Securing Internet Routing: The Puzzle Pieces

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Network Startup Resource Center

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Headlines/Incidents

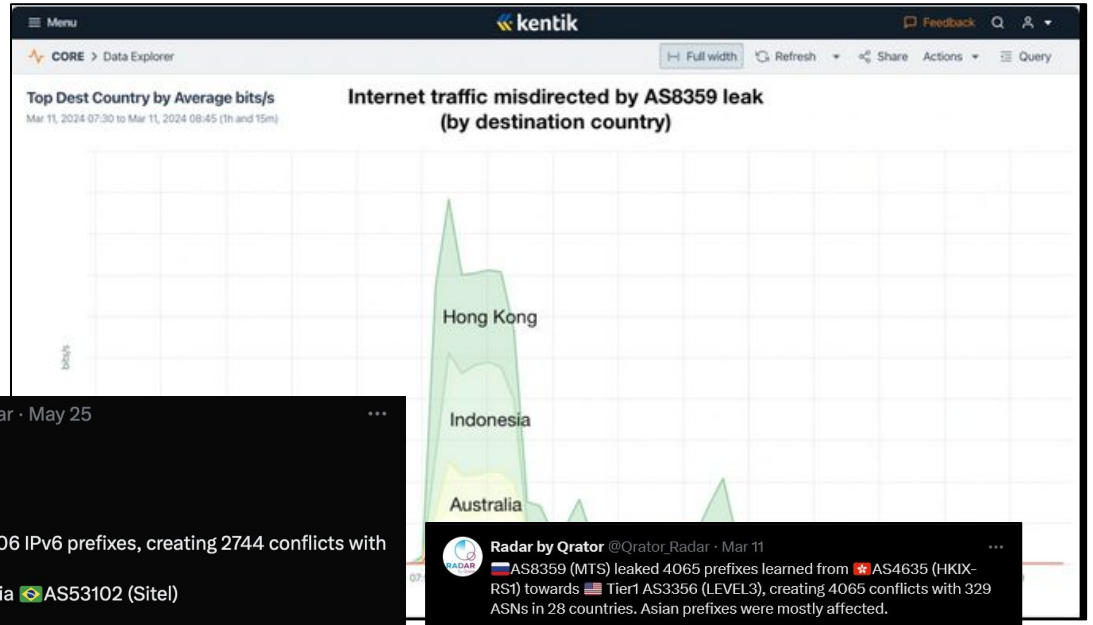
ars TECHNICA BIZ & IT TECH SCIENCE POLICY CARS GAMING &

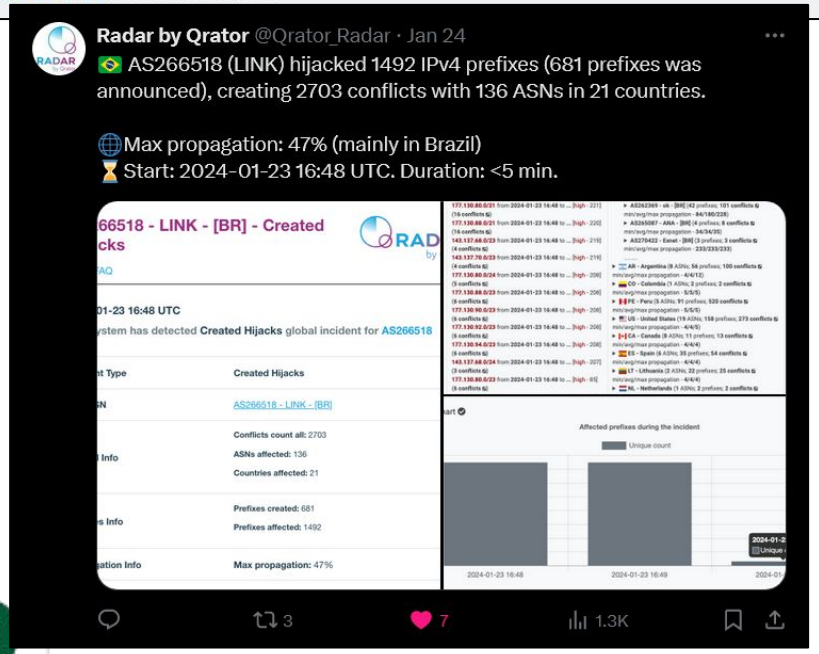
COMEDY OF ERRORS —

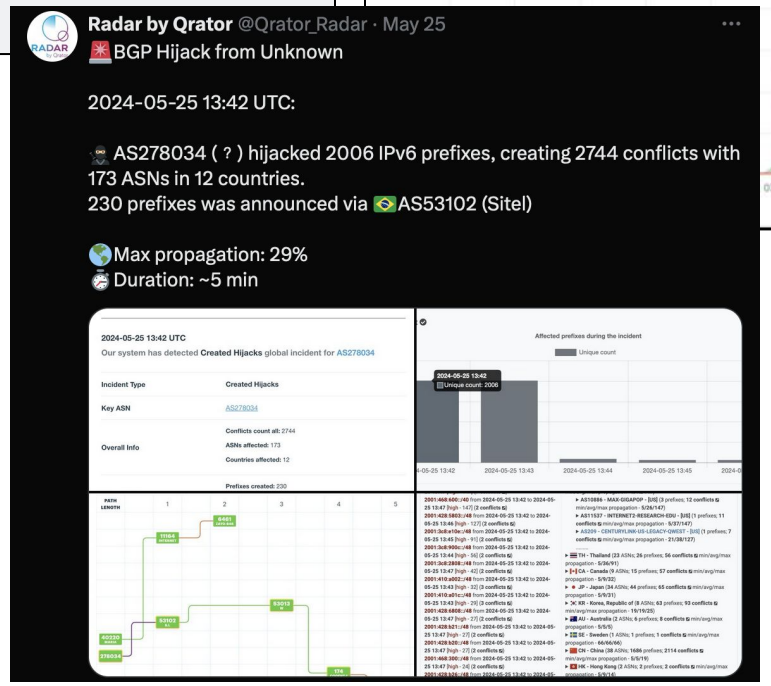
A “ridiculously weak” password causes disaster for Spain’s No. 2 mobile carrier

