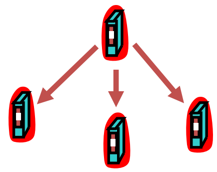

Content Distribution Networks (CDNs)

Mike Freedman

COS 461: Computer Networks

http://www.cs.princeton.edu/courses/archive/spr20/cos461/

Continuation of Lec 15

HTTP xfer = single object

Web pages = many objects

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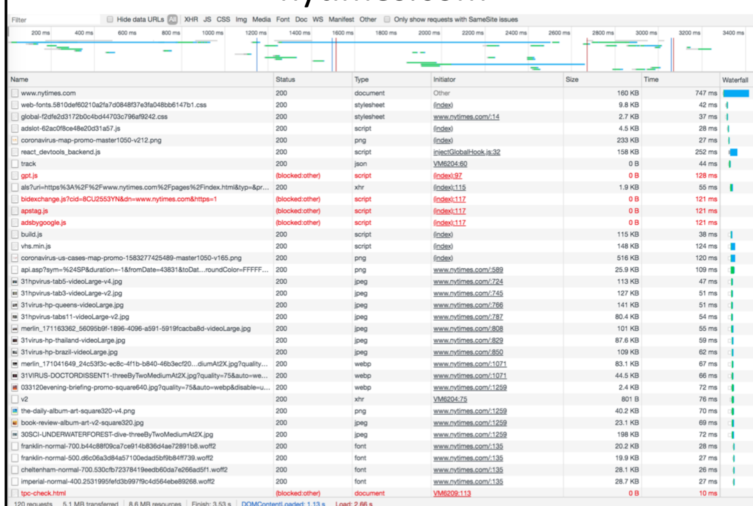
nytimes.com



How to handle many requests?

- Maximize goodput by reusing connections
  - Avoid connection (TCP) setup
  - Avoid TCP slow-start
- Client-server will maintain existing TCP connection for up to K idle seconds

```
GET / HTTP/1.1
Host: www.example.com
Connection: Keep-Alive
```

```
HTTP/1.1 200 OK
Date: Tue, 27 Mar 2001 03:50:51 GMT
Connection: Keep-Alive
```


Three approaches to multiple requests

Parallel Connections	Persistent Connections	Pipelined Connections
Conn 1:	Conn 1:	Conn 1:
• Request 1	• Request 1	• Request 1
• Response 1	• Response 1	• Request 2
	• Request 2	• Request 3
Conn 2:	• Response 2	• Response 1
• Request 2	• Request 3	• Response 2
• Response 2	• Response 3	• Response 3

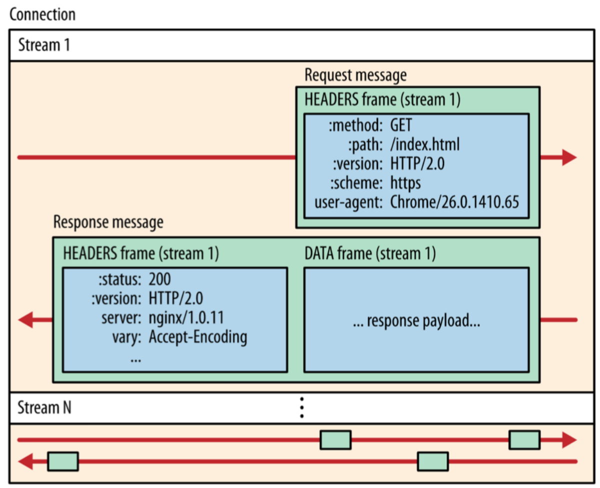
What are challenges with pipelining?

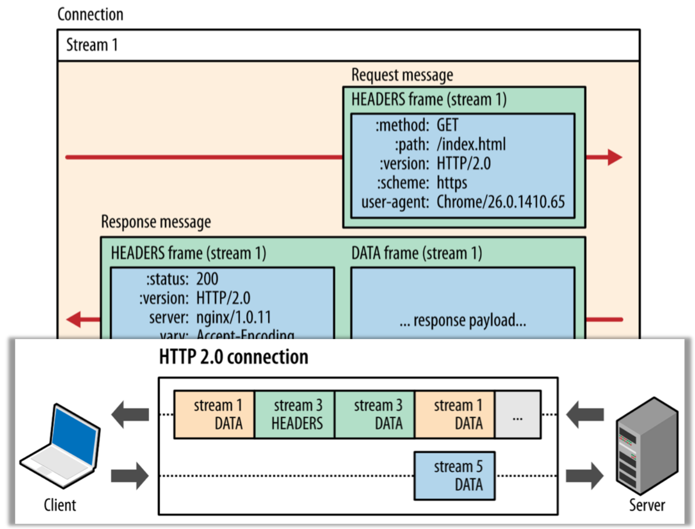
- Head-of-line blocking
  - Small xfers can "block" behind large xfer
- No reordering
  - HTTP response does not "identify" which request it's in response to; obvious in simple request/response
- Can behave *worse* than parallel + persistent
  - Can send expensive query 1 on conn 1, while sending many cheap queries on conn 2

Google's SPDY -> HTTP/2

- Server "push" for content
  - One client request, multiple responses
  - After all, server knows that after parsing HTML, client will immediately request embedded URLs
- Better pipelining and xfer
  - Multiplexing multiple xfers w/o HOL blocking
  - Request prioritization
  - Header compression

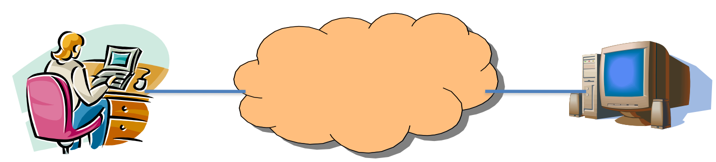
https://developers.google.com/web/fundamentals/performance/http2





