IP routing research issues

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Didn't Dijkstra, Bellman & Ford solve all that?

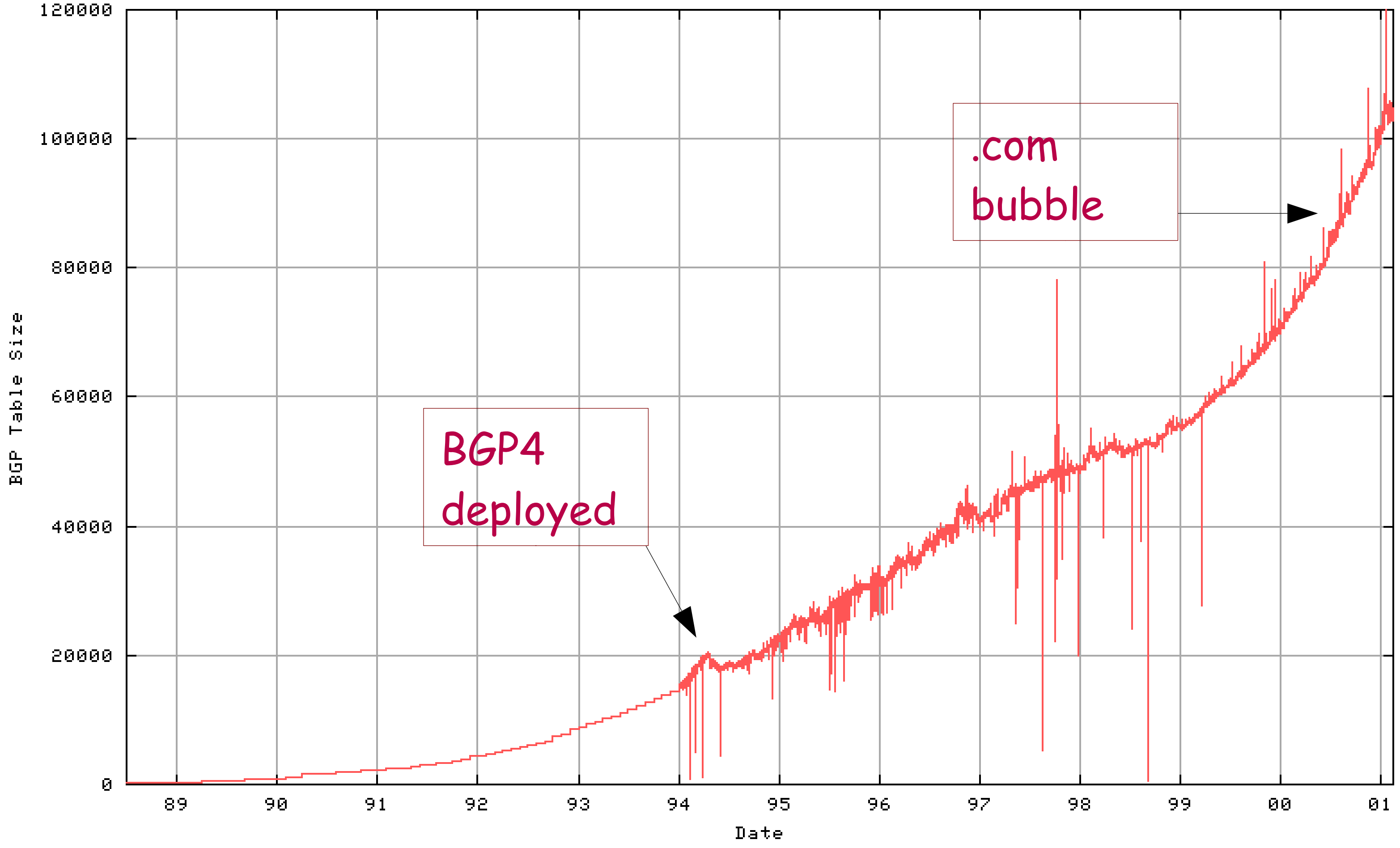
- Forget Dijkstra, the interesting part is wide area routing using BGP4, which is kind-of distance vector.
  - In any case, the actual route computation is the easy part.
- Graph theory doesn't really scale well when implemented as a distributed real-time algorithm
  - Especially when the graph keeps changing spontaneously
  - And some of the vertices misbehave
  - And economics is part of the problem

The players

- The core (inter-continental) ISPs, offering transit at a price to...
  - The peripheral (local) ISPs
  - Major customers with their own BGP4 speakers
- Internet Exchange Points
- Core router vendors
- Address registries and other operational bodies
- IETF
- Academic researchers

