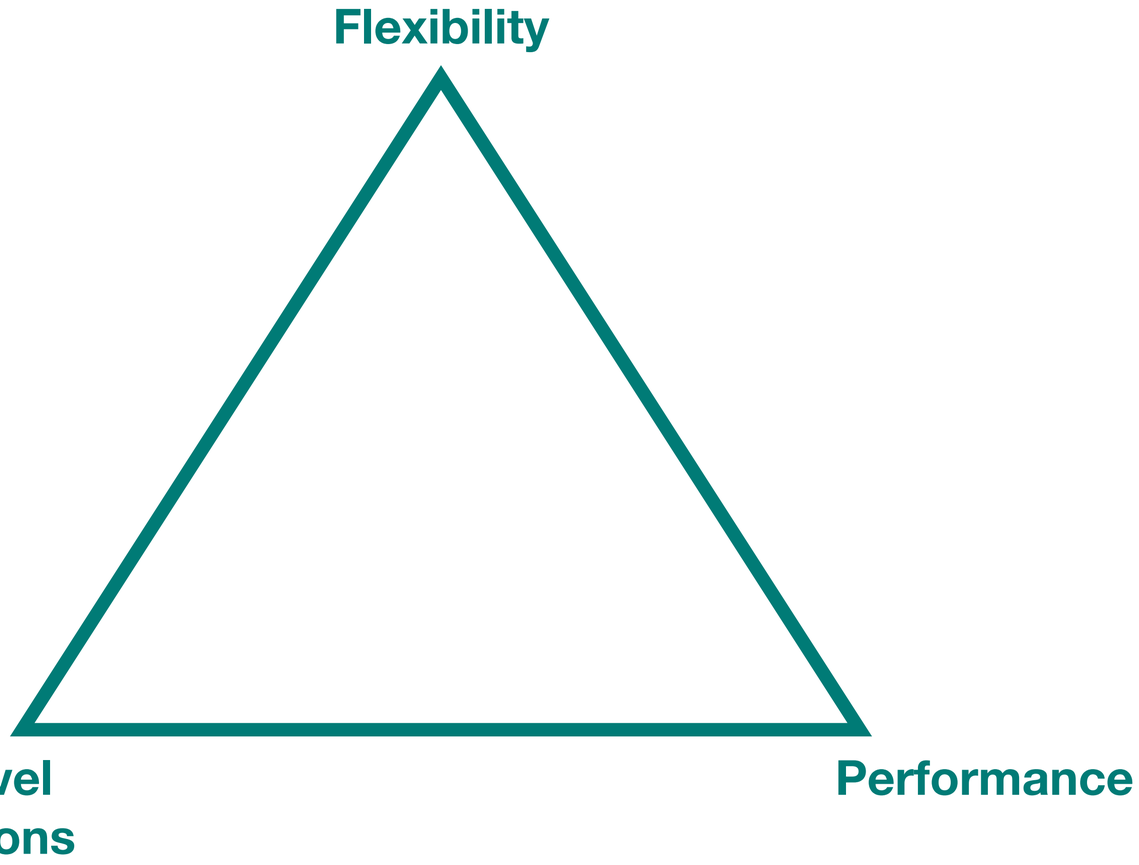
Analysis over reconstructed flows

(e.g., Zeek)



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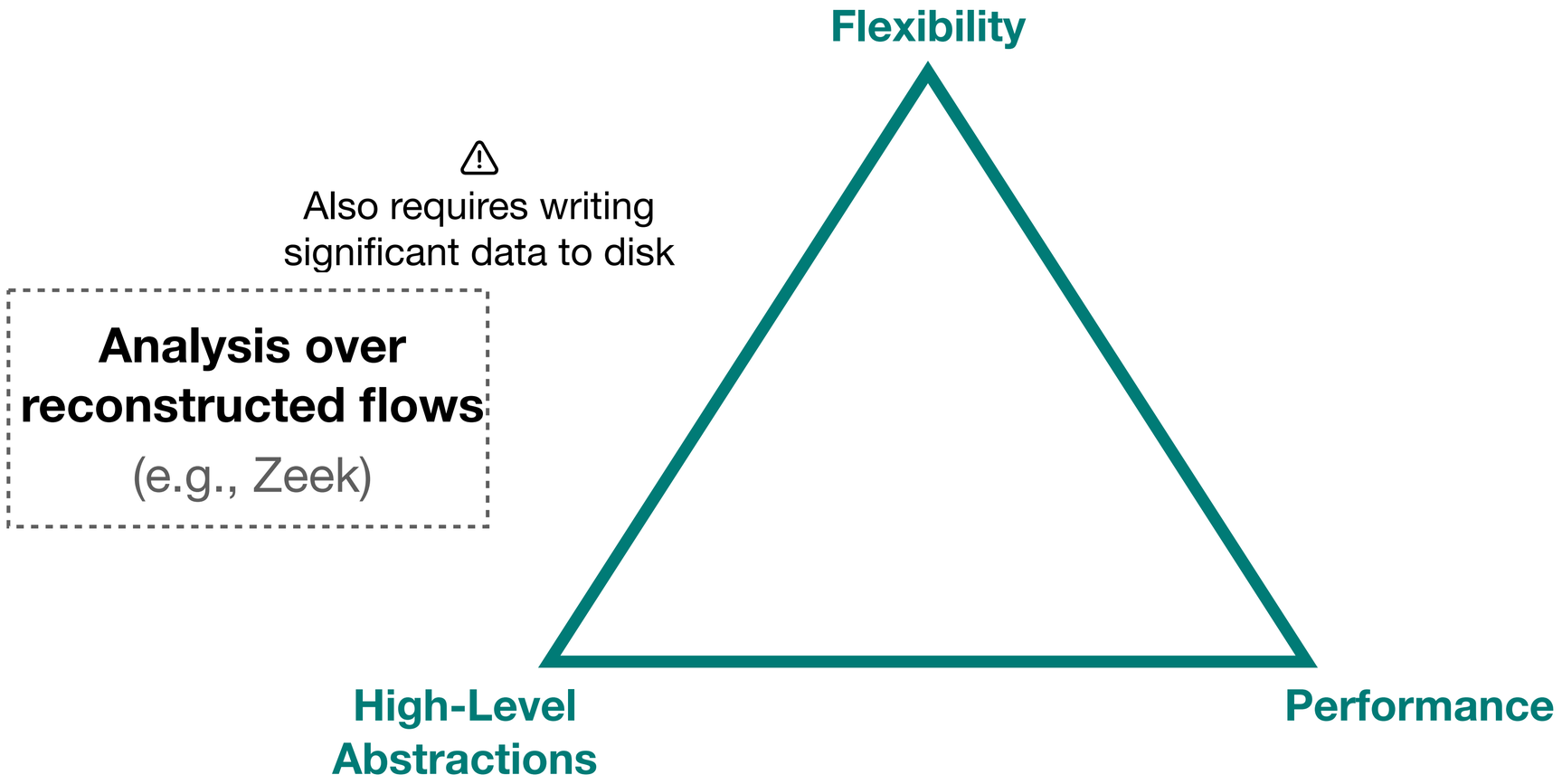

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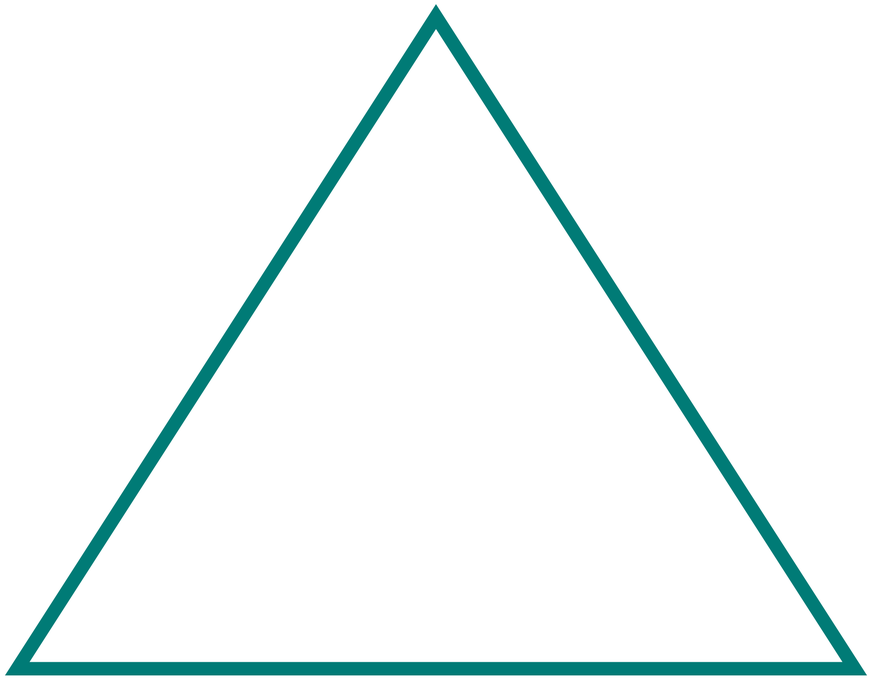

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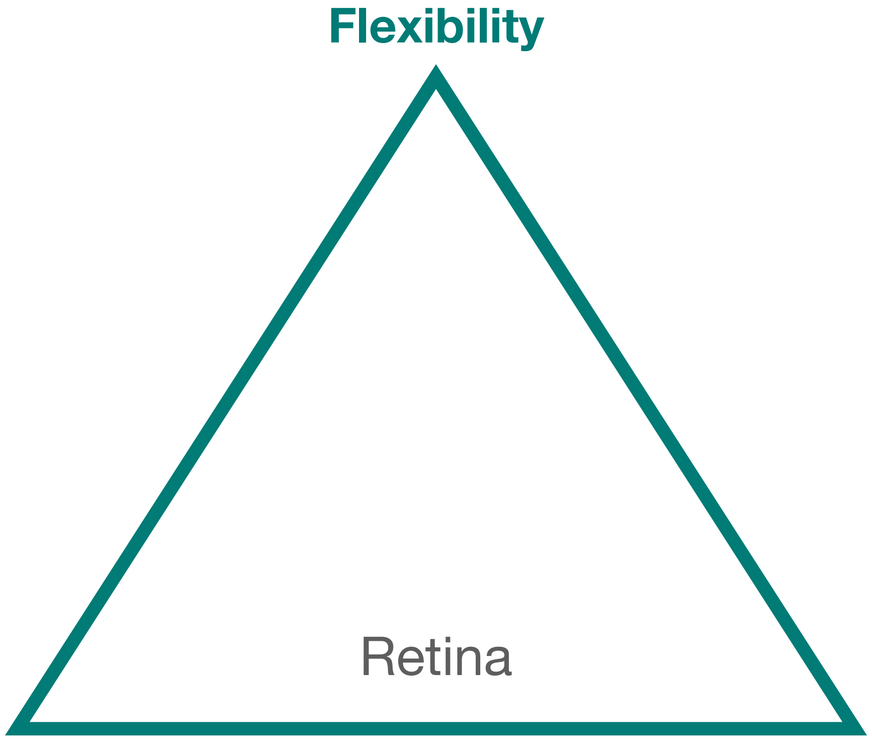

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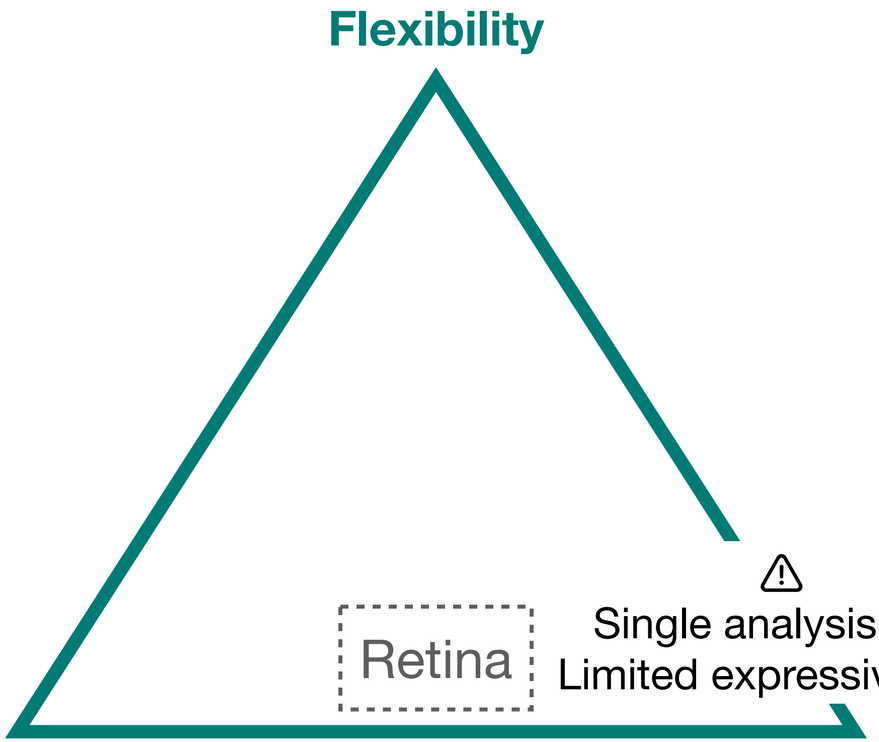

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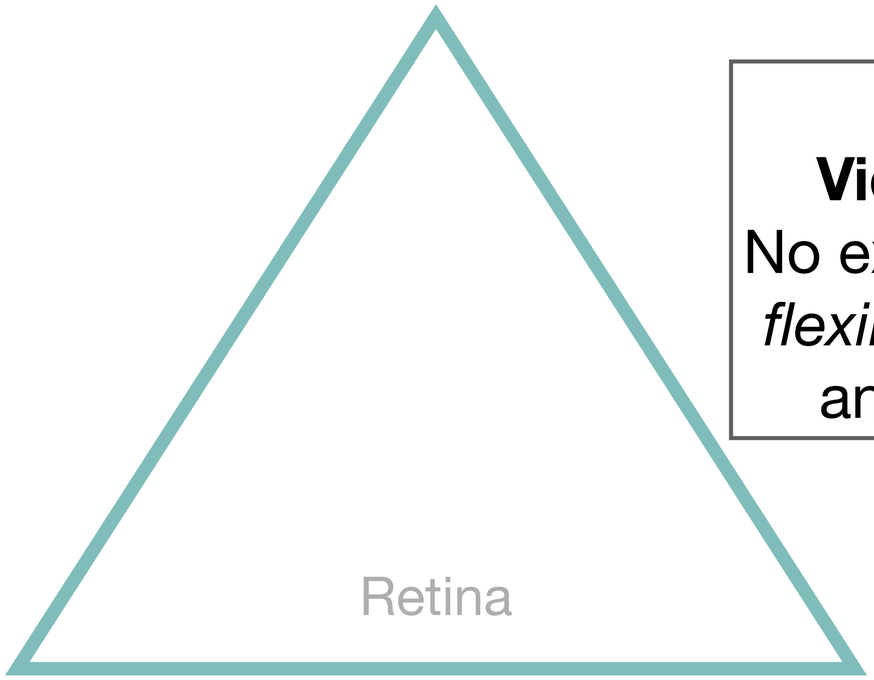