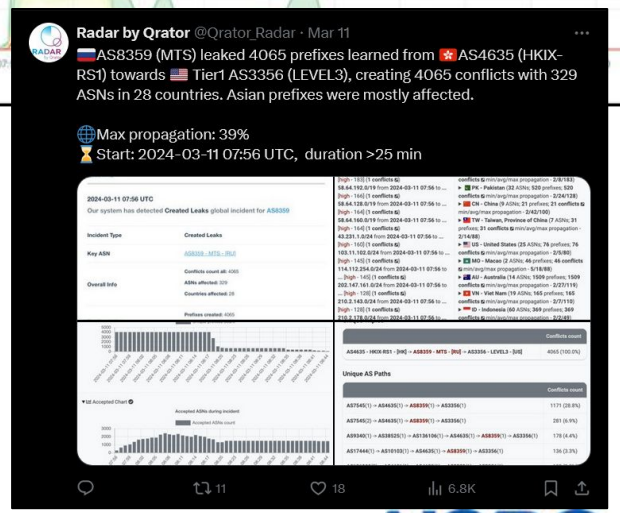
BGP tampering caused by poor security hygiene causes major outage for Orange España.

DAN GOODIN - 1/5/2024, 10:01 AM









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WHY

- NO ONE is in charge?
  - No single authority point for the Internet
  - No REFERENCE point for what's RIGHT in routing

WHY

- Routing works by RUMOUR
  - TELL what you know to your neighbours/LEARN what your neighbours know
  - Assume everyone is CORRECT/HONEST
    - *Is the originating network the rightful owner?*

WHY

- Routing works in REVERSE
  - What you TELL others (outbound adv) affects inbound traffic
  - What you TRUST and ACCEPT (inbound adv) affects outbound traffic

WHY

- And sadly, there is no EVIL (E-bit) bit
  - RFC3514 was a humorous attempt ☺️
- Since a bad routing update does not identify itself as BAD:
  - *Can we identify GOOD updates?*
  - *How do we identify what is GOOD?*

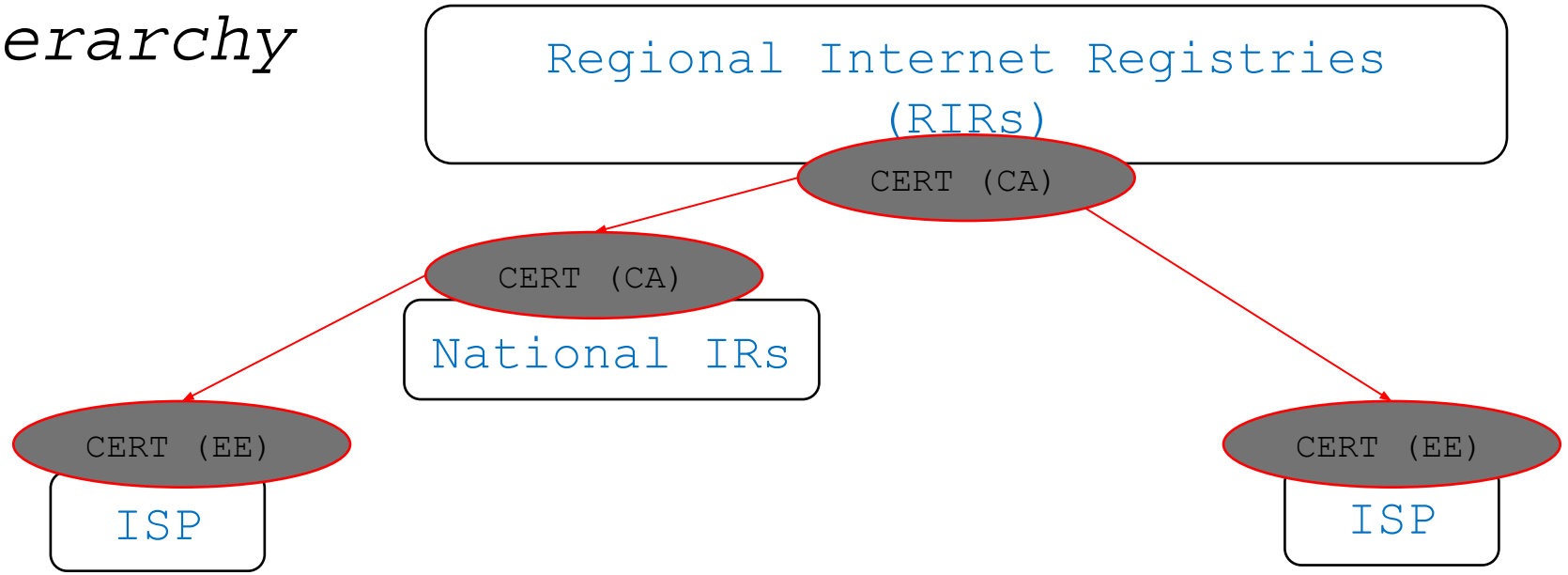
Identifying GOOD

- Back to basics - can we use Digital Signatures to convey the Authority to use?
  - Private key to sign the Authority, and
  - Public key to validate the Authority

If the holder of the resource has the private key, it can sign/authorise the use of the resource(s)!