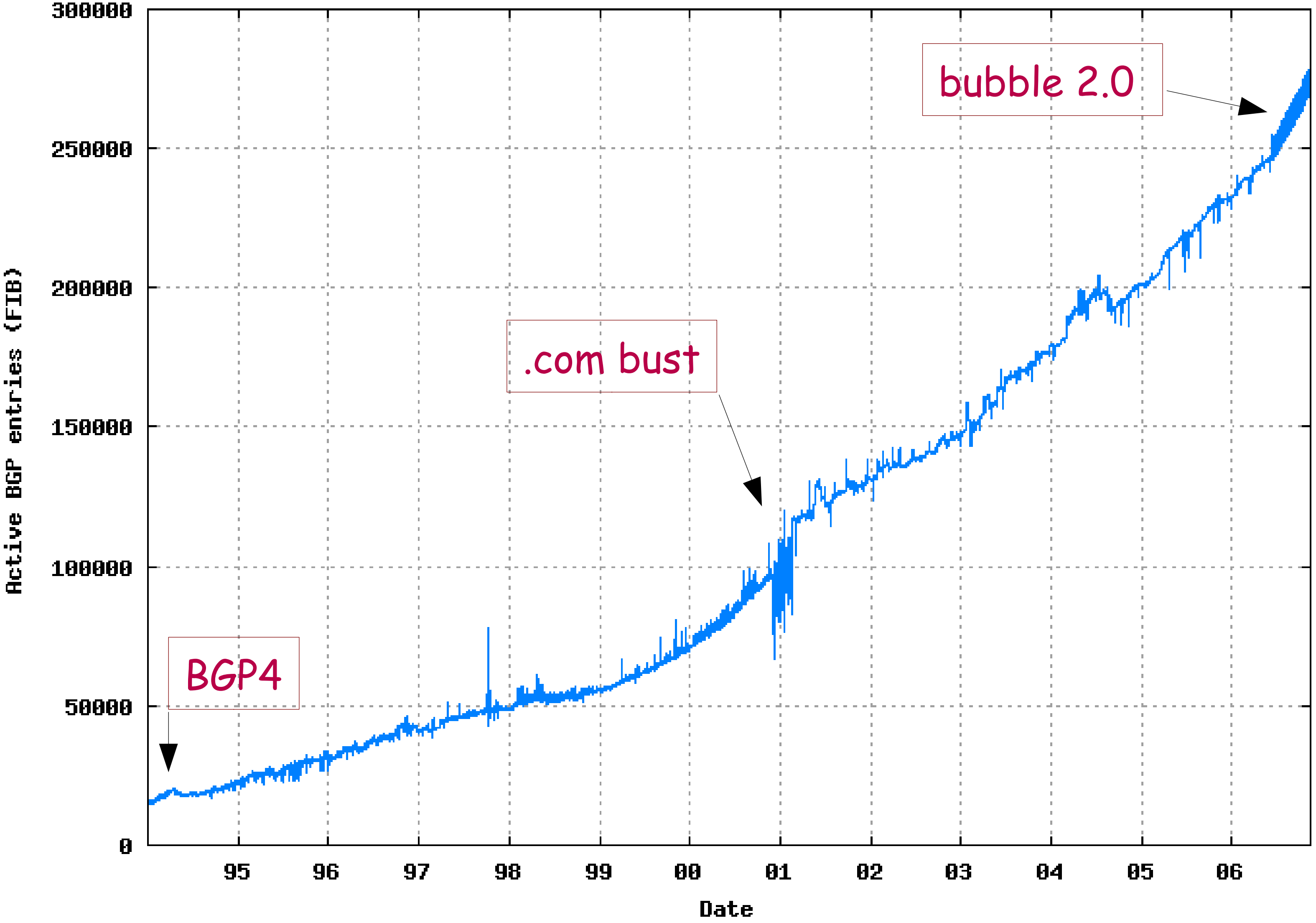
➔ **Conflicting technical and economic interests**

Ancient history



Things looked very worrying by early 1994, and very worrying again by late 2001.

Recent history



What's really going on?

- At times of rapid growth in the network (1994, 2000, 2006) we see accelerating growth in the BGP4 routing table.
- Most likely cause is growth in multihoming of larger customers
  - with present technology, every multihomed customer adds one prefix to the BGP4 table
    - (i.e. has its own route instead of being buried inside a single ISP's address space, RFC 4116)
  - the more the Internet succeeds, the more this becomes a problem

Why does it matter?

- Since 1990, core router memory size and forwarding speed have managed to keep up with the growth
  - In fact, core ISPs are carrying about a million routes internally (public BGP routes plus three times more customer VPN routes)
  - However, this costs money; routers that can handle a million routes and forward at many Gbit/s are not cheap
  - Maybe one day we will hit a hardware limit
- Route advertisements from ten or a hundred million autonomous systems are not a welcome prospect
  - Customer sites and customer "last kilometres" are much more subject to outages than ISPs
  - Thus, if each (multihomed) customer has its own route, there is concern that BGP4 UPDATE messages, and the consequent route re-computations, will maybe become overwhelming

Did you say "maybe"?