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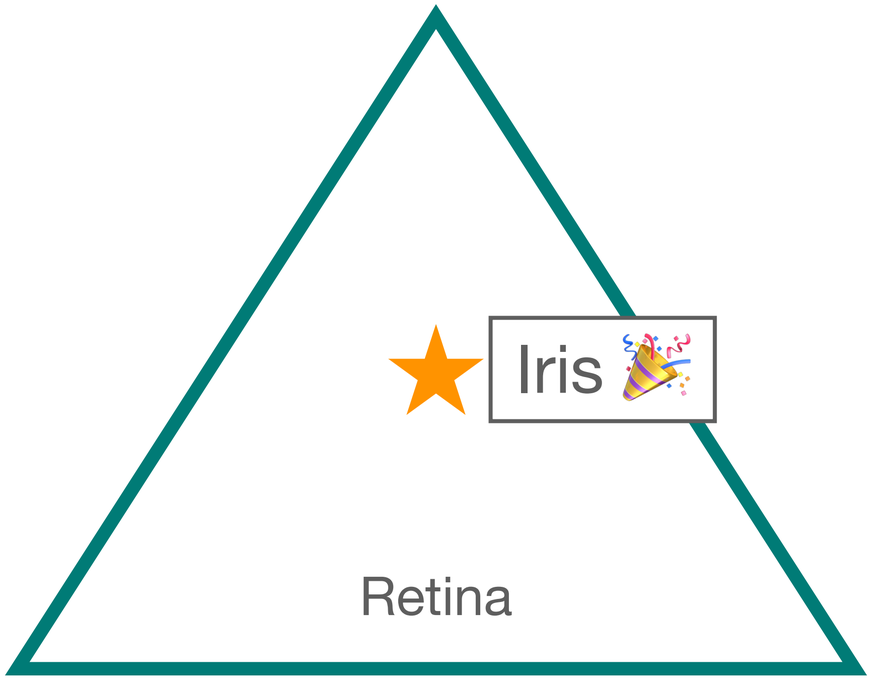
⚠

Video resolution example:
No existing tool provides enough *flexibility*, the right *abstractions*, and sufficient *performance.*

*without creating a new domain-specific tool

No Current System Provides all Three

… Yet?



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Compile-Time Optimization Enables
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fn video_lookup(
    &mut self, tls: &TlsHandshake,
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) -> FilterResult {
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```rust
#[datatype]
struct FeatureChunk { /* ... */ }

impl FeatureChunk {
   fn new(first_pkt: &L4Pdu) -> Self {
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struct ResolutionEst {
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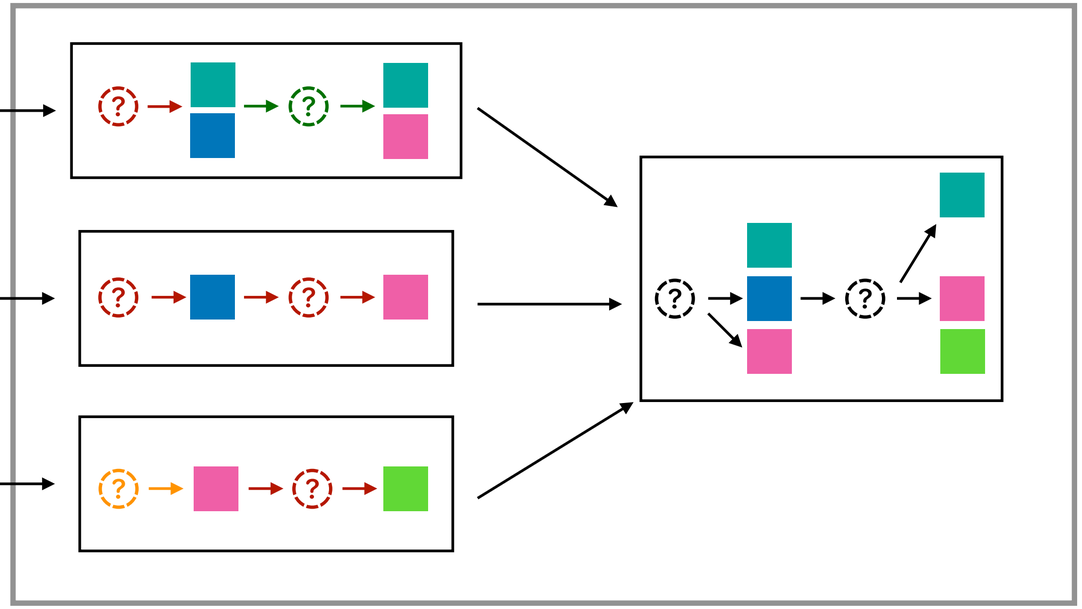
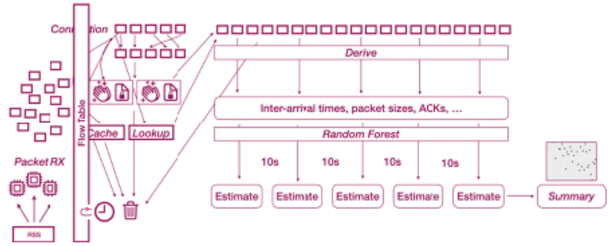


Iris Compiler

Merge, Deduplicate, Simplify



Iris Runtime

Many Concurrent Workloads with Minimal Aggregate Work

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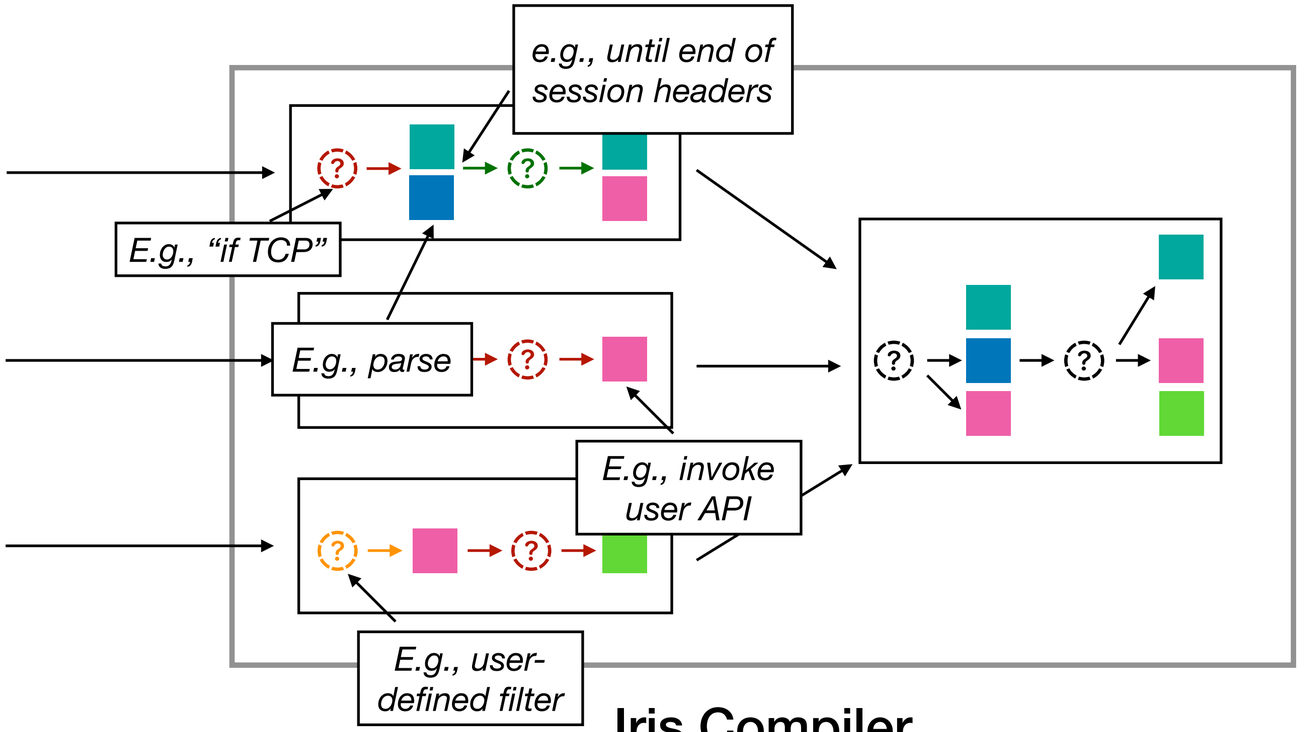

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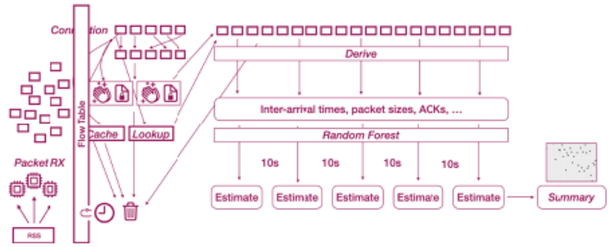

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Iris Contributions

1. Flexibility

Developers write code in a general-purpose programming language

2. Abstractions

…over connection- and application-layer data

3. Performance

…while retaining enough structure for the compiler to optimize across analysis tasks.

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Compiler

Iris Directly Exposes Common Types

Subscription Interface:
Filter + Data Type(s) + Callback

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#[callback("tls.sni contains 'nflx'")]
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Using Iris is Simple for Simple Use-Cases

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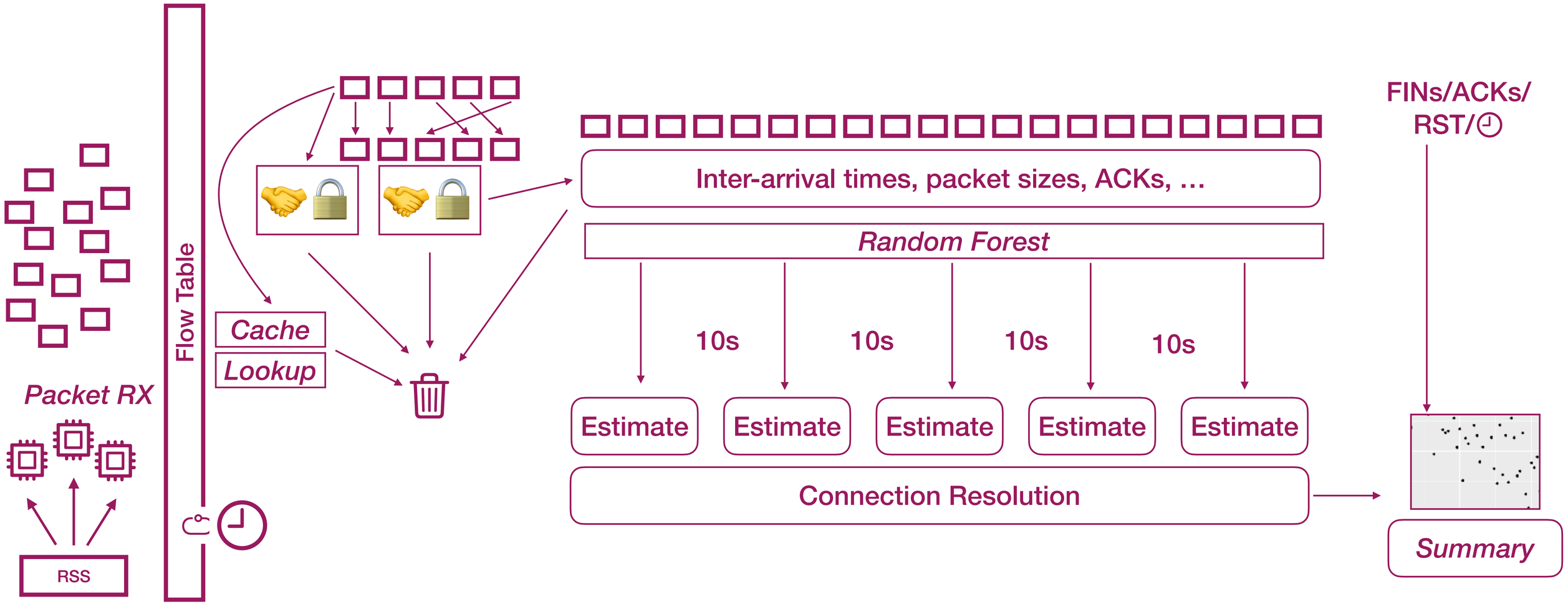