Identifying GOOD

- Ok, let us use digital signatures, but how do we establish TRUST in this framework?
  - *Follow the numbered resource allocation hierarchy*



Puzzle Pieces

- WHOIS lookup – to verify the holder of a resource(s)

```
~ whois -h whois.apnic.net 202.144.128.0
% [whois.apnic.net]
% Whois data copyright terms    http://www.apnic.net/db/dbcopyright.html

% Information related to '202.144.128.0 - 202.144.129.255'

% Abuse contact for '202.144.128.0 - 202.144.129.255' is 'systems@bt.bt'

inetnum:        202.144.128.0 - 202.144.129.255
netname:        DRUKNET
descr:          DrukNet System
descr:          DrukNet
descr:          Bhutan Telecom
descr:          Thimphu
country:        BT
admin-c:        JT106-AP
tech-c:         JT106-AP
abuse-c:        AB1276-AP
status:         ASSIGNED NON-PORTABLE
mnt-by:         MAINT-BT-DRUKNET
mnt-irt:        IRT-BTTELECOM-BT
last-modified:  2021-01-14T06:15:57Z
source:         APNIC
```

```
% Information related to 'AS18024'

% Abuse contact for 'AS18024' is 'systems@bt.bt'

aut-num:        AS18024
as-name:        BTTELECOM-AS-AP
descr:          Bhutan Telecom Ltd
country:        BT
org:            ORG-BTL2-AP
admin-c:        DNO1-AP
tech-c:         DNO1-AP
abuse-c:        AB1276-AP
mnt-lower:      MAINT-BT-DRUKNET
mnt-routes:     MAINT-BT-DRUKNET
mnt-by:         APNIC-HM
mnt-irt:        IRT-BTTELECOM-BT
last-modified:  2021-01-14T06:16:00Z
source:         APNIC
```

```
% Information related to '202.144.128.0/20AS18024'

route:          202.144.128.0/20
descr:          DRUKNET-BLOCK-A1
country:        BT
notify:         ioc@bt.bt
mnt-by:         MAINT-BT-DRUKNET
origin:         AS18024
last-modified:  2018-09-18T09:37:40Z
source:         APNIC
```

Puzzle Pieces

- IRR (Internet Routing Registry) lookup
  - Publish my routing intent (route origination) and in some cases, inter-AS routing policies

```
~ whois -h whois.radb.net 202.144.128.0
route:      202.144.128.0/23
descr:      DRUKNET-VSNL Route Object
origin:     AS17660
mnt-by:     MAINT-VSNL-IN
changed:    ip.admin@vsnl.co.in 20070102
source:     RADB

route:          202.144.128.0/20
descr:          DRUKNET-BLOCK-A1
country:        BT
notify:         ioc@bt.bt
mnt-by:         MAINT-BT-DRUKNET
origin:         AS18024
last-modified:  2018-09-18T09:37:40Z
source:         APNIC
```

```
~ whois -h whois.radb.net AS17660
aut-num:        AS17660
as-name:        BT-Bhutan
descr:          Divinetworks for BT
admin-c:        DUMY-RIPE
tech-c:         DUMY-RIPE
status:         OTHER
mnt-by:         YP67641-MNT
mnt-by:         ES6436-RIPE
created:        2012-11-29T10:31:33Z
last-modified:  2018-09-04T15:26:24Z
source:         RIPE-NONAUTH
remarks:        ****************************
remarks:        * THIS OBJECT IS MODIFIED
remarks:        * Please note that all data that is generally regarded as personal
remarks:        * data has been removed from this object.
remarks:        * To view the original object, please query the RIPE Database at:
remarks:        * http://www.ripe.net/whois
remarks:        ****************************

aut-num:        AS17660
as-name:        DRUKNET-AS
descr:          DrukNet ISP
descr:          Bhutan Telecom
descr:          Thimphu
country:        BT
import:         from AS6461 action pref=100; accept ANY
export:         to AS6461 announce AS-DRUKNET-TRANSIT
import:         from AS2914 action pref=150; accept ANY
export:         to AS2914 announce AS-DRUKNET-TRANSIT
import:         from AS6453 action pref=100; accept ANY
export:         to AS6453 announce AS-DRUKNET-TRANSIT
import:         from AS42 action pref=250; accept AS42
```

Puzzle Pieces

- IRR (Internet Routing Registry) entries
  - Helps craft route filters (prefix/as-path) with RPSL tools (*rtconfig/bgpq3-4*)

```
~ bgpq4 -bl PEERv4-IN AS17660
PEERv4-IN = [
    45.64.248.0/22,
    103.245.240.0/22,
    103.245.242.0/23,
    119.2.96.0/19,
    202.144.128.0/19,
    202.144.128.0/20,
    202.144.128.0/23,
    202.144.144.0/20,
    202.144.148.0/22
];
~ bgpq4 -S APNIC -bl PEERv4-IN AS17660
PEERv4-IN = [
    45.64.248.0/22,
    103.245.240.0/22,
    103.245.242.0/23,
    119.2.96.0/19,
    202.144.128.0/19
];
```

```
~ bgpq4 -6bl PEERv6-IN AS17660
PEERv6-IN = [
    2405:d000::/32,
    2405:d000:7000::/36
];
~ bgpq4 -S APNIC -6bl PEERv6-IN AS17660
PEERv6-IN = [
    2405:d000::/32,
    2405:d000:7000::/36
];
```

```
~ bgpq4 -l BTv4-IN AS-DRUKNET-TRANSIT
no ip prefix-list BTv4-IN
ip prefix-list BTv4-IN permit 27.123.224.0/19
ip prefix-list BTv4-IN permit 27.123.224.0/22
ip prefix-list BTv4-IN permit 27.124.64.0/20
ip prefix-list BTv4-IN permit 27.124.64.0/22
ip prefix-list BTv4-IN permit 27.124.68.0/22
ip prefix-list BTv4-IN permit 27.124.72.0/22
ip prefix-list BTv4-IN permit 27.124.76.0/22
ip prefix-list BTv4-IN permit 43.230.208.0/24
ip prefix-list BTv4-IN permit 45.64.248.0/22
ip prefix-list BTv4-IN permit 45.64.248.0/23
ip prefix-list BTv4-IN permit 45.64.250.0/24
ip prefix-list BTv4-IN permit 45.64.251.0/24
ip prefix-list BTv4-IN permit 103.7.252.0/22
ip prefix-list BTv4-IN permit 103.10.236.0/22
```

```
~ bgpq4 -6l BTv6-IN AS-DRUKNET-TRANSIT
no ipv6 prefix-list BTv6-IN
ipv6 prefix-list BTv6-IN permit 2001:df3:e180::/48
ipv6 prefix-list BTv6-IN permit 2001:df5:a300::/48
ipv6 prefix-list BTv6-IN permit 2400:1440::/32
ipv6 prefix-list BTv6-IN permit 2400:4e60::/32
ipv6 prefix-list BTv6-IN permit 2400:4e60::/33
ipv6 prefix-list BTv6-IN permit 2400:4e60:8000::/33
ipv6 prefix-list BTv6-IN permit 2403:580::/32
ipv6 prefix-list BTv6-IN permit 2403:580::/33
ipv6 prefix-list BTv6-IN permit 2403:580:8000::/33
ipv6 prefix-list BTv6-IN permit 2403:8700::/32
ipv6 prefix-list BTv6-IN permit 2404:5540::/32
ipv6 prefix-list BTv6-IN permit 2404:5540::/33
ipv6 prefix-list BTv6-IN permit 2404:5540::/34
```

```
~ bgpq3 -3f 17660 -l BT-IN AS-DRUKNET-TRANSIT
no ip as-path access-list BT-IN
ip as-path access-list BT-IN permit ^17660(_17660)*$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(18024|18025|59219|132232)$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(134715|135666|137925|137994)$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(140695)$
~ bgpq4 -f 17660 -l BT-IN AS-DRUKNET-TRANSIT
no ip as-path access-list BT-IN
ip as-path access-list BT-IN permit ^17660(_17660)*$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(18024|18025|59219|132232)$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(134715|135666|137925|137994)$
ip as-path access-list BT-IN permit ^17660(_[0-9]+)*_(140695)$
```