- Yes. Twice. There may be a hardware limit somewhere in the future. There may be a dynamic limit to BGP4 updates somewhere in the future.
- I'm not aware of any convincing science behind those two *maybes*.
  - The hardware vendors are unlikely to reveal their technical projections to competitors
  - I haven't seen any convincing models of massive scale BGP4 dynamics (there are observational studies)

Why didn't anybody tell me?

- They did. For example, RFC 1380 (November 1992) discussed "the routing table explosion"
  - The short term fix was classless addressing and BGP4
  - We're still looking for the long term fix
- The IETF NIMROD effort worked on a potential solution (1994-1998)
- The IAB routing workshops in 1998 and 2006 (RFC 2902 and RFC 4984) and the IAB network layer workshop in 1999 (RFC 2956) all considered these issues.
- Current efforts are focussed in the IRTF Routing Research Group (RRG)

Why didn't the Internet explode?

- If the increasing growth rates that we saw in 1994 and 2000 had continued indefinitely, no doubt there would have been a meltdown.
  - BGP4/CIDR saved us once
  - The .com bust saved us once
  - Sad to say, NAT has saved us many times
  - We need to understand the renumbering bogeyman and the PI heresy

The renumbering bogeyman

This ship has sailed for IPv4, but we should really try to do better for IPv6.

- There is unimaginable resistance to IP address renumbering among site IT operations people.
- They, and many application developers, have broken Rule 1:

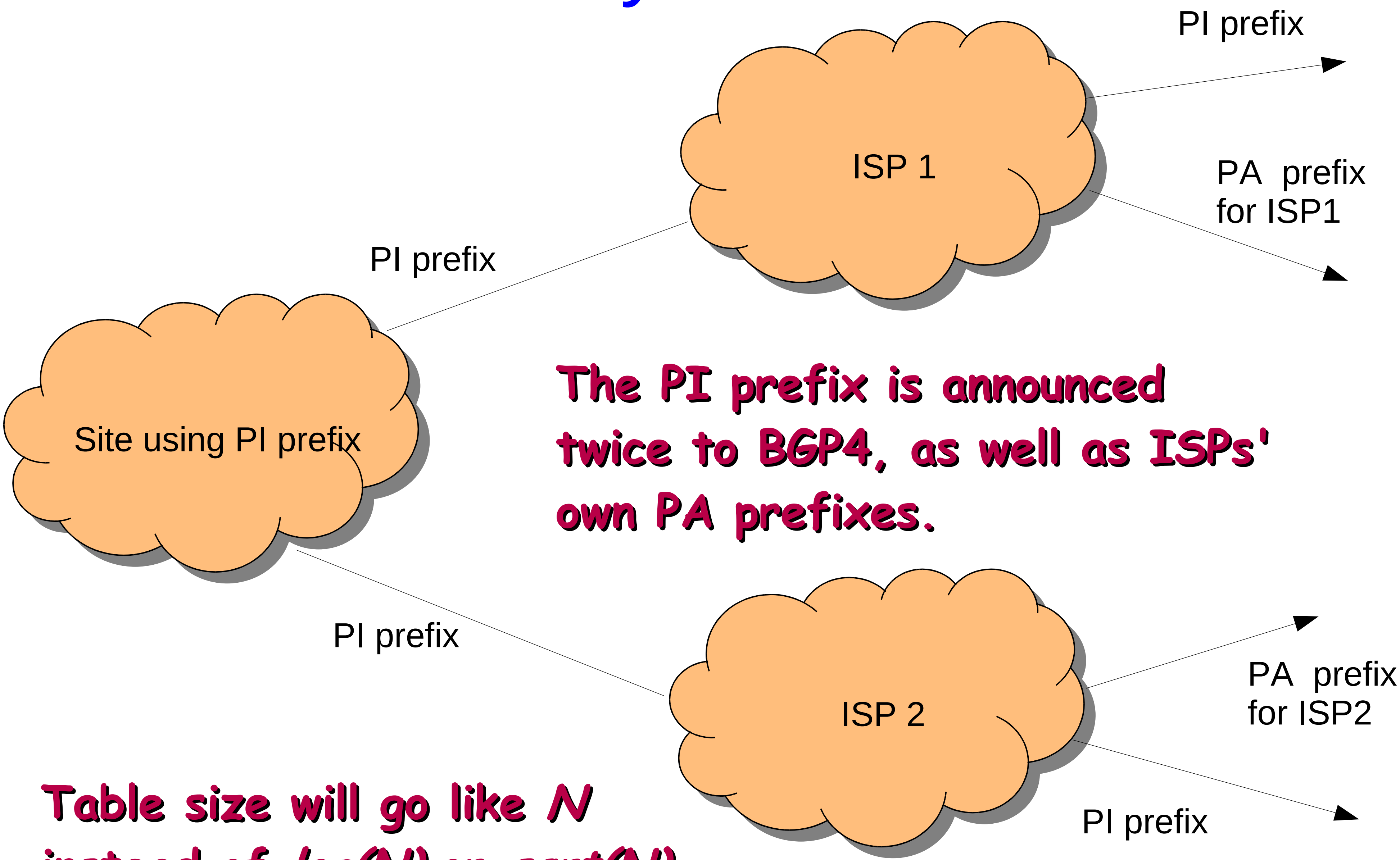
  NEVER embed an IP address in software or store it in a file; ALWAYS use DNS names.