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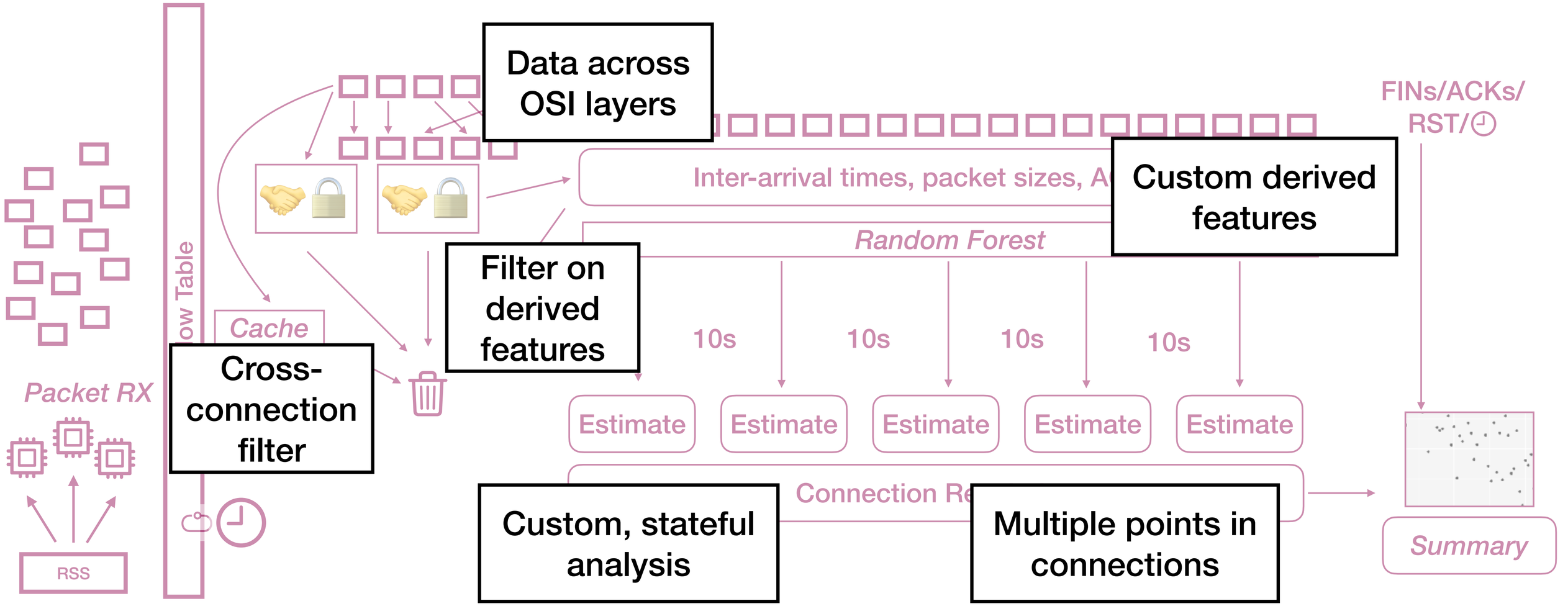
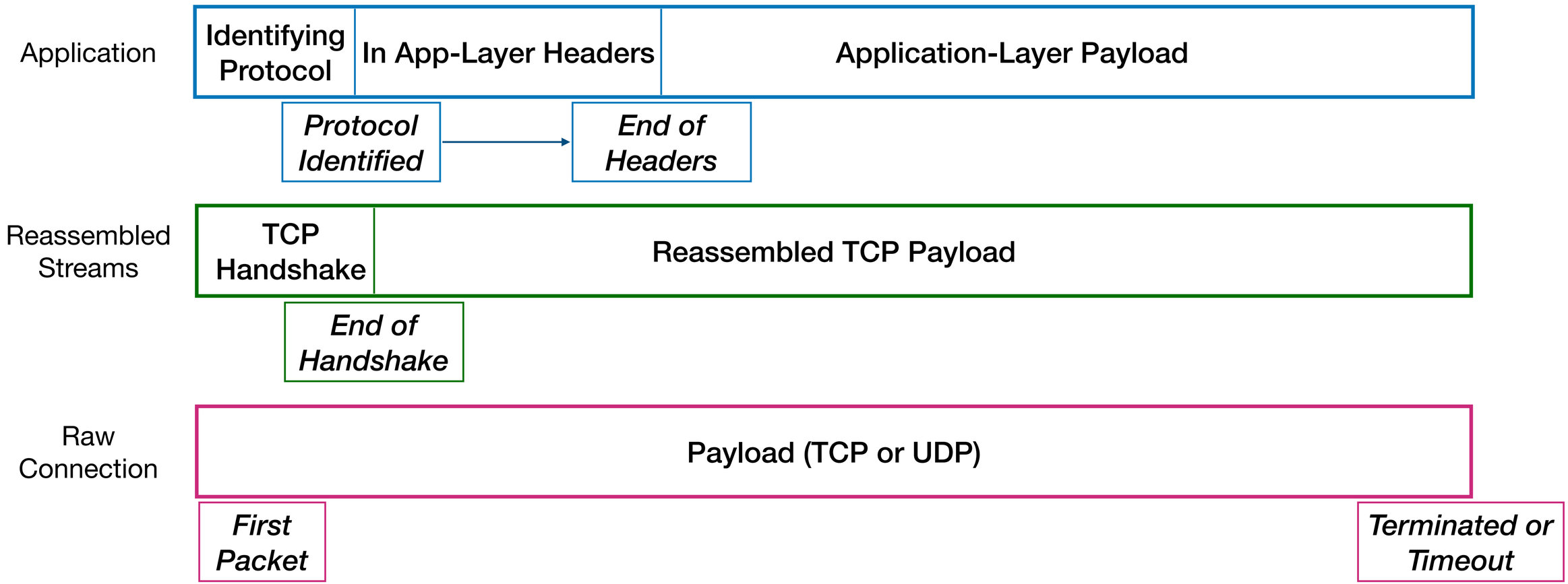


Iris allows users to define every subscription component in a general-purpose programming language.

Users Define Subscriptions by Hooking into Iris' Connection Processing Workflow



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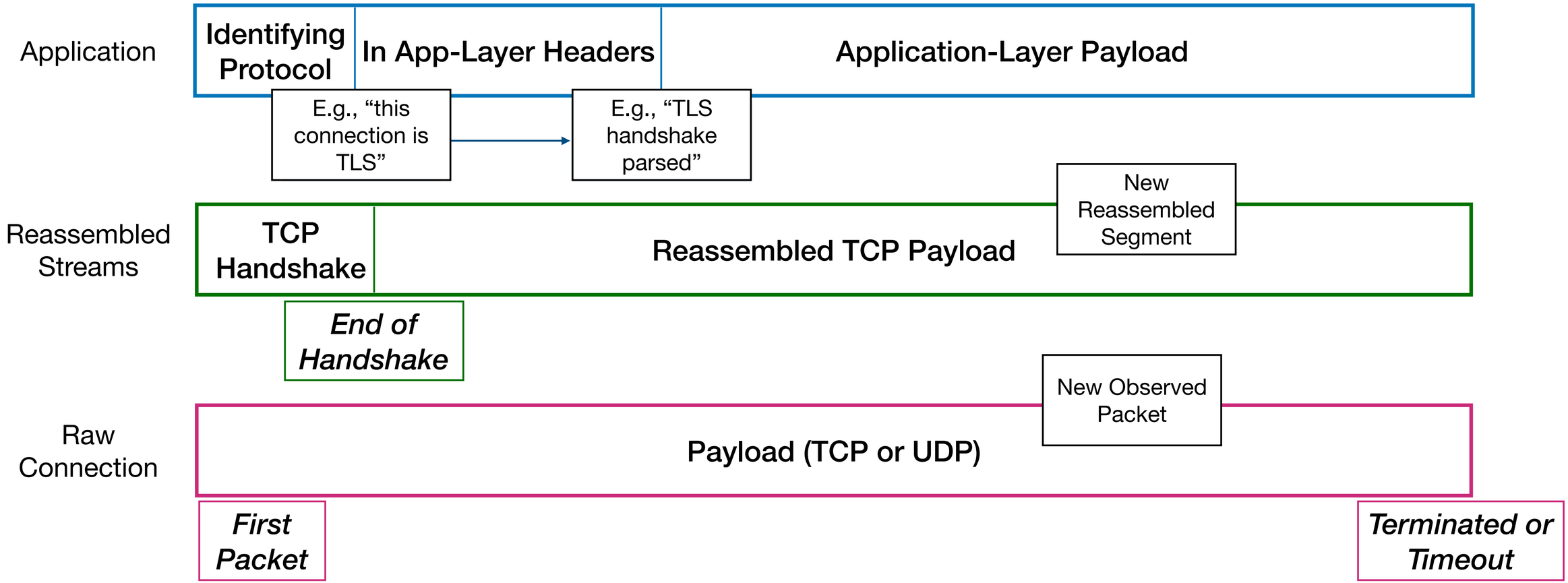
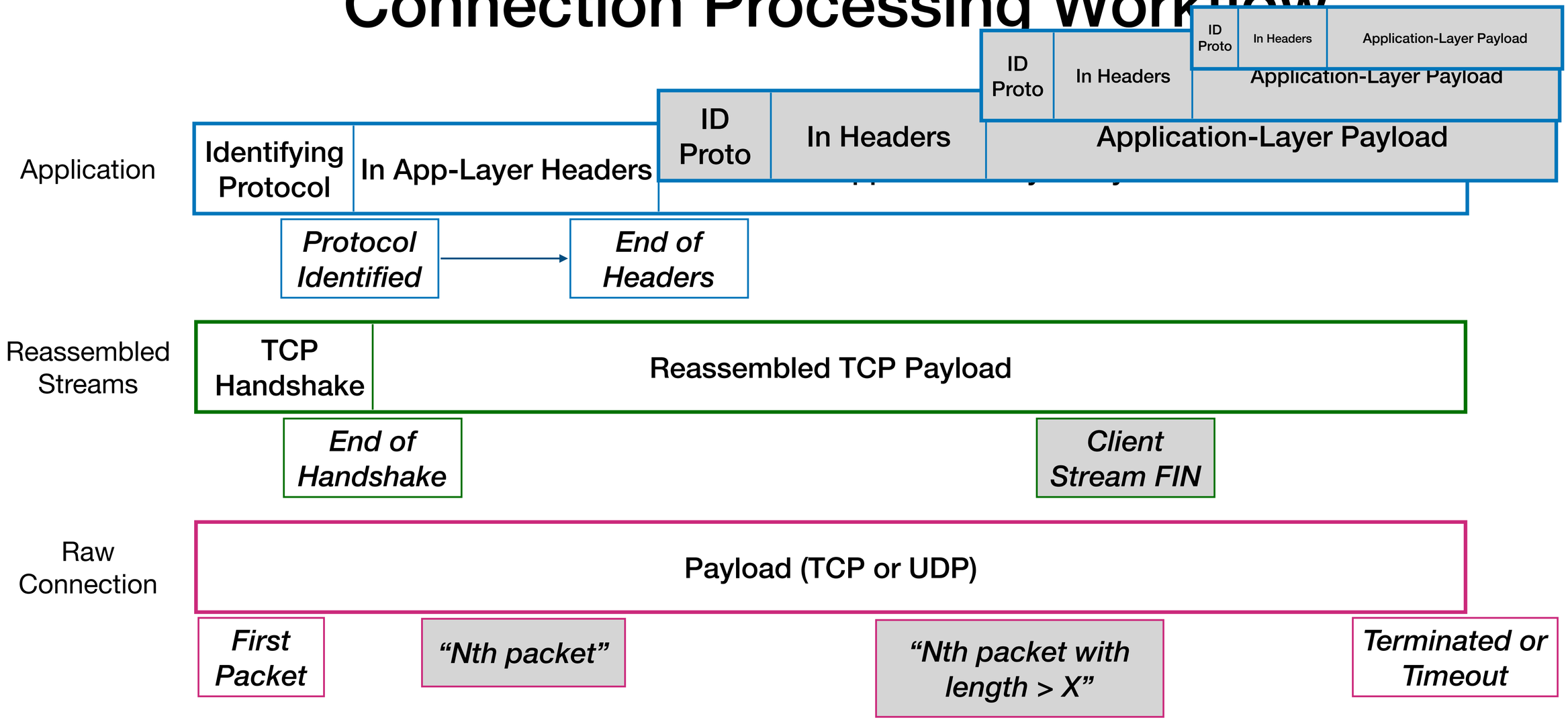


Users Define Subscriptions by Hooking into Iris' Connection Processing Workflow



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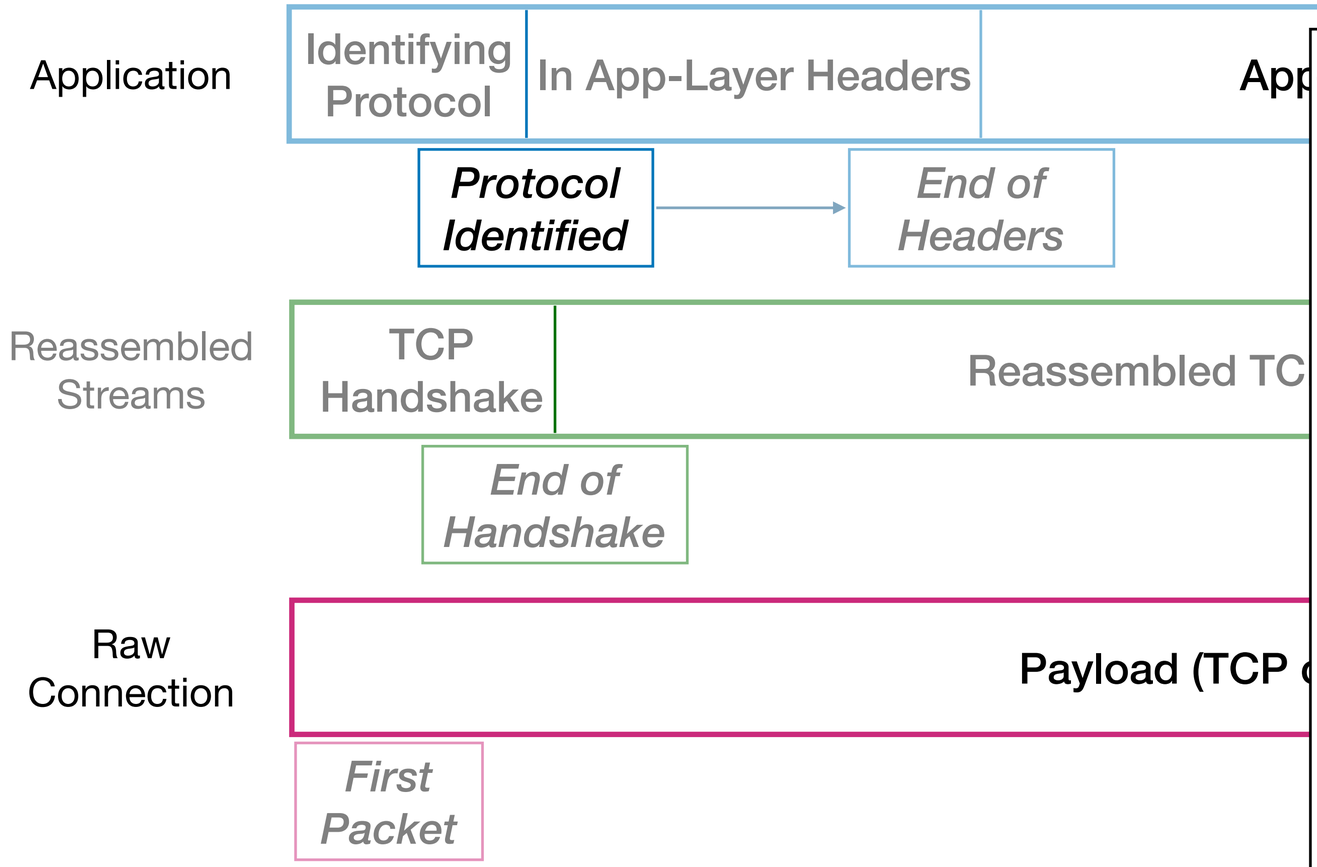
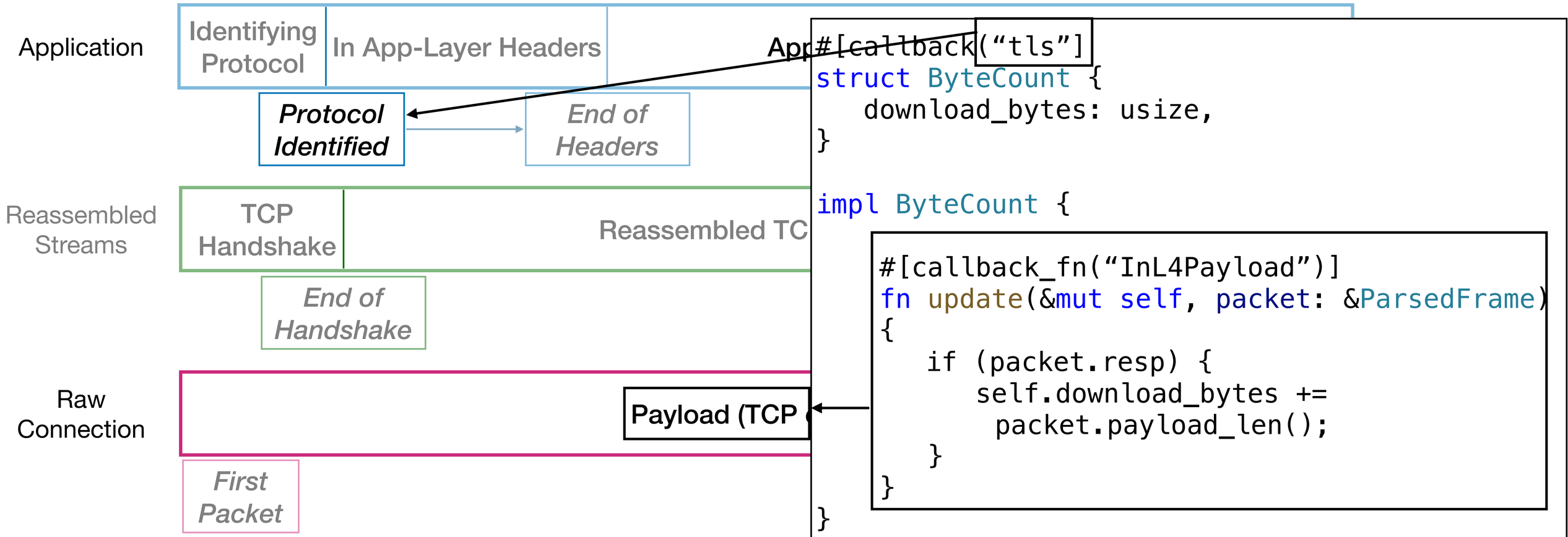



```
#[callback("tls")]
struct ByteCount {
   download_bytes: usize,
}

impl ByteCount {

    #[callback_fn("InL4Payload")]
    fn update(&mut self, packet: &ParsedFrame)
    {
        if (packet.resp) {
            self.download_bytes +=
              packet.payload_len();
        }
    }
}
```