Puzzle Pieces

- Issues with IRR
  - No single authority model
    - Is an entry genuine/correct?
  - Too many RRs
    - If two RRs contain conflicting data - which one to use/trust?
  - Incomplete data
    - If a route is not in a RR ~ invalid or is the RR just missing data?

- Issues with IRR Filters
  - Your filters ONLY as good as the correctness of the IRR entries!
    - GOOD idea to rely on authoritative sources:
      - `-S` in `bgpq3/4`, or `-s` in `rtconfig`

Aside – IRR improvements

- prop-151 (Aftab): restricting non-hierarchical as-set
  - Helps fix *name collision* issues
  - as-set can ONLY be created by the maintainer of the ASN in the object

```
as-set:      AS-AMAZON
descr:       Amazon ASNs
members:     AS-AMAZON-NA, AS-AMAZON-AP, AS-AMAZON-EU, AS16509:AS-AMAZON
admin-c:     AC6-ORG-ARIN
tech-c:      AC6-ORG-ARIN
notify:      noc@amazon.com
mnt-by:      MAINT-AS16509
changed:     noc@amazon.com 20230420  #17:54:10Z
source:      RADB

as-set:          AS-AMAZON
tech-c:          DUMY-RIPE
admin-c:         DUMY-RIPE
mnt-by:          KATERINA-MNT
created:         2022-10-23T19:05:59Z
last-modified:   2022-10-23T19:05:59Z
source:          RIPE
```

- Hierarchical as-set (RFC2622)
  - AS-DRUKNET-TRANSIT
    - non-hierarchical as-set
  - AS4826:AS-VOCUS
    - hierarchical as-set
    - <AS#>:AS-<as_set_name>

```
as-set:          AS4826:AS-VOCUS
descr:           Vocus Communications AS4826 AS-SET
members:         AS4826,AS4826:AS-CUSTOMERS
admin-c:         VPL1-AP
tech-c:          VPL1-AP
remarks:         For queries please email the below contacts
remarks:         NOC - ********
remarks:         IRR Data - ********
remarks:         Peering enquiries - ********
mnt-by:          MAINT-AU-VOCUS
last-modified:   2022-05-29T00:28:23Z
source:          APNIC
```

Aside – IRR improvements

- **RADB & RPKI**
  - RADB migrated to IRRDv4 on 13th November 2023
  - New RPKI based features implemented
    - **route/route6** objects that is inconsistent with a corresponding ROA will be rejected
    - RPKI Invalid objects will no longer be visible in a query
    - *Not Found* or *Valid* will not be affected

Prefix: 1.1.1.0/24
ASN: 13335

Route: 1.1.1.0/24
Origin: AS13335
Source: RADB

Route: 1.1.1.0/25
Origin: AS13335
Source: RADB

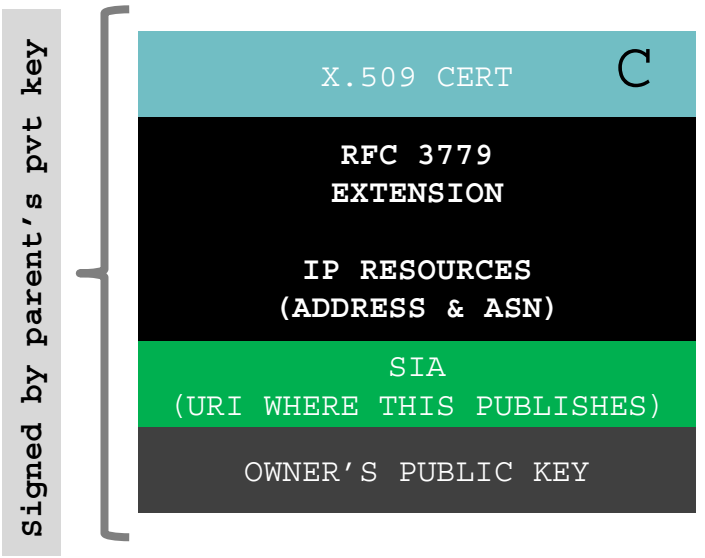
Route: 1.1.1.0/25
Origin: AS12345
Source: RADB

Puzzle Pieces

- Route Origin Authorization (ROA)
  - Binding of prefixes & nominated ASN
  - Can be verified crypto-magically
  - Multiple ROAs can exist for the same prefix