- There are many aspects of network management that are address-dependent.
- The consequence is a great attachment to having "my own address space."

The PI heresy

- BGP4/CIDR contained growth in 1994 because of the move to ISP-based addresses (*provider aggregation* or PA addressing).
- Sadly, the address registries were persuaded to assign *provider independent* (PI) address prefixes to individual user sites, in direct contradiction to address aggregation.
  - The site avoids the renumbering bogeyman
  - If it multihomes, the PI prefix will lead to its own BGP4 table entry (and UPDATES whenever connectivity flips between ISPs)

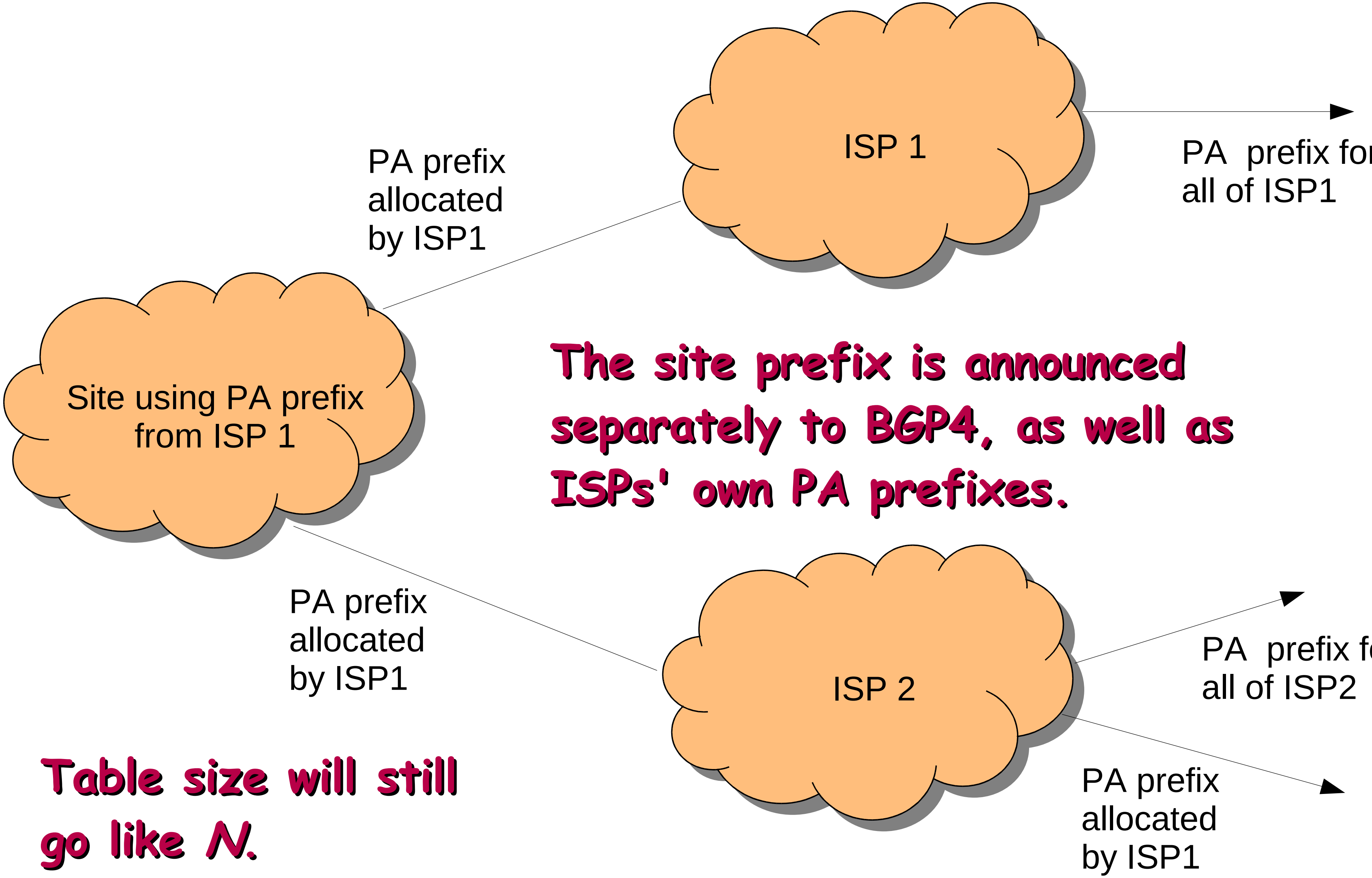
Why PI hurts



The PI prefix is announced twice to BGP4, as well as ISPs' own PA prefixes.