Users Define Subscriptions by Hooking into Iris' Connection Processing Workflow



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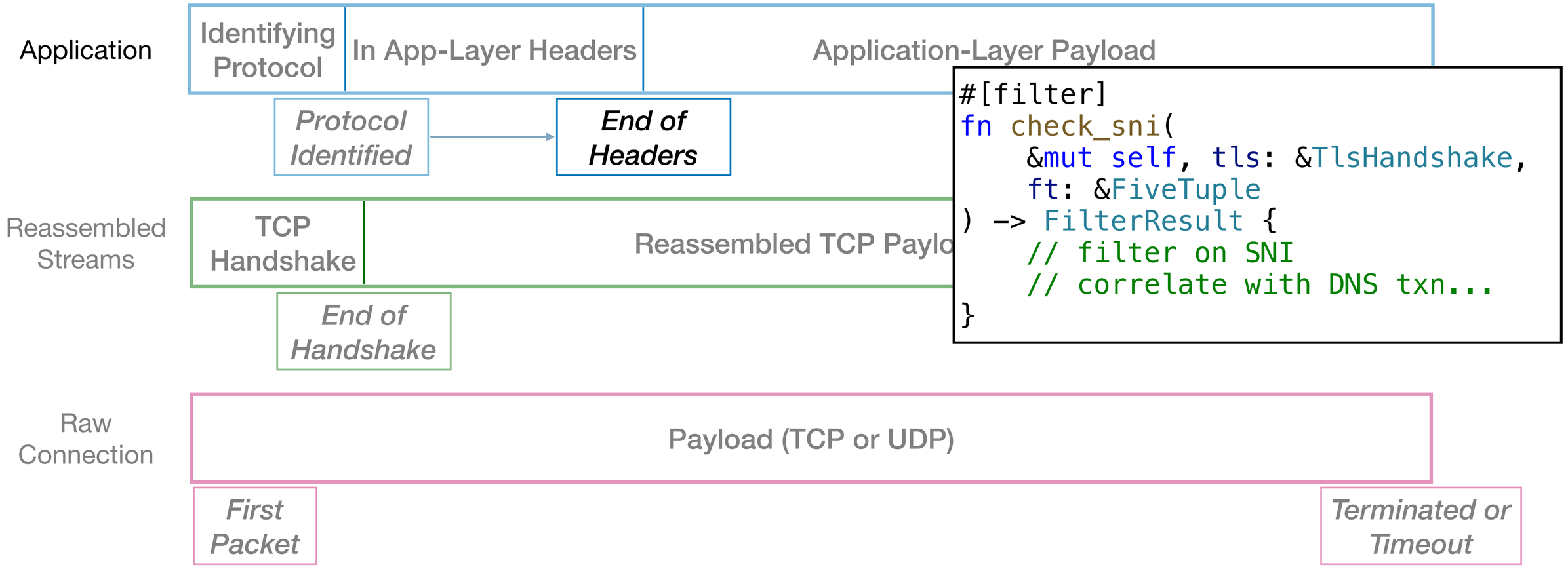

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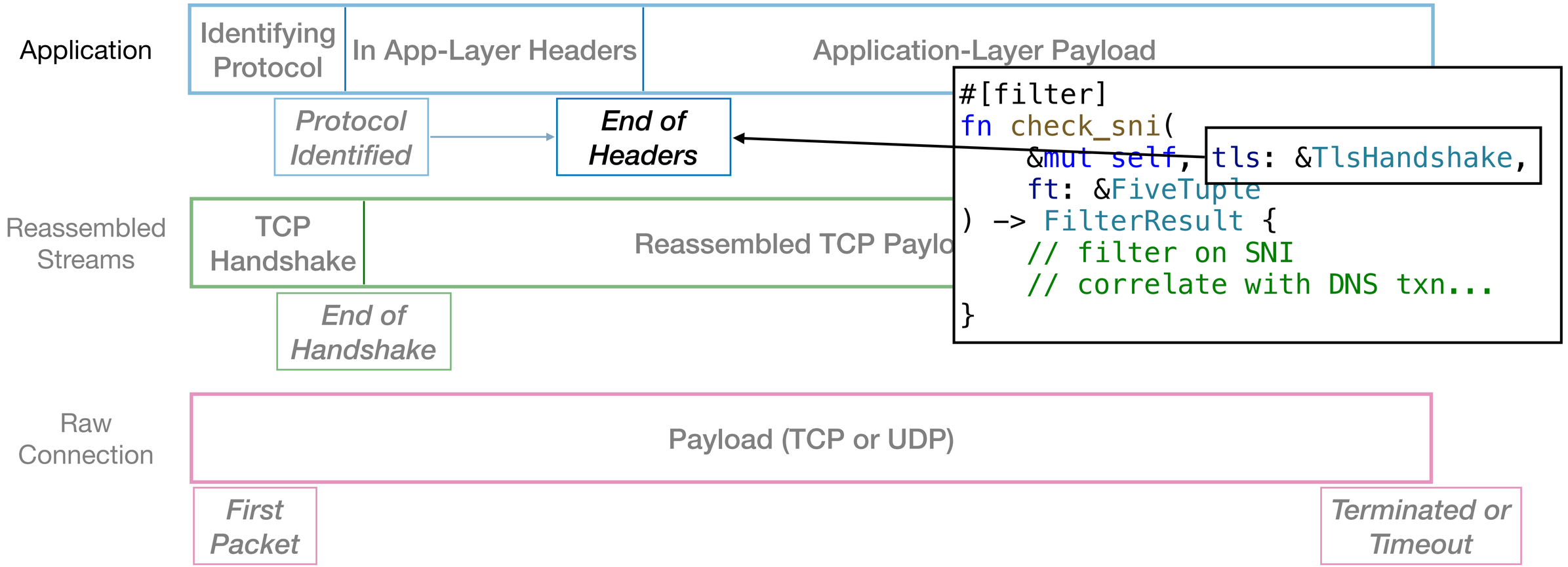


Users Compose Abstractions to Create More Complex Subscriptions

```
#[filter]
fn check_sni(
    &mut self, tls: &TlsHandshake,
    ft: &FiveTuple
) -> FilterResult {
    // filter on SNI
    // correlate with DNS txn...
}
```

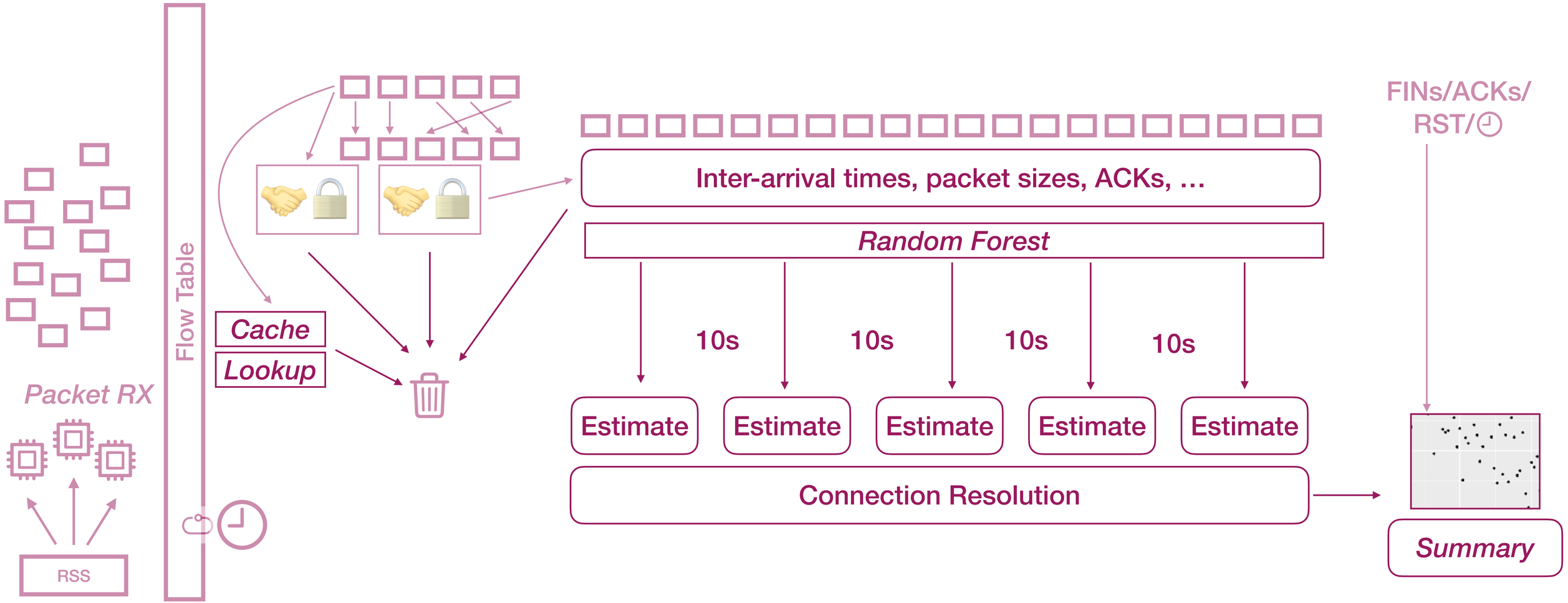
```
#[callback("tls and check_sni)"]
struct ByteCount {
   download_bytes: usize,
}

impl ByteCount {

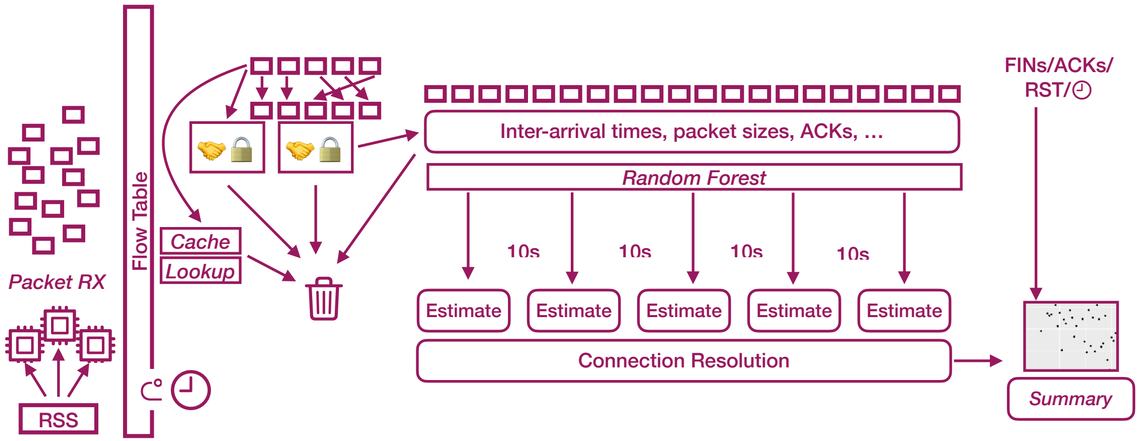
    #[callback_fn("InL4Payload")]
    fn update(&mut self, packet: &ParsedFrame)
    {
        if (packet.resp) {
            self.download_bytes +=
             packet.payload_len();
        }
    }
}
```

Iris Implements and Composes Common Traffic Analysis Primitives

Motivating Example: Video Resolution



Before



Thousands of LoC

With Iris

~170 LoC

10 cores, >100Gbps

Motivating Example: Video Resolution

Iris Contributions

1. Flexibility

Developers write code in a general-purpose programming language

2. Abstractions

…over connection- and application-layer data

Programming Model

3. Performance

…while retaining enough structure for the compiler to optimize across analysis tasks.

Compiler

Iris Contributions

TL;DR: Construct and merge per-subscription control flow.

1. Flexibility

Developers write code in a general-purpose programming language

2. Abstractions

…over connection- and application-layer data

Programming Model

3. Performance

…while retaining enough structure for the compiler to optimize across analysis tasks.

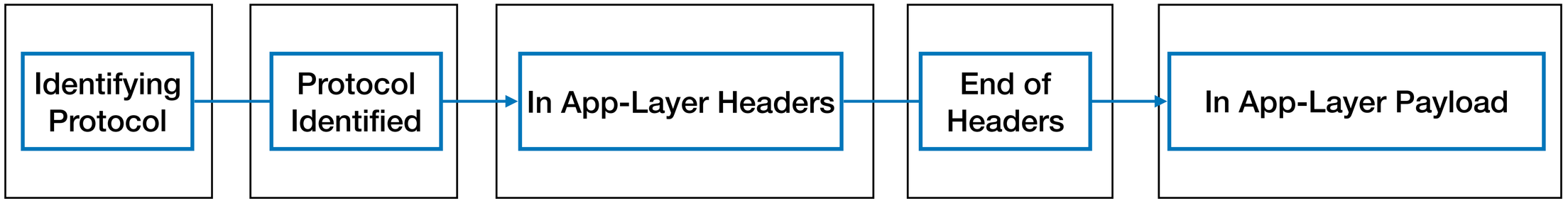
Compiler

By Mapping Subscriptions onto State Machines, Iris Builds Control Flow Graphs

⚠ Very simplified!
Additional layers omitted.