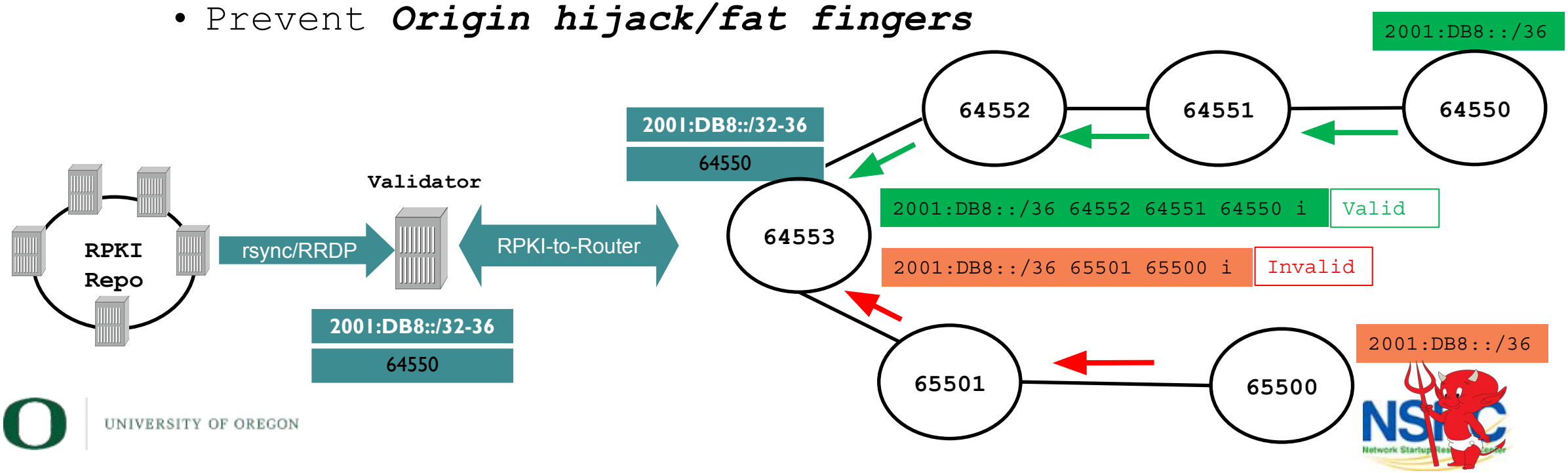
Prefix	202.144.128.0/20
Max-length	/20
Origin ASN	AS18024

```
route:          202.144.128.0/20
descr:          RPKI ROA for 202.144.128.0/20 / AS18024
remarks:        This AS18024 route object represents routing data retrieved
                from the RPKI. This route object is the result of an automated
                RPKI-to-IRR conversion process performed by IRRd.
max-length:     20
origin:         AS18024
source:         RPKI  # Trust Anchor: apnic
```



Puzzle Pieces

- Route Origin Validation (ROV)
  - Validating received routes against validated ROAs
  - What can it help with?
    - Validate if an ASN is permitted to originate a route
    - Prevent ***Origin hijack/fat fingers***



Puzzle Pieces

- ROA BCPs
  - Use max-length judiciously
    - Only cover those prefixes announced in BGP ~ minimal ROA RFC9319
  - Multi-ASN network?
    - Aggregates/sub-aggs: Transit ASN
    - More specifics: Access ASN
  - ROA with **AS0** origin (RFC7607)
    - Not to be confused with undelegated/unassigned AS0 ROA

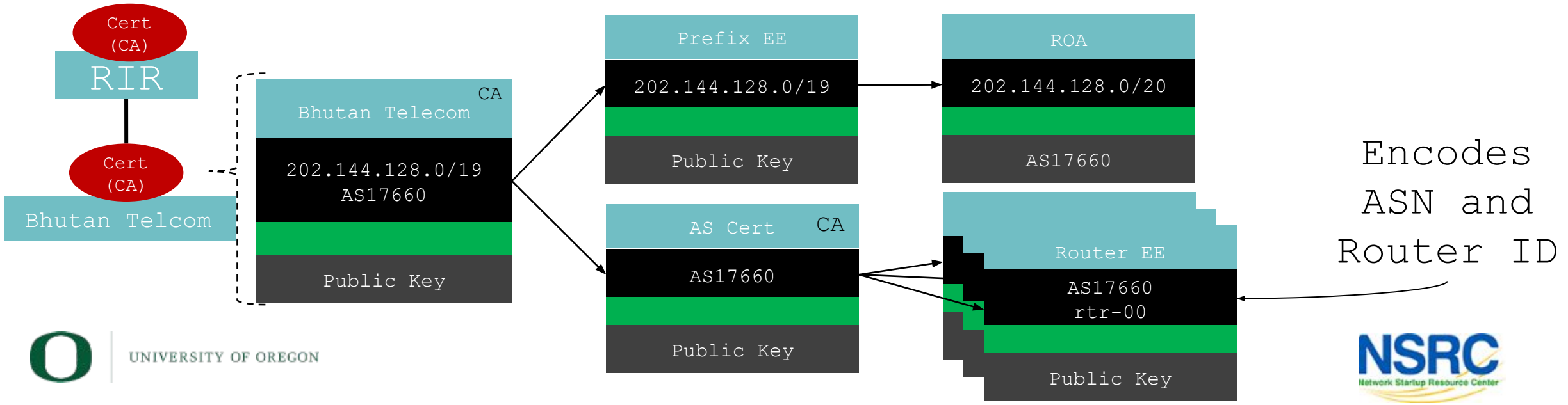
https://blog.apnic.net/2020/04/10/rise-of-the-invalids/