Table size will go like *N* instead of *log(N)* or *sqrt(N)*.

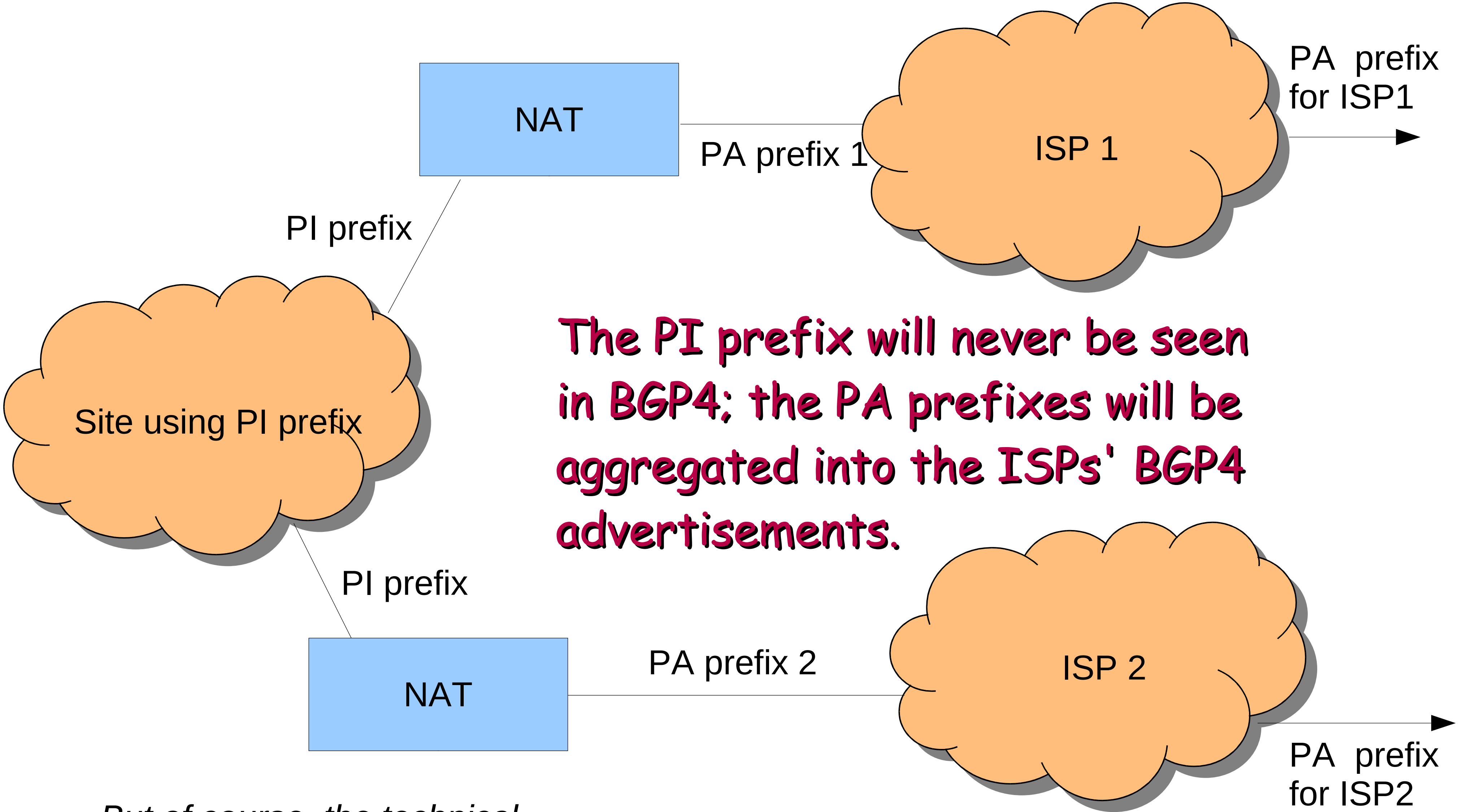
Even PA multihoming hurts



The site prefix is announced separately to BGP4, as well as ISPs' own PA prefixes.

Table size will still go like *N*.