By Mapping Subscriptions onto State Machines, Iris Builds Control Flow Graphs

Treat state machines as incremental processing blocks



By Mapping Subscriptions onto State Machines, Iris Builds Control Flow Graphs

Subscription

```
#[callback("tls and video_lookup")]
struct ResolutionEst {
    resolutions: Vec<usize>,
}

// impl ResolutionEst
#[callback_fn]
fn update(
    &mut self, feats: &FeatureChunk
) -> bool {
    /* ... */
}

#[callback_fn("ConnTerminated")]
fn end(&mut self) { /* ... */ }
```

Map subscriptions to *actions* in state machines

Actions: incremental processing steps (at state/transitions)

By Mapping Subscriptions onto State Machines, Iris Builds Control Flow Graphs

Subscription

```rust
#[callback("tls and video_lookup")]
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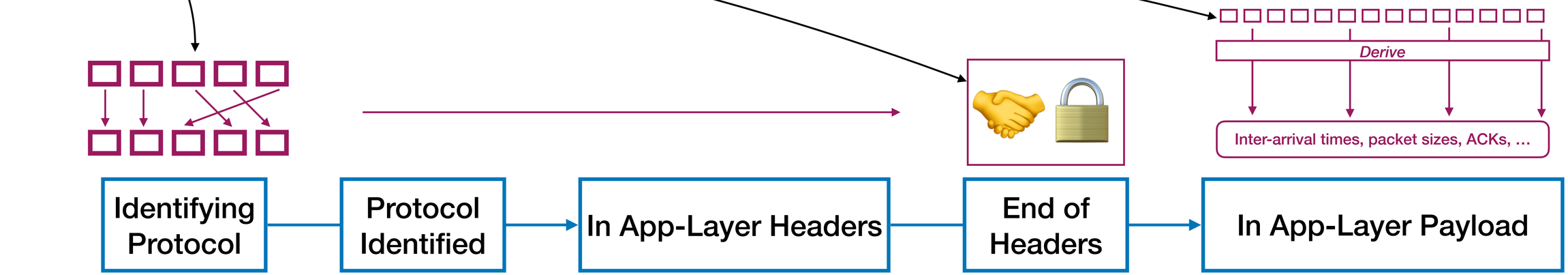

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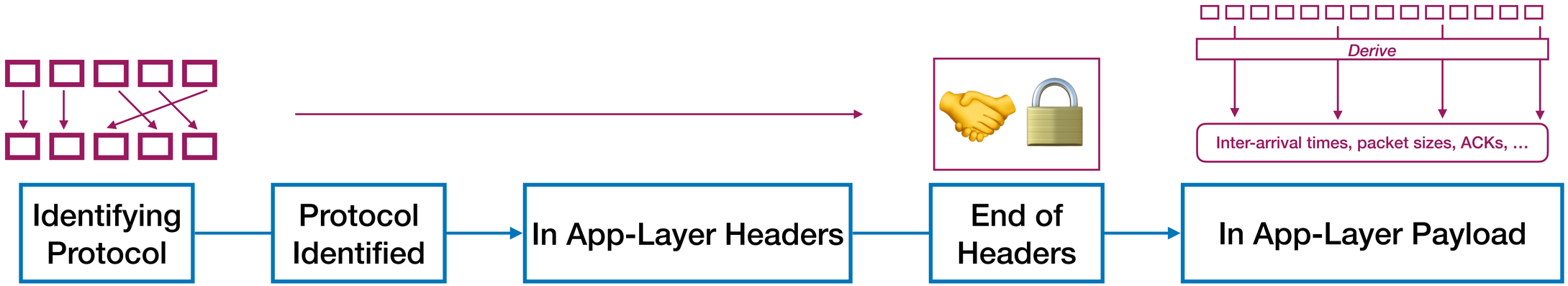

Incorporate subscription filters

Add incremental conditions to each processing step

By Mapping Subscriptions onto State Machines, Iris Builds Control Flow Graphs

Subscription

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#[callback("tls and video_lookup")]
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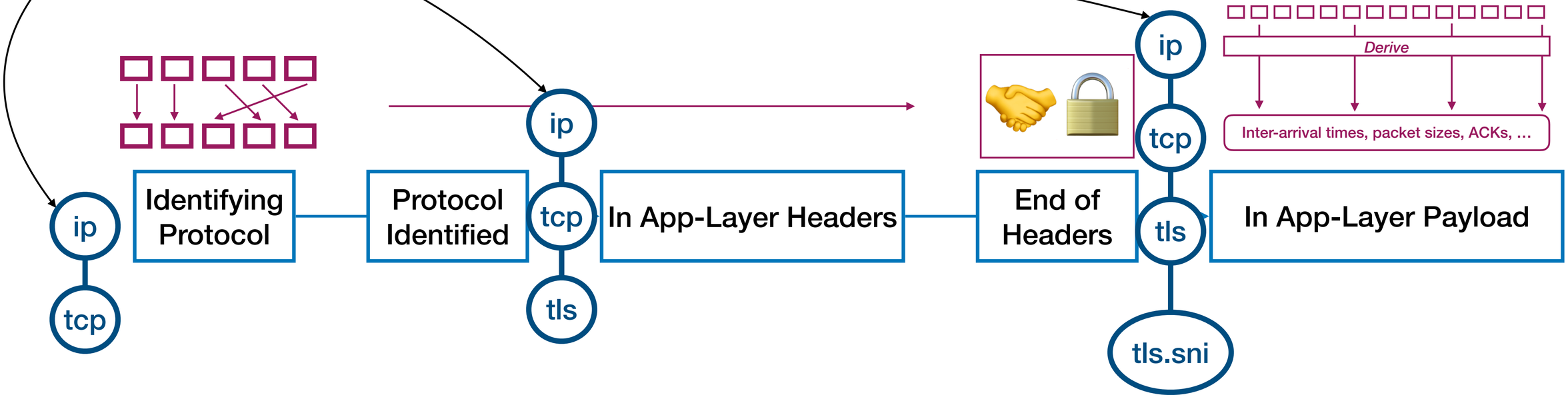

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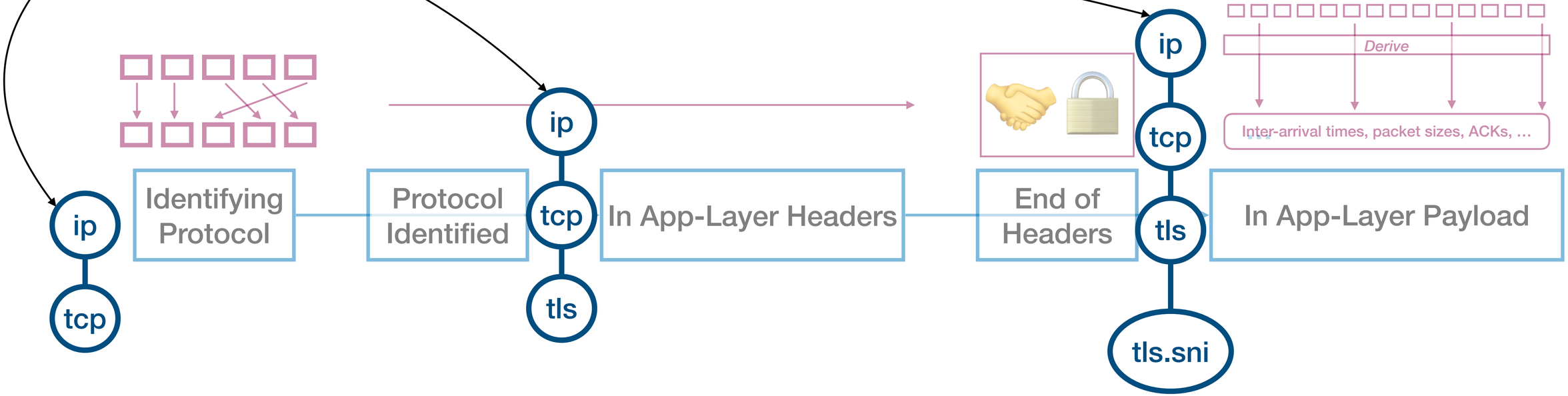
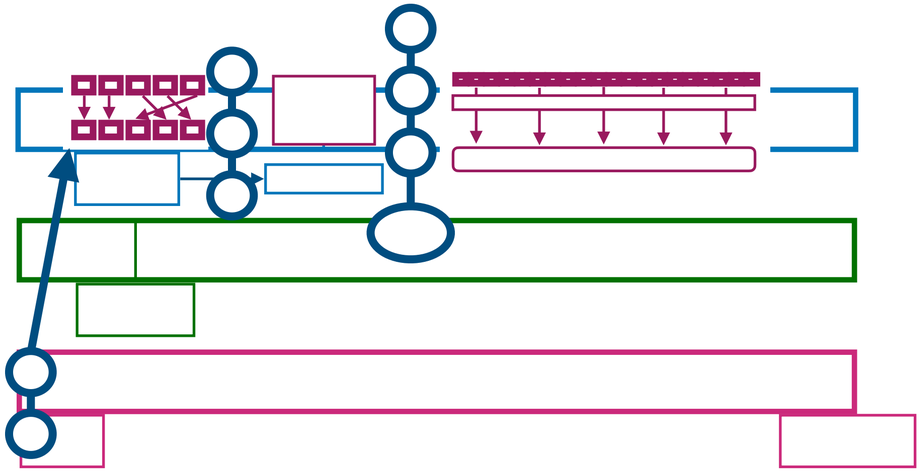