- ROV BCPs
  - Default routes?
  - Secure the RTR session
    - SSH/MD5/TLS/TCP-AO/TLS
  - iBGP propagation – RFC8097
  - Know your platform:
    - RTR refresh timer ☐ route refresh (Adj_RIB_In or soft reconfig in)

https://blog.apnic.net/2022/04/04/rpki-2021-retrospective/

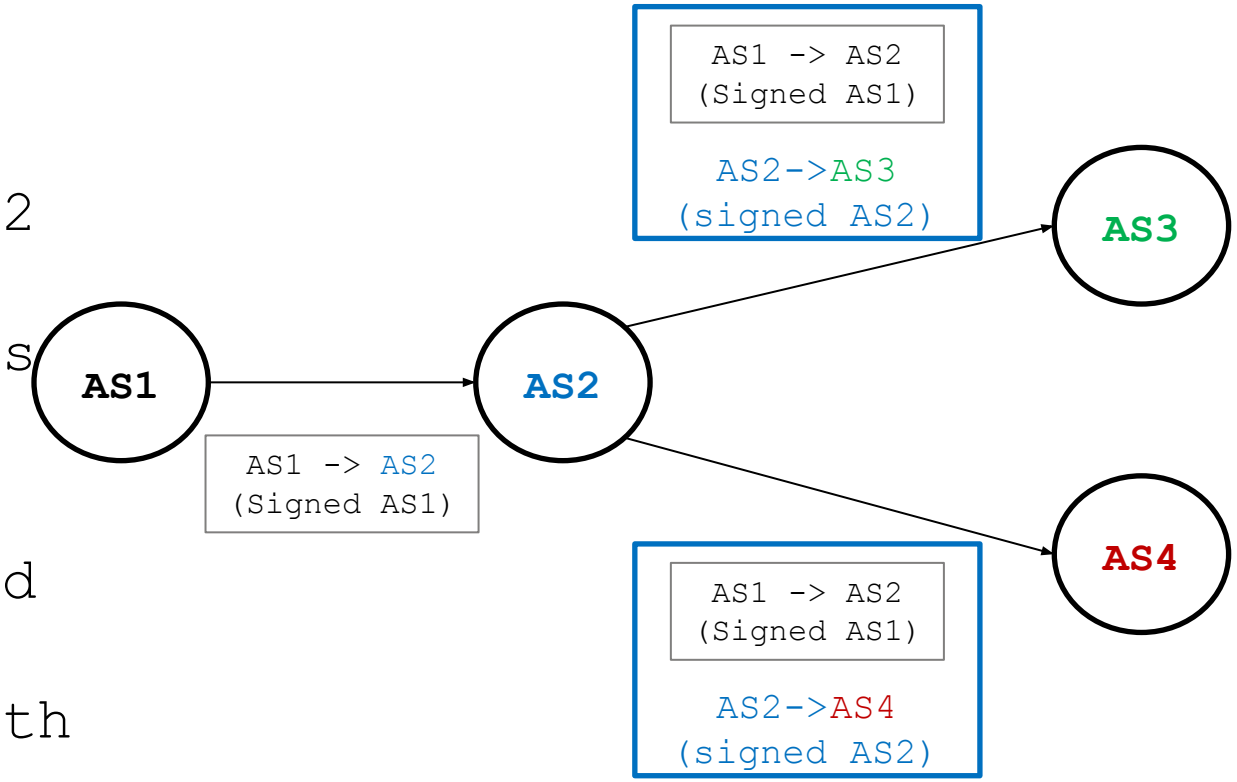
Puzzle Pieces

- Are ROAs and ROV enough?
  - Forged origin ASN: will PASS the ROV test & will be accepted as GOOD
- Ideas?
  - Secure the PATH ~ AS path validation (per prefix) ☐ BGPsec



Puzzle Pieces

- BGPsec (RFC8205)
  - Forward Path Signing
    - AS1 signs the message to AS2
    - AS2 signs the message to AS3/AS4, encapsulating AS1's message
  - Validation
    - ROA check for the prefix and origin AS
    - validate the received AS path against the chain of signatures (for each AS in the AS path) with AS key



Puzzle Pieces

- BGPsec (RFC8205) Challenges
  - Cannot jump across non-BGPsec routers/networks
    - traditional BGP (no BGPsec UPDATE messages)
  - Complex crypto & key distribution mechanism
    - CPU intensive (*validate signatures*)
    - Memory intensive (*per prefix BGPsec UPDATE; new attributes to carry signatures and certs/key IDs for every AS in the AS path)*
  - Possible hack
    - ***Routers could generate key pair -> send cert request to RPKI for signing***
  - Lack of clarity
    - distributing the collection of certs required to validate path signature

Puzzle Pieces

- Route leak prevention
  - We already talked whitelist of customer/peer prefixes under IRR filtering
  - Don’t announce routes/prefixes learned from your peers to other peers
  - Apply max prefix limits ~ doesn’t help against partial leaks.

Puzzle Pieces

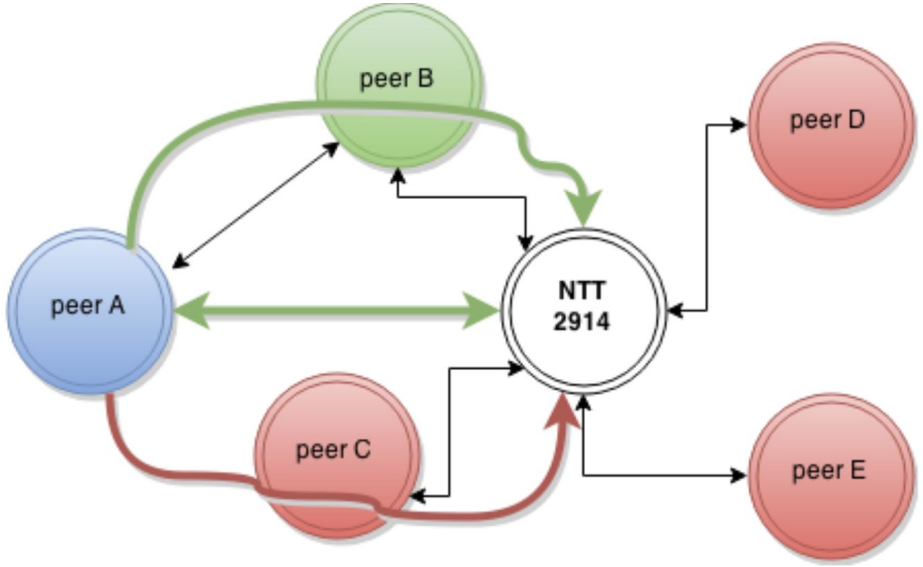
- Peerlock-lite ~ *adapted from Job's NANOG67*
  - Wikipedia says [7018, 7922, 3320, 3257, 6830, 3356, 2914, 5511, 3491, 1239, 6453, 6762, 1299, 12956, 701, 6461]
    - https://en.wikipedia.org/wiki/Tier_1_network
  - Will you sell transit to these networks?
    - REJECT any prefixes you receive from your customers which contains a big network ASN anywhere in the AS_PATH

```
ip as-path access-list 99 permit \
   _(174|701|1239|1299|2828|2914|3257|3320|3356 \
      |3549|5511|6453|6461|6762|7018|12956)_

route-map ebgp-customer-in deny 1
match as-path 99
```