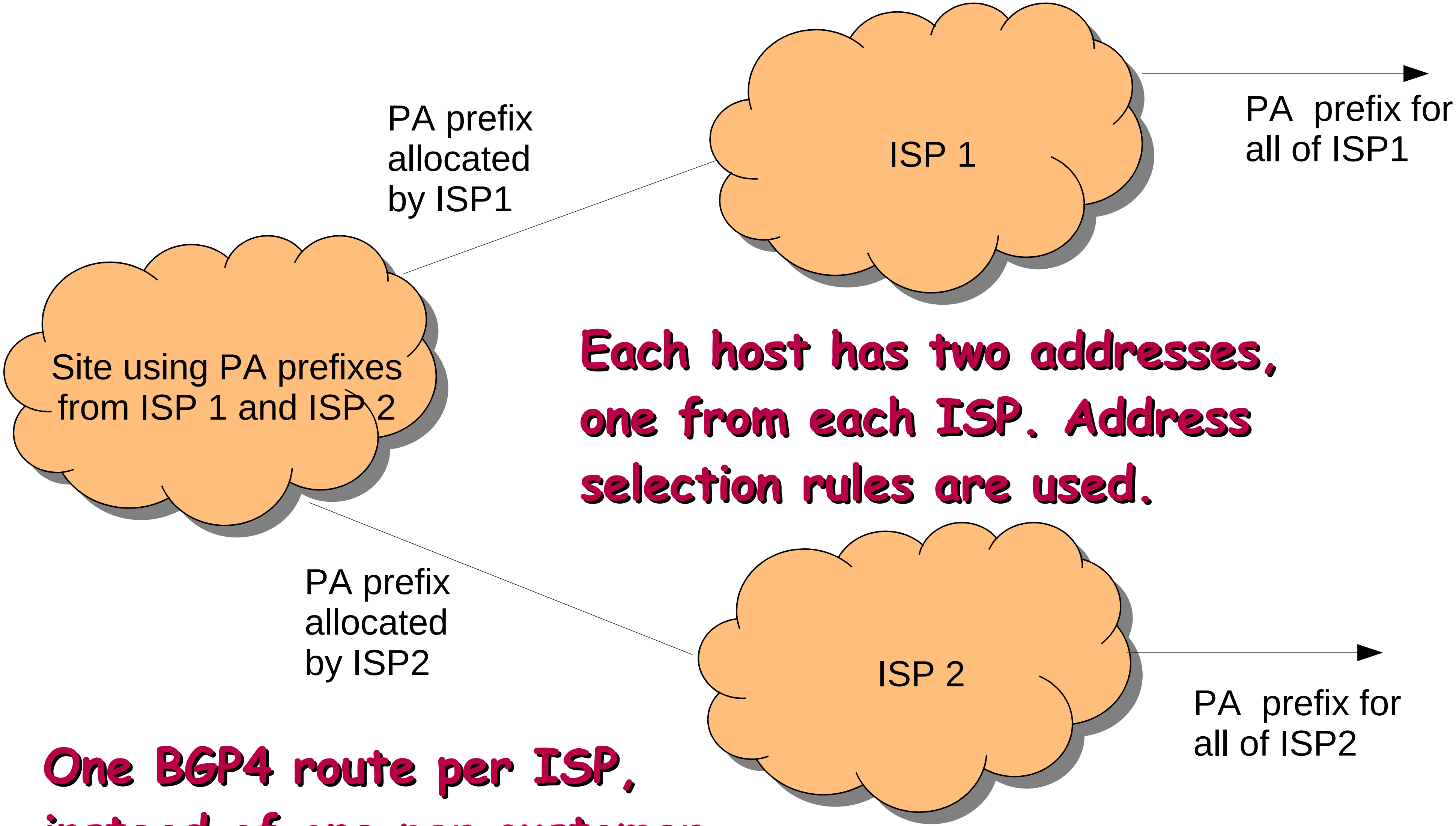
Saved by the NAT?



The PI prefix will never be seen in BGP4; the PA prefixes will be aggregated into the ISPs' BGP4 advertisements.

But of course, the technical community really wants to get rid of NAT.

Plan A (for IPv6): Multiple PA prefixes per site



Each host has two addresses, one from each ISP. Address selection rules are used.

One BGP4 route per ISP, instead of one per customer.

Him again

- There are no obvious technical defects in Plan A, but it's meeting operational resistance.
- It assumes that large user sites
  - have systematic address management and DNS generation
  - are willing to add and remove IPv6 prefixes (i.e., stepwise renumbering) when they switch ISPs
  - are prepared to update procedures for address management
- It also disturbs traffic management and business models for ISPs
- It doesn't help IPv4 at all
- Hence, the search is on for Plan B

Routing (and addressing) issues (1)

[draft-narten-radir-problem-statement]

- Alignment of Incentives
- Pressures on Routing Table Size
  - Traffic Engineering
  - Multihoming
  - End Site Renumbering
  - Acquisitions and Mergers
  - Address Allocation Policies
  - Dual Stack Pressure on the Routing Table
  - Internal Customer Routes
  - IPv4 Address Exhaustion

Routing (and addressing) issues (2)

- Additional Pressures on Control Plane Load
  - Interconnection Richness
- Questionable Operational Practices
  - Rapid shuffling of prefixes
  - Long prefixes to reduce Route Hijacking
  - Ignorance of effects on aggregation

Solution criteria (1)

[draft-narten-radir-problem-statement]

- Provide sufficient benefits to the party bearing the costs of deploying and maintaining the technology to recover the cost for doing so.
- Reduce the growth rate of the DFZ control plane load. In the current architecture, this is dominated by the routing, which is dependent on:
  - The number of individual prefixes in the DFZ
  - The update rate associated with those prefixes.
- Any change to the control plane architecture must result in a reduction in the overall control plane load, and shouldn't simply shift the load from one place in the system to another, without reducing the overall load as a whole.