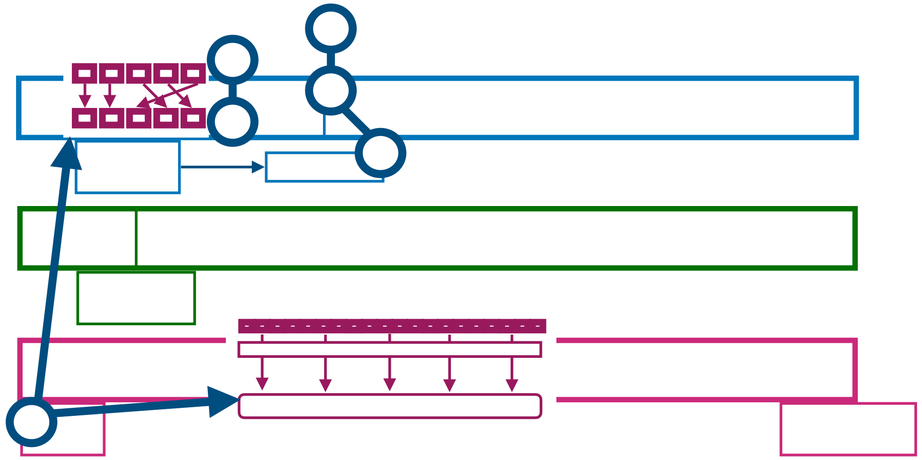


At runtime, Iris uses incremental filters to discard actions, data, and connections.

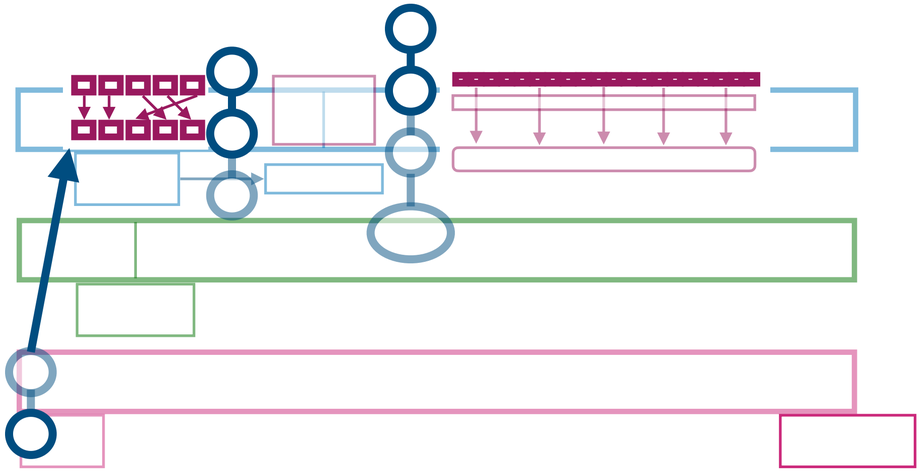
→ Minimal work necessary to fulfill subscriptions.

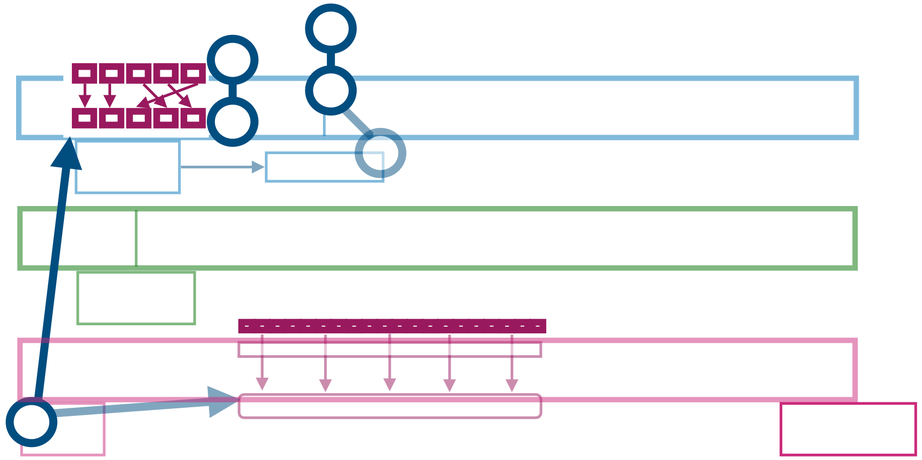
By Building Control Flow Graphs, Iris Can Merge Multiple Subscriptions





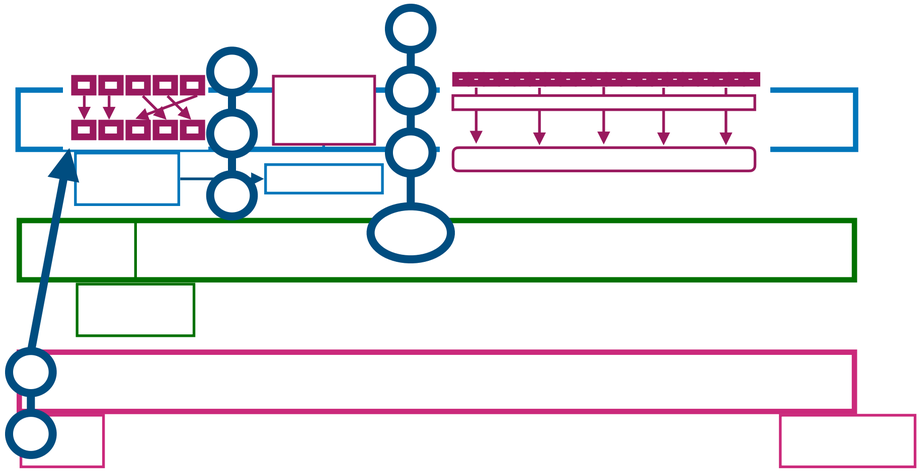
By Building Control Flow Graphs, Iris Can Merge Multiple Subscriptions

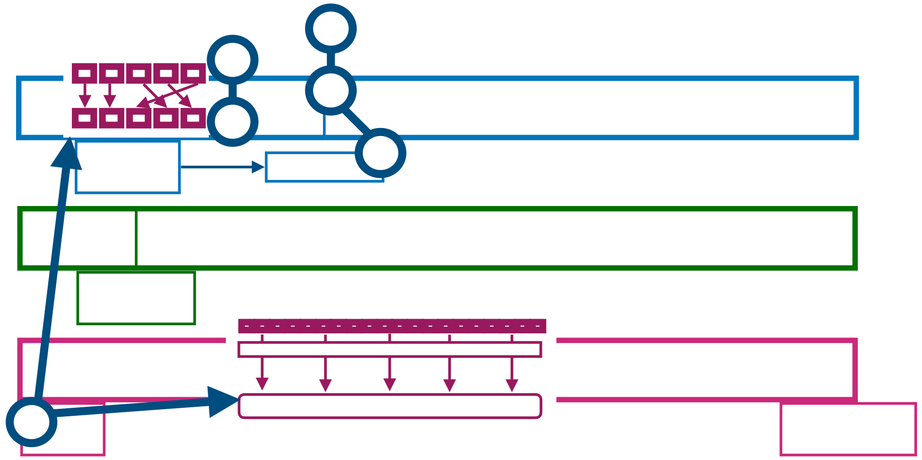




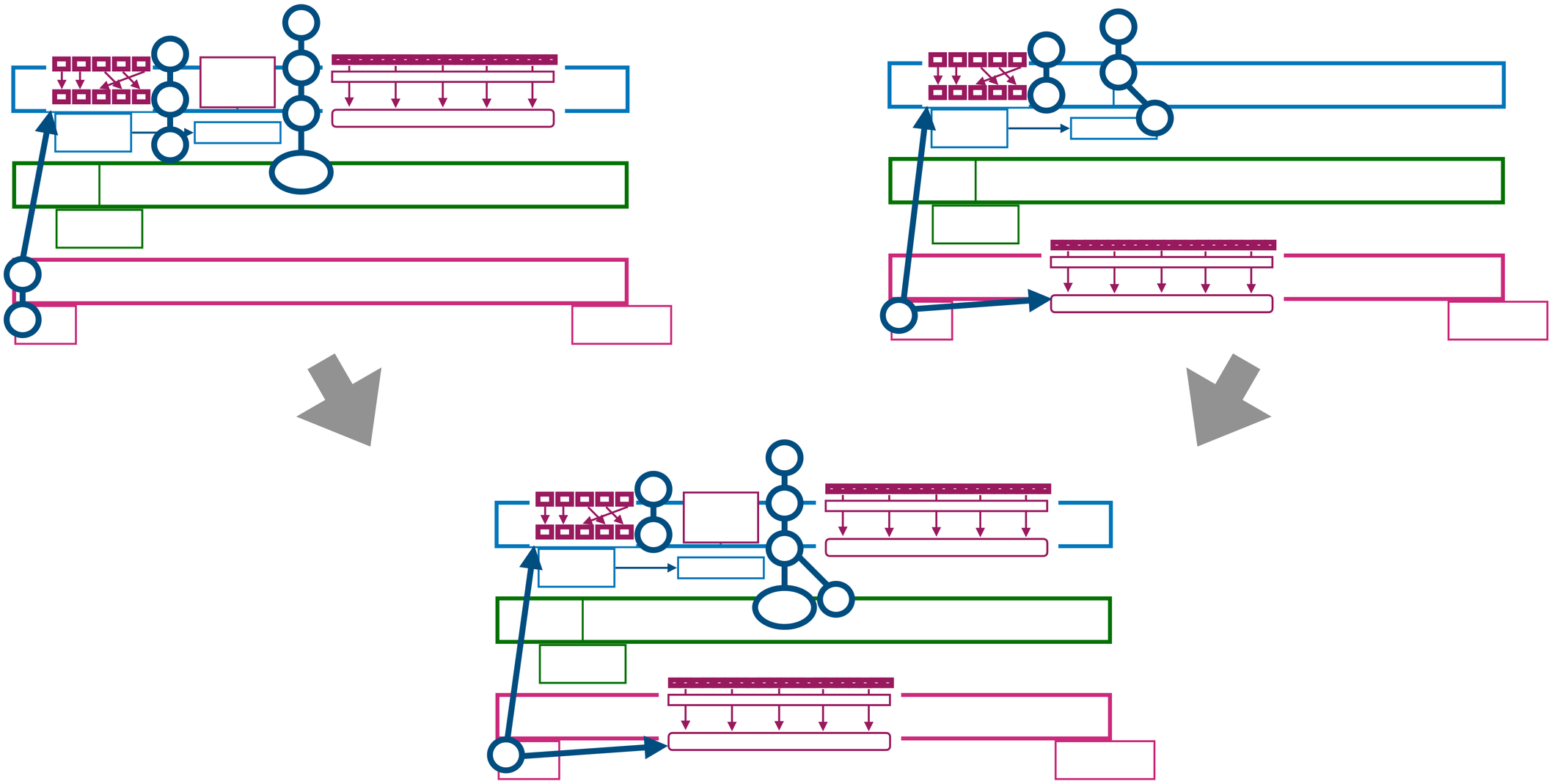
Subscriptions typically share some requirements.

By Building Control Flow Graphs, Iris Can Merge Multiple Subscriptions

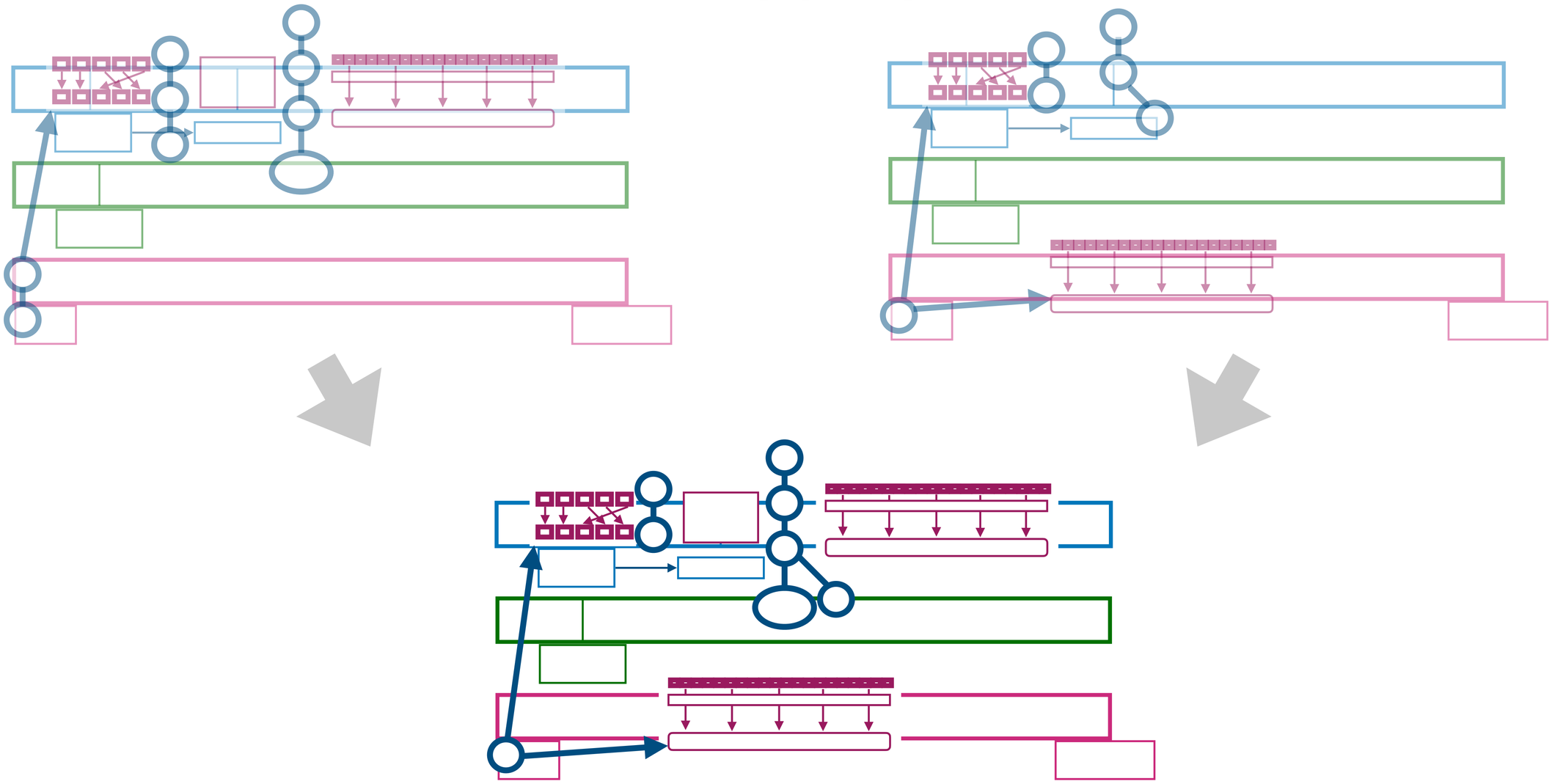




By Building Control Flow Graphs, Iris Can Merge Multiple Subscriptions



Multiple Subscriptions
Minimal Aggregate Work



Iris Evaluation

Iris Compiler: Performance

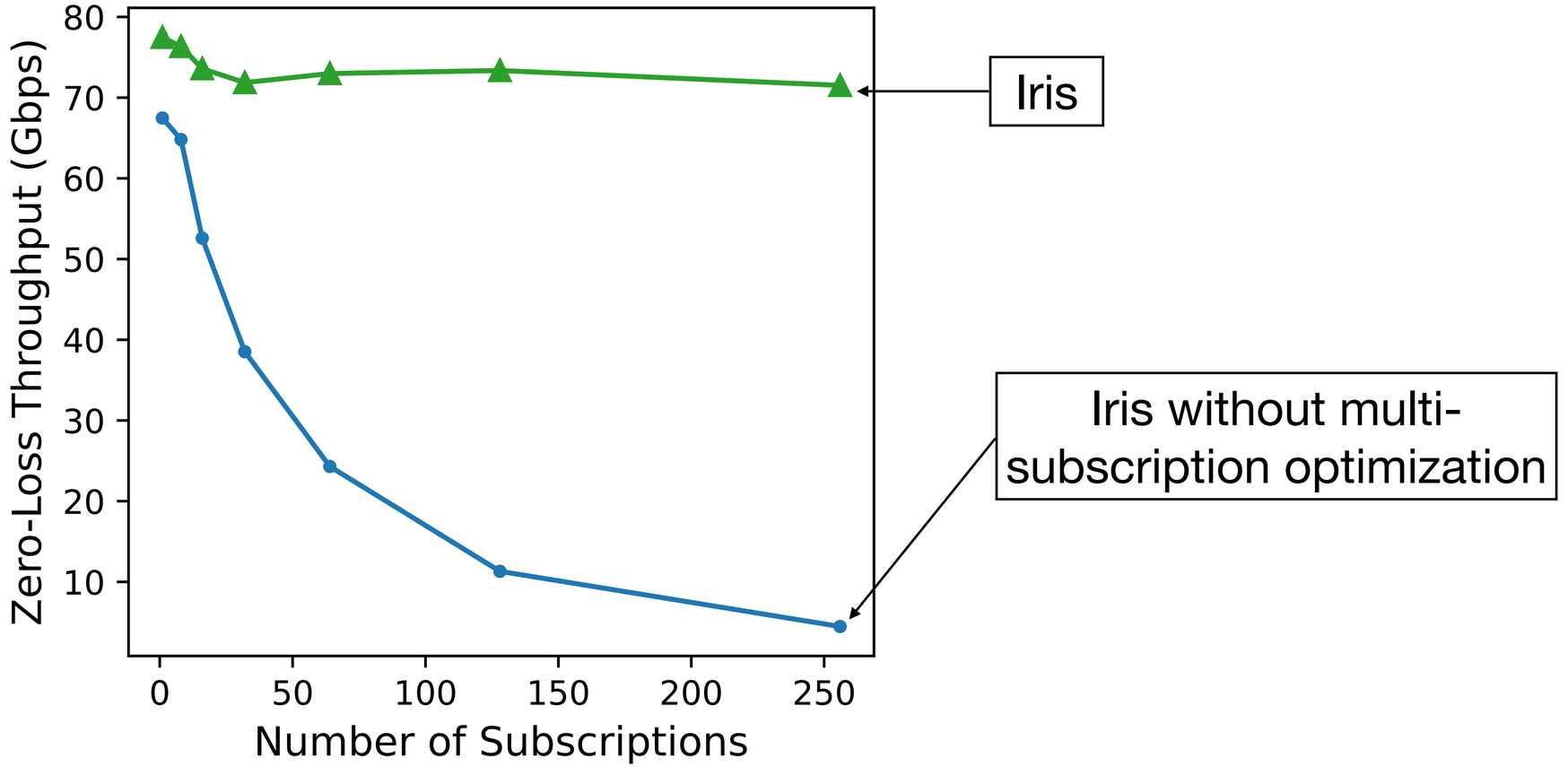
- Does Iris scale to many subscriptions (analysis tasks)?
- Does Iris effectively share work across subscriptions?

Interface: Flexibility + High-Level Abstractions

- Can we easily express complex, real-world use-cases in Iris?

Iris Scales to Hundreds of Subscriptions

Evaluation on Stanford's network, two cores to force CPU bottleneck



HTTP transactions with *N* malicious hosts

Iris Scales to Hundreds of Subscriptions

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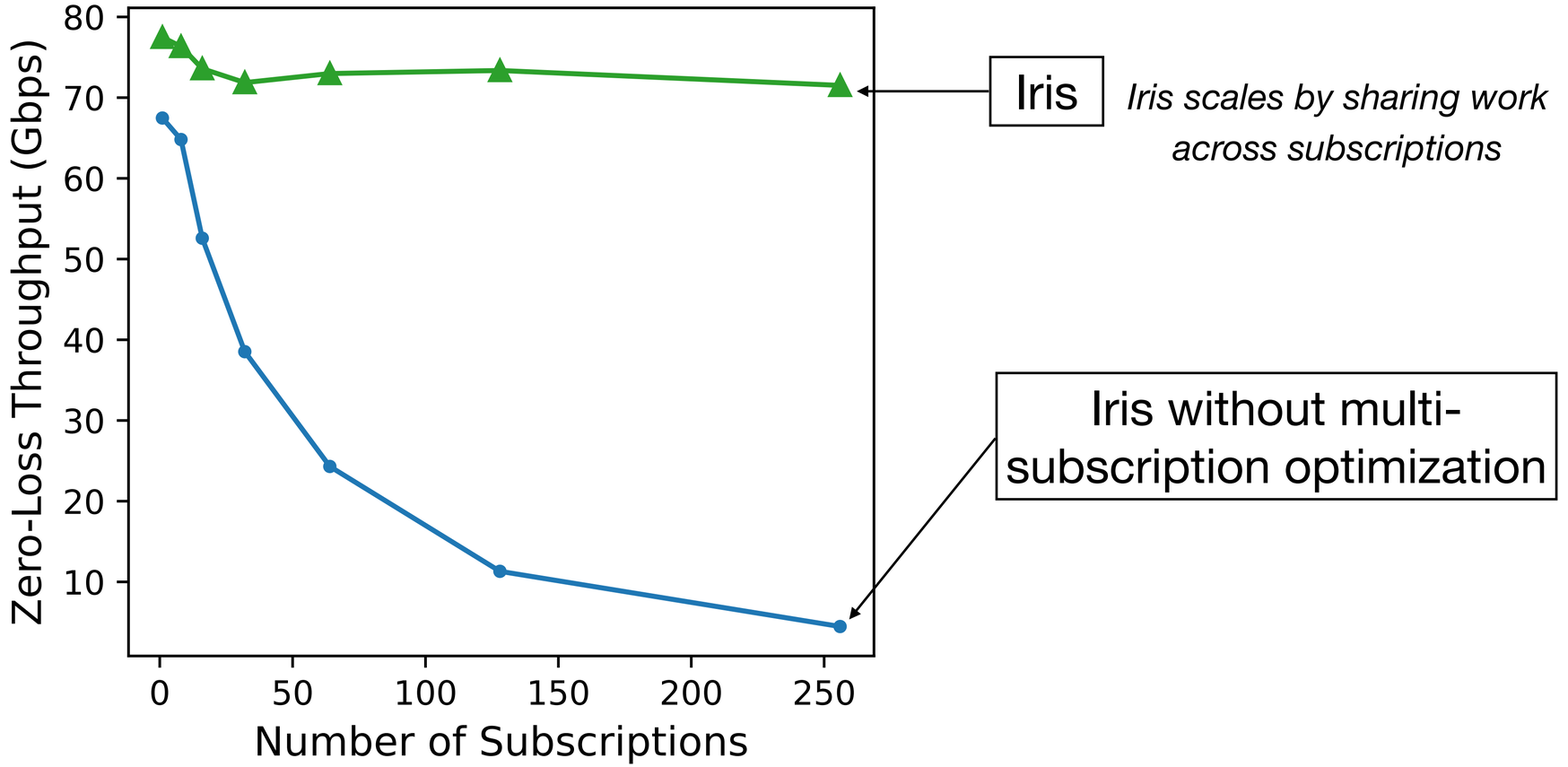