Puzzle Pieces

- Peerlock~ *adapted from Job's NANOG67 talk*
  - Given ASNs A, B, C, D, and E as NTT's peers.
  - Peer A subscribes to the peerlock idea (Protected ASN) and indicates that peer B is an "Allowed Upstream"



OK: ^A_
OK: ^B_A_
NOT OK: ^C_A_
NOT OK: ^D_A_
NOT OK: ^E_A_

Puzzle Pieces

- BGP Roles
  - Update to the BGP OPEN message ~ *BGP Role Capability*
  - Must be advertised to and received from a peer
    - If advertised and but not received: SHOULD ignore and establish traditional session
    - Strict mode: if advertised and not received - REJECT
  - Roles:
    - Provider | Customer | Peer | RS | RS-client
  - Allowed relationship pairs
    - Provider <-> Customer
    - Customer <-> Provider
    - RS <-> RS-Client
    - RS-Client <-> RS
    - Peer <-> Peer

BIRD

```
protocol bgp {
        local as 65001;
        neighbor 127.20.0.1 as 65000;
        multihop;
        source address 127.20.0.2;
        strict bind on;
        ipv4 {
                import all;
                export all;
        };
        local role customer;
}
```

FRR

```
router bgp 64502
  neighbor 172.16.200.101 remote-as 64501
  neighbor 172.16.200.101 ebgp-multihop
  neighbor 172.16.200.101 passive
  neighbor 172.16.200.101 local-role customer
```

https://blog.qrator.net/en/route-leak-prevention-and-detection-rfc9234_162/

Puzzle Pieces

- BGP Roles
  - Only to Customer (OTC) attribute
    - Optional non-transitive attribute
  - Ingress procedure:
    - If a route with the OTC Attribute is received from a Customer or an RS-Client, then it is a route leak and MUST be considered ineligible.
  - Egress procedure:
    - If a route contains the OTC Attribute, it MUST NOT be propagated to Providers, Peers, or RSes

Solution	Status	Version
BIRD	+	Appeared in 2.0.11
FRR	+	Appeared in 8.4
OpenBGPD	+	7.5
Mikrotik	Reduced functionality	Appeared before RFC

https://blog.qrator.net/en/route-leak-prevention-and-detection-rfc9234_162/

Puzzle Pieces

- ASPA (AS Provider Authorization)
  - Looks at malformed AS_PATHs from customers and peers to detect malicious hijacks and route leaks

  – ASPA is a digitally signed object that binds
    - Set of Provider ASNs (SPAS) to a Customer ASN (CAS) for a specific AFI – *signed by the holder of the Customer ASN*

  – For Routing, the ASPA is an attestation
    - that the AS holder (CAS) has authorized the SPAS to propagate its announcements onwards (upstreams/peers)

Puzzle Pieces

- ASPA (AS Provider Authorization) object

```
ASPA := {
    customer_asn (signer)
    providers (authorized to propagate to peers/upstreams)
    AFI (IPv4/IPv6)
}
```

Puzzle Pieces

- Pair Verification (AS1, AS2)
  - *Retrieve cryptographically valid ASPA in a selected AFI with a customer value of AS1.*
  - *If there is no valid ASPA record for AS1 the procedure exits with an outcome of* ***unknown***
  - *If AS2 is included in the SPAS, then the procedure exits with an outcome of* ***valid***
  - *Otherwise, the procedure exits with an outcome of* ***invalid***

Puzzle Pieces

- ASPA in ACTION - 26 January’23

Hi all,

Since a few days OpenBGPD is able to do ASPA verification and filtering based on the outcome. Right now my system detected one ASPA invalid path that is an actuall route leak. So it seems ASPA is working :)

```
--- begin terminal transcript ---
$ bgpctl show rib in avs invalid as 945
flags: * = Valid, > = Selected, I = via IBGP, A = Announced,
       S = Stale, E = Error
origin validation state: N = not-found, V = valid, ! = invalid
aspa validation state: ? = unknown, V = valid, ! = invalid
origin: i = IGP, e = EGP, ? = Incomplete

flags  vs destination          gateway         lpref   med aspath origin
      V-! 2606:b0c0:b00b::/48  2001:4bf8::253    100     0 8271 6939 61138 945 i
--- end terminal transcript ---
```

```
Subject info access:      rsync://rpki.august.tw/repo/AS945/0/AS945.asa
ASPA valid until:         Sun 17 Dec 2023 14:17:12 +0000
Customer AS:              945
Provider Set:
    1: AS: 1299
    2: AS: 6939
    3: AS: 32097
    4: AS: 50058
```

```
01/26/23 01:54:24 A 2606:b0c0:b00b::/48 13830 3356 6939 61138 945
01/26/23 01:54:24 A 2606:b0c0:b00b::/48 13830 50058 50058 50058 50058 945
01/26/23 01:54:24 A 2606:b0c0:b00b::/48 14907 6939 61138 945
01/26/23 01:54:24 A 2606:b0c0:b00b::/48 14907 50058 50058 50058 50058 945
01/26/23 01:54:24 A 2606:b0c0:b00b::/48 206499 6939 61138 945
```

https://www.manrs.org/2023/02/unpacking-the-first-route-leak-prevented-by-aspa/

Puzzle Pieces

- ASPA ~ Timeline [BGP, RP, RTR, Signer]

2023	• OpenBSD rpki-client and OpenBGPD • Routinator, Krill and RTRTR, StayRTR, rpki-prover, and RIPE NCC have either released ASPA-capable software or are in advanced stages to do so. • APNIC signer demo - https://github.com/APNIC-net/rpki-aspa-demo
2024	• 6-10 months for IETF to ratify ASPA • SIDROPS in later stages of specifying the ASPA standard • Tom Harrison (APNIC RPKI Lead): will start hosted in 2024
2025	• RIRs make Signers available
2026	• COTS BGP Speakers implementations

https://www.manrs.org/2023/05/estimating-the-timeline-for-aspa-deployment/

Need Help?