Solution criteria (2)

- Allow any end site wishing to multihome to do so
- Support ISP and enterprise Traffic Engineering needs
- Allow end sites to switch providers while minimizing configuration changes to internal end site devices.
- Provide end-to-end convergence/restoration of service at least comparable to that provided by the current architecture
- *It goes without saying:* be deployable on the running Internet with adequate performance and scaling, at acceptable cost.

Focus on Multihoming

- This is the key issue; if we can't solve this, nothing else can be solved*
- After years of concern, we only know two approaches that avoid the PI heresy and NAT
  1. Ignore the routing system; solve the problem end to end between hosts (using multiple addresses per host).
  2. Split addressing into two layers: a locator used for routing and traffic engineering, and an identifier used between the hosts.

** Multicast and mobility issues are not discussed in this talk. It's implicit that the solution has to support traffic engineering at least as well as BGP4 today.*

Host-based multihoming: SHIM6

- Inserts shim code at the top of the IPv6 stack
  - remote host has several IPv6 addresses (one PA address per ISP)
  - one of them is used as Upper Layer ID (i.e. the address used in socket calls, TCP checksums, IPsec, etc.)
  - the shim switches dynamically between the PA addresses (i.e. the addresses used in the packet headers vary)
  - zero visibility at routing level; only host software is touched
  - host sites must operate one PA prefix per ISP
  - a bit more complicated than it sounds, due to reachability and security issues
- Takes traffic engineering partly out of the hands of ISPs
  - ISPs would like control of ingress path selection, currently implemented by BGP4 policy

Routing-based multihoming: research

- Basic idea is not new: split apart the functions of an address*
  - *identifier* is used end-to-end (e.g. TCP checksum, IPsec)
  - *locator* is used for routing site-to-site (and for traffic engineering)
- Not clear how to make this change successfully on a running Internet
  - cut the IPv6 address in two halves (64 bit locator and 64 bit identifier)? Doesn't help IPv4.
  - encapsulate normal IP packets (with identifier-addresses) in tunnels (with locator-addresses)?
  - add an explicit identifier layer?
- Ongoing work in the IRTF Routing Research Group

*can arguably be traced as far back as a paper by Louis Pouzin in 1974

Menagerie of proposals
(not all in RRG)

- LISP - Cisco-driven "map and encap" approach
  - for IPv4 (until addresses really run out) and IPv6
- AIRA
- APT
- CRIO
- BGP hierarchy
- HIP
- HRA
- ILNP
- IPvLX
- Ivip
- Six/One
- TAMARA
- TRRP
- V6DH