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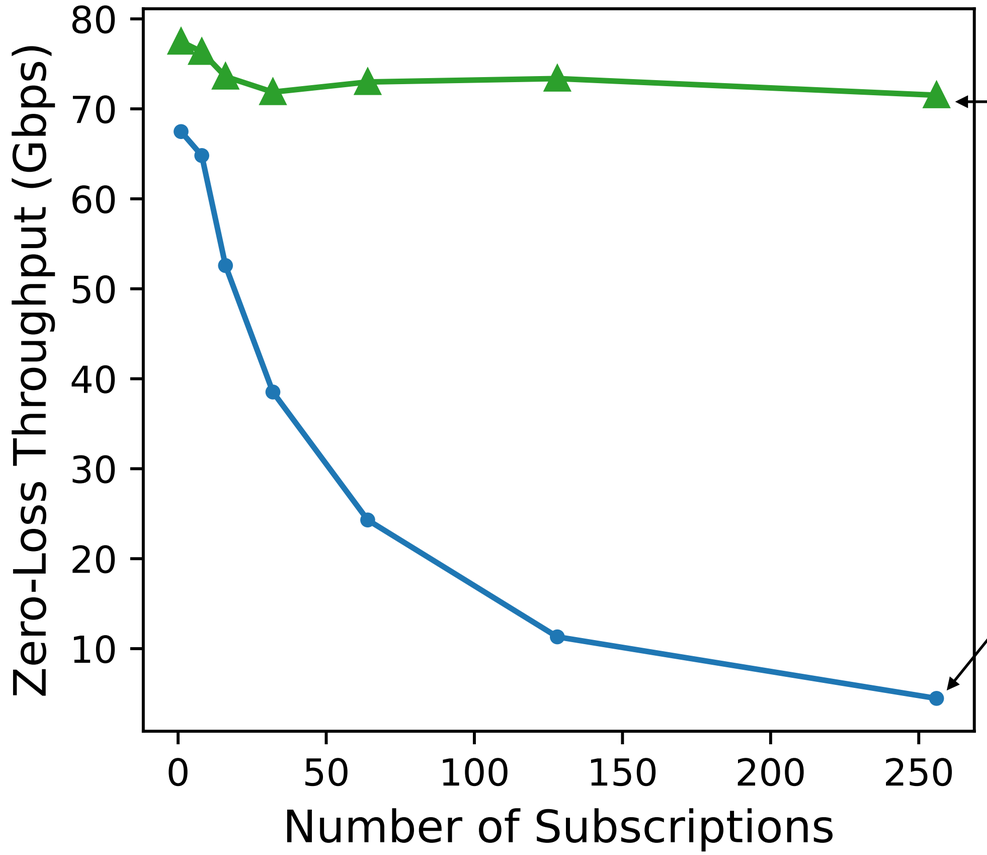


Iris

Iris scales by sharing work across subscriptions

Iris without multi-subscription optimization

Scaling multiple subscriptions <u>requires</u> sharing incremental work.

HTTP transactions with *N* malicious hosts

Evaluating Iris with Real-World Analysis

Measuring Security Practices *(DeKoven ’19)*

OpenVPN Censorship Risks *(Xue ’22)*

Estimating Video Resolution *(Bronzino ’19)*

All concurrently

Evaluating Iris with Real-World Analysis

Measuring Security Practices *(DeKoven ’19)*

Application-layer parsing

OpenVPN Censorship Risks *(Xue ’22)*

Custom data type

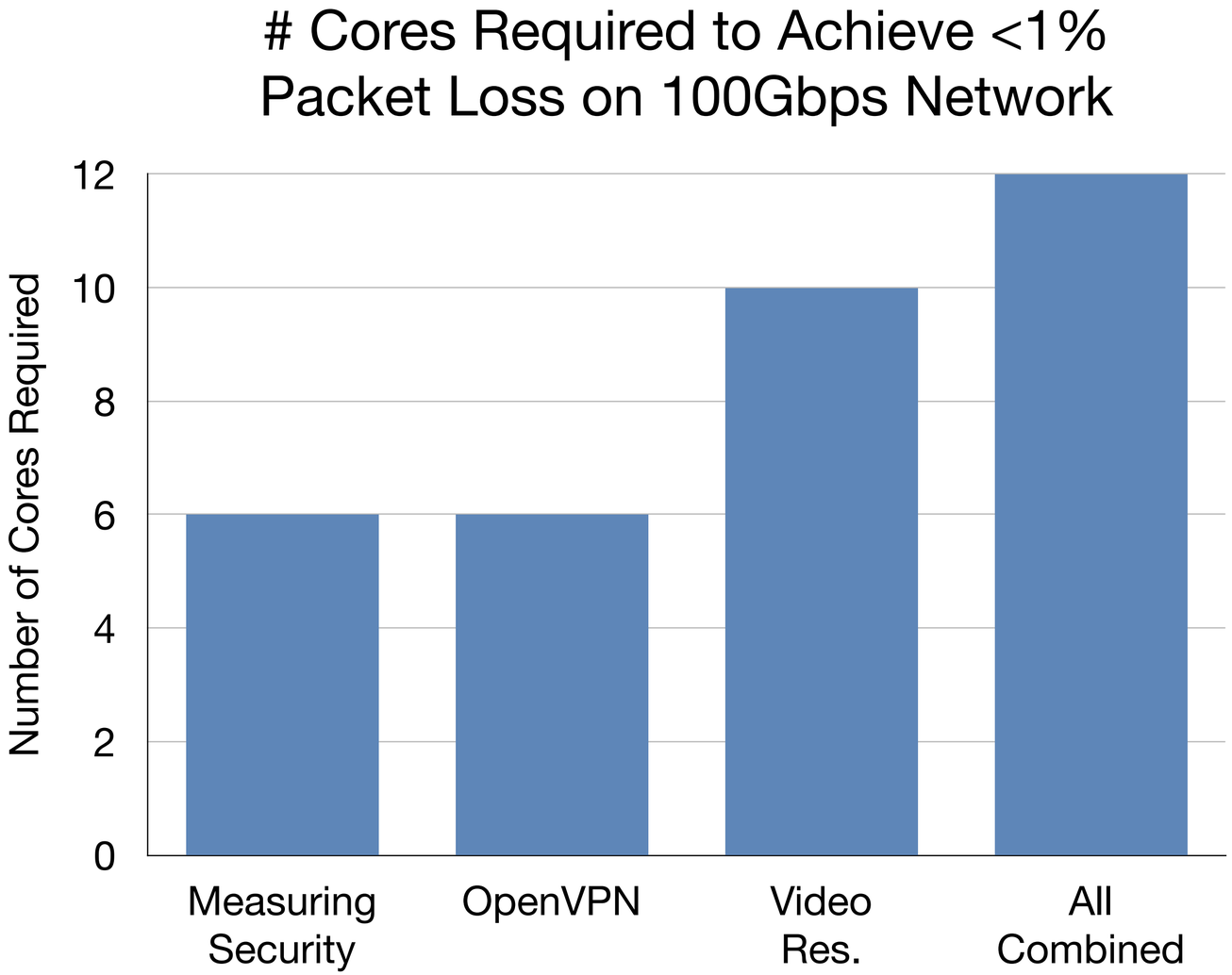
Estimating Video Resolution *(Bronzino ’19)*

Complex callback

All concurrently

Multiple heterogeneous subscriptions

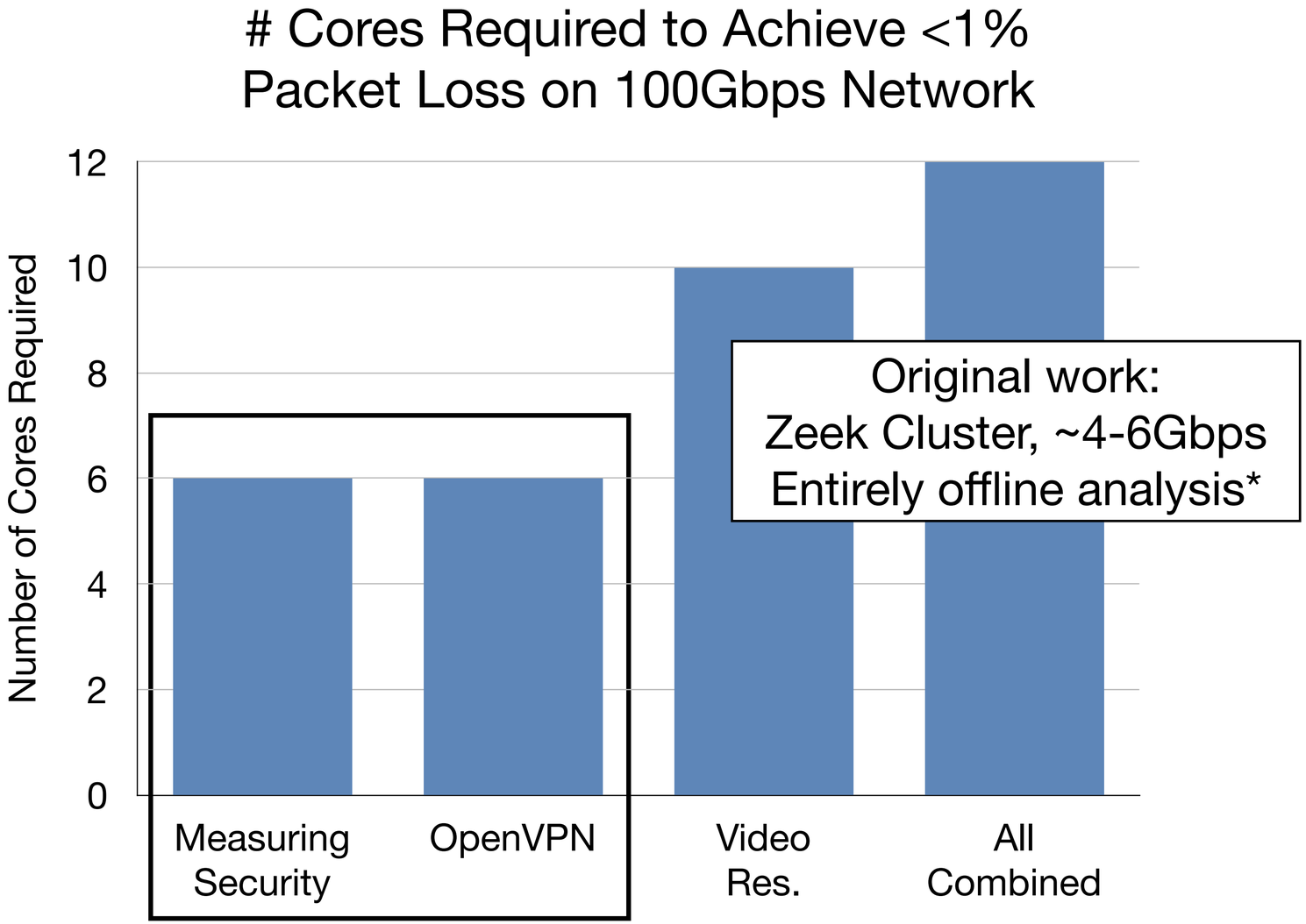
Iris Runs Complex Experiments at Line Rate



Lines of Code Required to Implement in Iris

Measuring Security	~200 LoC
OpenVPN	~230 LoC
Video Resolution	~170 LoC

Iris Runs Complex Experiments at Line Rate

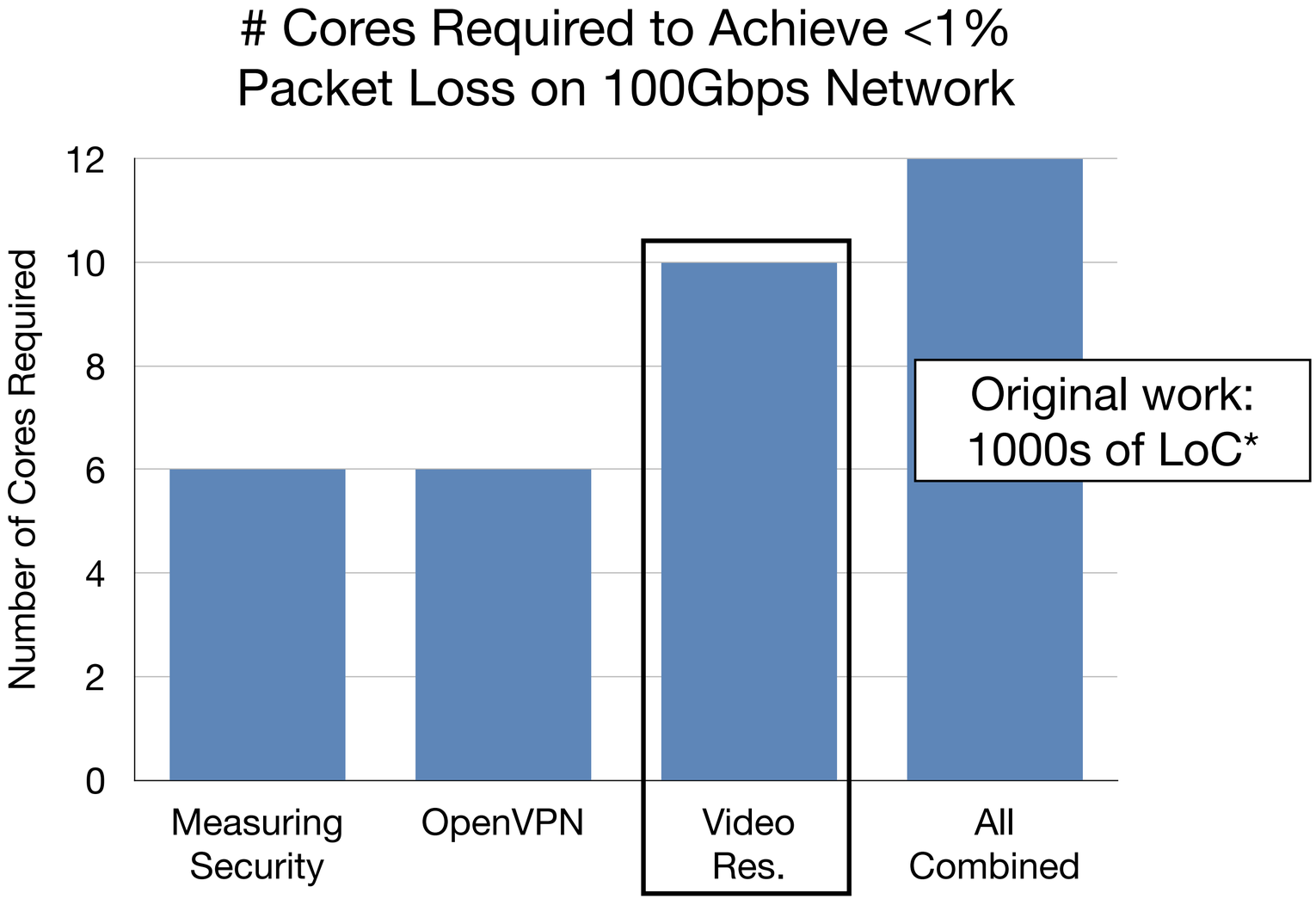


Lines of Code Required to Implement in Iris

Measuring Security	~200 LoC
OpenVPN	~230 LoC
Video Resolution	~170 LoC

*We were unable to replicate these studies in Zeek given our storage and compute constraints

Iris Reduces Developer Effort

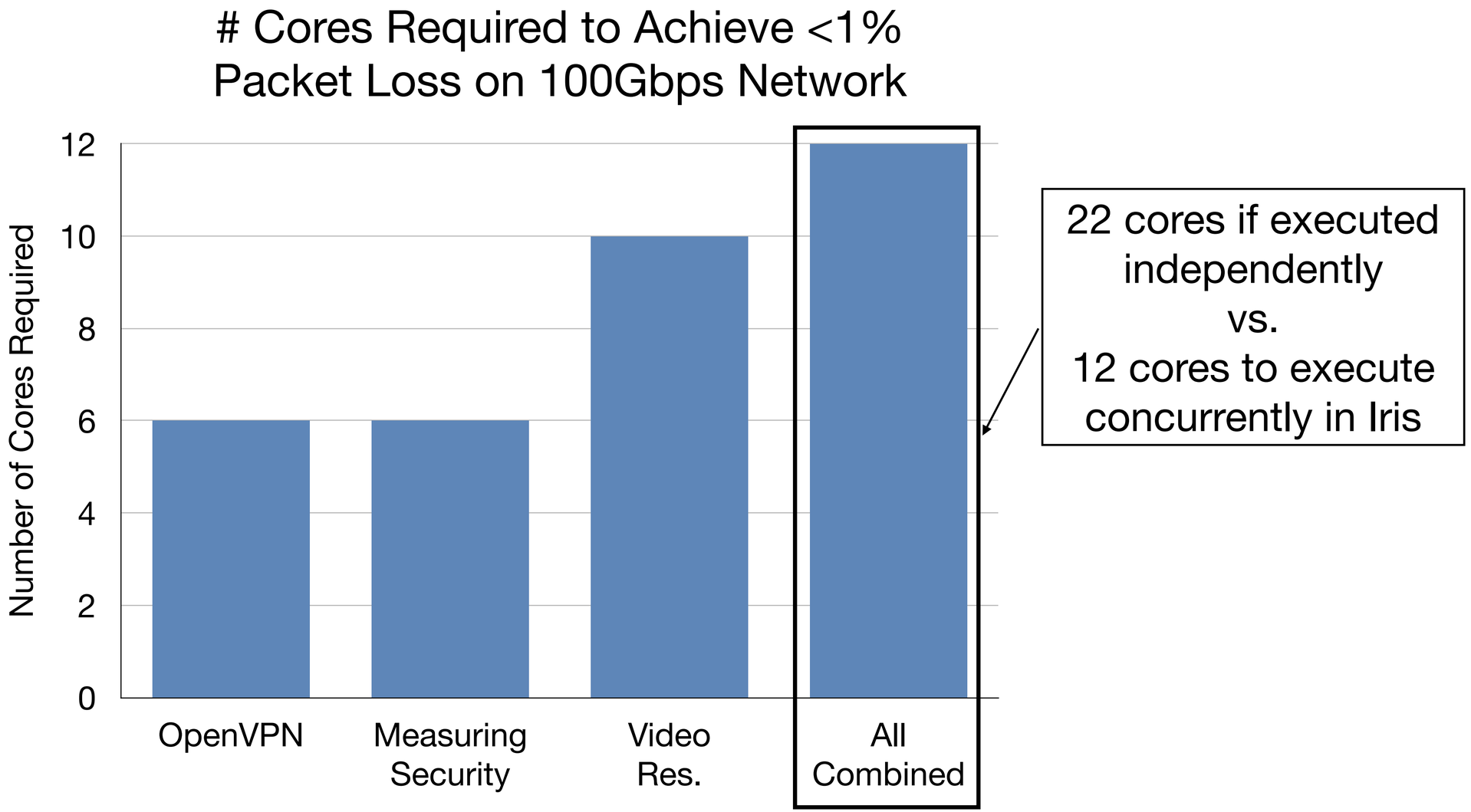


Lines of Code Required to Implement in Iris

Measuring Security	~200 LoC