- Want to learn more about:
  - crafting route filters,
  - securing Internet routing best practices/tools
    - RPKI
    - ROV
    - MANRS
- Refer to NSRC's free training videos at:
  - https://learn.nsrc.org/bgp

Troubleshooting Tools

- How/where do engineers, researchers, and analysts find the data about the incidents discussed so far?
  - Many network operators (ISPs) run their own looking glass.
  - Many of us rely on globally distributed collectors like:
    - RouteViews (the original looking glass since 1995), and
    - RIPE's RIS (routing information service)

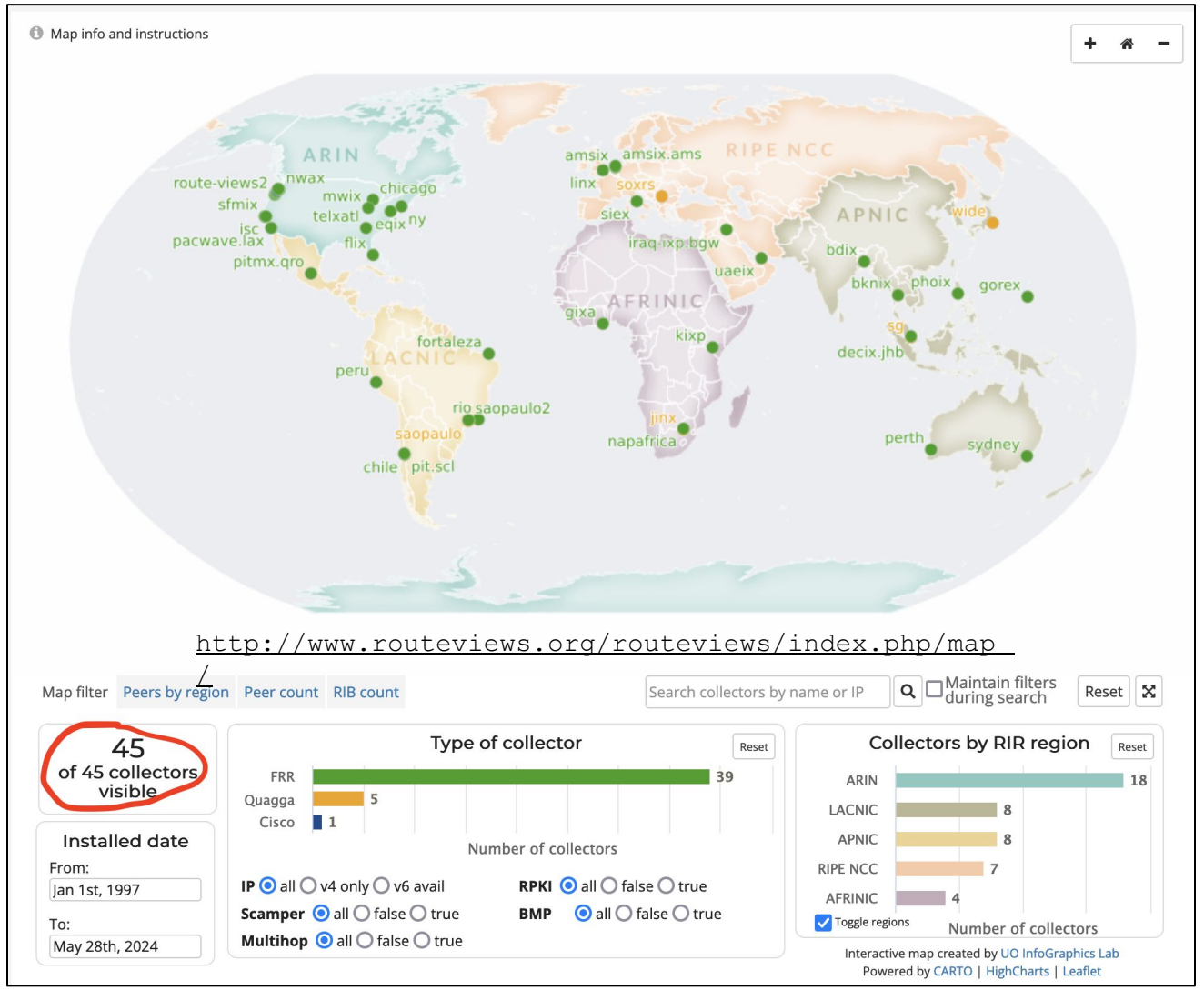
RouteViews

- A collaborative router looking glass to share BGP views among network operators and researchers.
  - RouteViews was founded at the University of Oregon's Advanced Network Technology Center (ANTC) in 1995. Data archives (*every 2 hours*) began in 1997 and amount to 50TBs (compressed) today.
  - The group is currently led by the Network Startup Resource Center (NSRC) group engineering team at the University of Oregon.

Why RouteViews?

- Originally conceived in 1995 as a tool for Internet Operators to look at the BGP table from different locations/backbones around the world to troubleshoot and assess:
  - *reachability, hijacks, peer visibility, mass withdrawals, and RPKI status*
- The 27-year data-set of BGP information archived by RouteViews since 1997 has become an invaluable research resource
  - RouteViews data has been used in over 1000 research papers.
  - http://www.routeviews.org/routeviews/index.php/papers/

RouteViews Collector Map



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NSRC
Network Startup Resource Center

Peering with RouteViews

- Send full table (if you can)
- Remove default routes
- Remove NULL routes
- Remove RFC1981 addresses
- RouteViews don’t accept/want ADD-PATH (TX/RX)
- RouteViews don’t send routes to you (ONLY collects)
- When peering with multi-hop collectors, set ebgp-multihop

https://www.routeviews.org/routeviews/index.php/peering-request-form/

khàawp Khun Kráp

ขอบคุณ ครับ