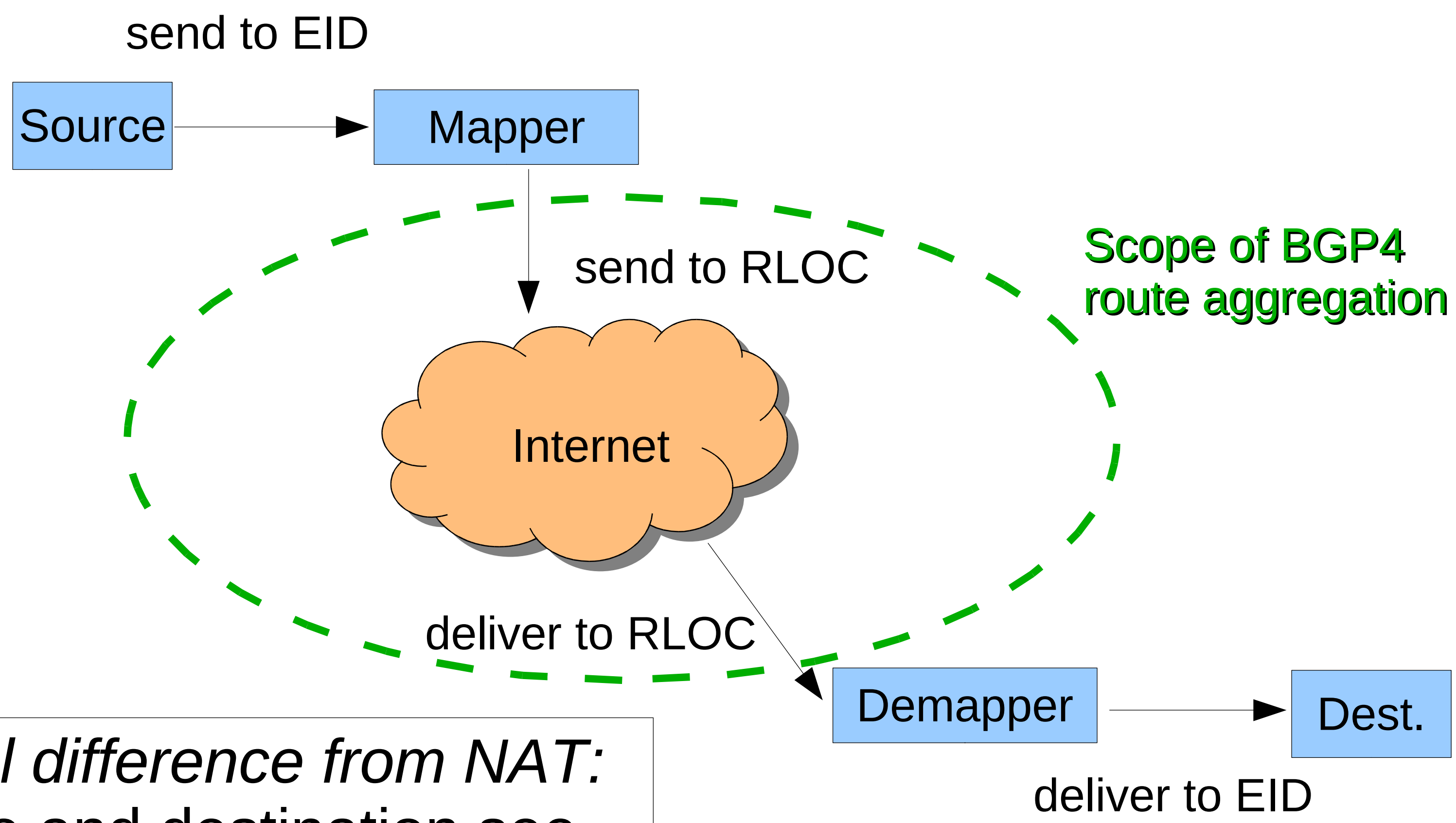
Commonality

- All have some form of distinction between *locator* and *identifier*
  - but when used locally, identifiers may become locators
- All therefore need some end-to-end mapping between locator space and identifier space
  - effectively, we've inserted either a layer of routing hierarchy or an extra layer of addressing, or both.
- Many need a globally visible mapping database of some kind
  - some ride on DNS, but that raises scale and performance concerns

Mapping

EID = End-system identifier - not assumed to aggregate in BGP4

RLOC = Routing locator - aggregates in BGP4



Critical difference from NAT:
Source and destination see exactly the same EID.

Taxonomy (1)
[draft-halpern-rrg-taxonomy]

- Possible end system identifications:
  - Name, such as DNS
  - globally unique location insensitive bit string
  - globally unique location sensitive bit string
  - purely local identifiers [not considered useful in the Internet]
- Possible maps:
  - DNS to EID
  - DNS to RLOC
  - EID to RLOC
  - RLOC to EID

Taxonomy (2)

- Possible map distribution models:
  - Push - source of an EID->RLOC mapping entry pushes it out to all mapping boxes (border routers) in the world
  - Pull - a mapping box requests an EID->RLOC mapping entry when it needs to send to a new EID
    - on demand
    - from a cached distributed database (like DNS)
  - Hybrid - selective push
- These issues have critical impact on scaleability and performance.

Taxonomy (3)

- Possible implementation mechanisms:
  - Encapsulation and tunnelling
  - Rewrite address at each end
  - End-system based management of separate ID layer

Compatibility and deployment

- RLOCs are clearly PA addresses.
- Are EIDs PI addresses or something new?
- Do A and AAAA records deliver EIDs?
- Do upper layers use EIDs in socket calls and 3rd party references?
- Are host software changes needed?
- How does the solution interwork with existing BGP4 deployment and existing hosts and routers?
  - Is stepwise deployment OK?
- Impact on MTU size and fragmentation?

Preserving the API?

- We've learnt from trying to deploy IPv6 that the routers and the IP stacks are the *easy* part. Anything that appears above the socket API creates a Y2K-like problem.
- In my opinion, any new solution that invalidates the socket API again, or even requires noticeable changes to TCP code, is undeployable.
- In my opinion, the routing community tends to underestimate the importance of this.

BTW

- If you think that compact routing research might be relevant, see *On Compact Routing for the Internet,* Krioukov et al, ACM SIGCOMM CCR **37**(3) 43-52, July 2007.
  - Some pragmatic work on compressing tables by "virtual aggregation" may help. See *A White Paper on Reducing FIB Size through Virtual Aggregation,* Francis et al, Cornell University, work in progress, 2008. (www.cs.cornell.edu/People/francis/va-wp.pdf)

Sources

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