OpenVPN	~230 LoC
Video Resolution	~170 LoC

*Original artifact not available; preliminary version of Traffic Refinery, which has ~6K LoC

Iris Optimizes Across Multiple Subscriptions



Iris: Expressive Traffic Analysis for the Modern Internet

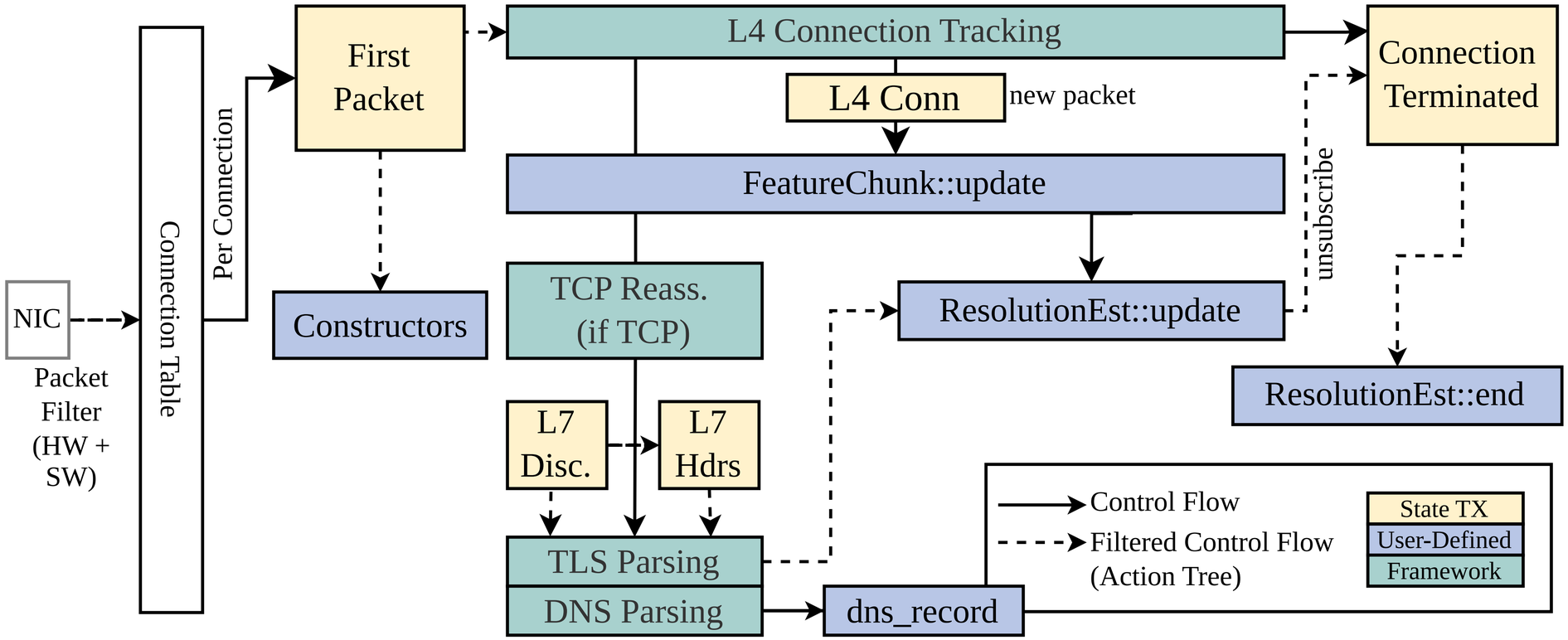
Thea Rossman, Diana Qing, Gerry Wan, Zakir Durumeric
Stanford University

https://github.com/stanford-esrg/iris

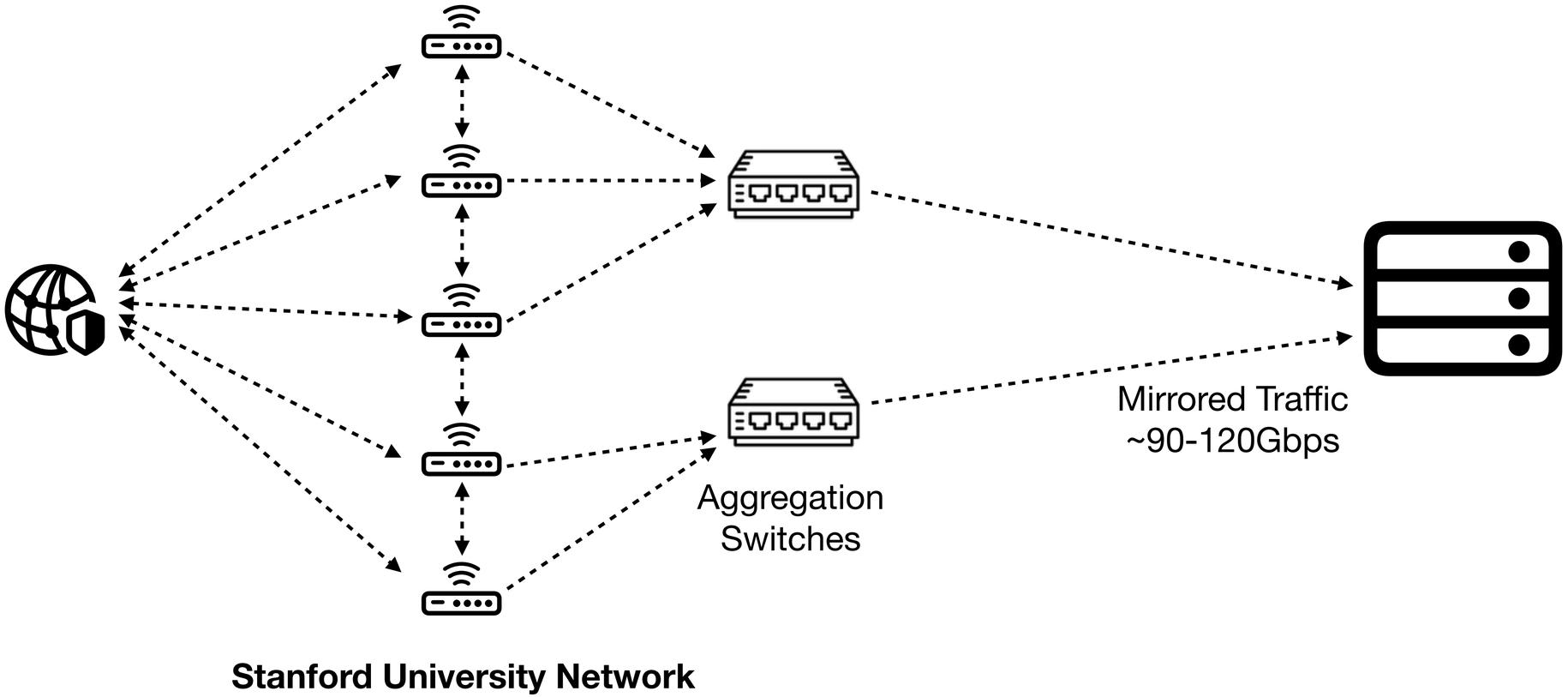
Contact: thea.rossman@cs.stanford.edu

Additional Slides

Generated Runtime Pipeline



Experiment Setup



Real-World Case Studies

	Max. Memory Utilization (App)	Max. Memory Utilization (DPDK)
Measuring Security	3.9GB	2.2GB
OpenVPN	2.5GB	1.0GB
ML QoS	3.5GB	1.5GB
All	5.0GB	3.5GB

Compilation Time

- Scales with number and complexity of subscriptions
- Majority of time is Rust release optimizations
- Development (debug builds) are typically fast

	Debug	Release	Iris
Use Cases (all)	2.5s	30s	50ms
HTTP - One Subscr.	5s	30s	15ms
HTTP - 5k Subscr.	30s	120s	18s

Ethics

- **Ethics Review**: Stanford privacy office, network IT, IRB (out of scope)
- **Privacy**: anonymize IP addresses, minimize data collection, perform flow-level analysis online (when possible), delete data within 2 weeks, no DHCP
- **Impact on Users:** mirrored traffic only
- **Operational Security**: rigorous access controls on network tap
- **Dual Use**: not optimized for latency or dragnet monitoring, not introducing fundamentally new capabilities