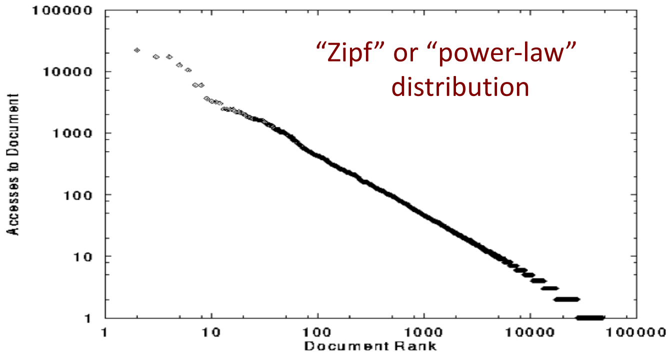
Why Web Caching?

Single Server, Poor Performance



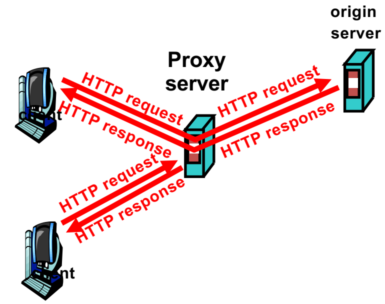
- Single server
  - Single point of failure
  - Easily overloaded
  - Far from most clients
- Popular content
  - Popular site
  - “Flash crowd” (aka “Slashdot effect”)
  - Denial of Service attack

Skewed Popularity of Web Traffic



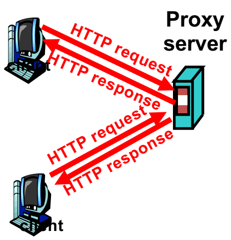
Characteristics of WWW Client-based Traces
Carlos R. Cunha, Azer Bestavros, Mark E. Crovella, BU-CS-95-01

Proxy Caches



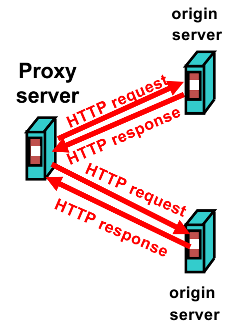
Forward Proxy

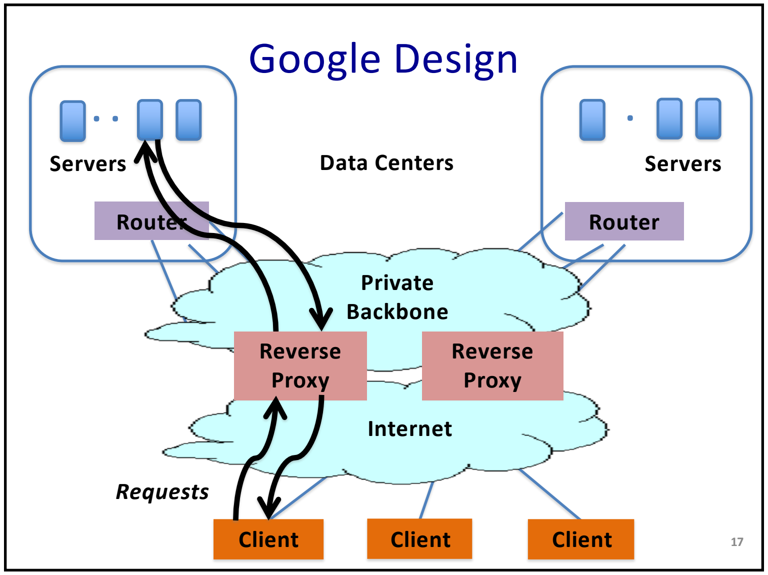
- Cache "close" to the client
  - Under administrative control of client-side AS
- Explicit proxy
  - Requires configuring browser
- Implicit proxy
  - Service provider deploys an "on path" proxy
  - … that intercepts and handles Web requests



Reverse Proxy

- Cache "close" to server
  - Either by proxy run by server or in third-party content distribution network (CDN)
- Directing clients to the proxy
  - Map the site name to the IP address of the proxy





Proxy Caches

(Y) Forward (M) Reverse (C) Both (A) Neither

- Reactively replicates popular content
- Reduces origin server costs
- Reduces client ISP costs
- Intelligent load balancing between origin servers
- Offload form submissions (POSTs) and user auth
- Content reassembly or transcoding on behalf of origin
- Smaller round-trip times to clients
- Maintain persistent connections to avoid TCP setup delay (handshake, slow start)

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Proxy Caches

(Y) Forward (M) Reverse (C) Both (A) Neither

- Reactively replicates popular content **C**
- Reduces origin server costs **C**
- Reduces client ISP costs **Y**
- Intelligent load balancing between origin servers **M**
- Offload form submissions (POSTs) and user auth **A**
- Content reassembly or transcoding on behalf of origin **C**
- Smaller round-trip times to clients **C**
- Maintain persistent connections to avoid TCP setup delay (handshake, slow start) **C**

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Modern HTTP Video-on-Demand

- Download “content manifest” from origin server
- List of video segments belonging to video
  - Each segment 1-2 seconds in length
  - Client can know time offset associated with each
  - Standard naming for different video resolutions and formats: e.g., 320dpi, 720dpi, 1040dpi, …
- Client downloads video segment (at certain resolution) using standard HTTP request.
  - HTTP request can be satisfied by cache: it’s a static object
- Client observes download time vs. segment duration, increases/decreases resolution if appropriate

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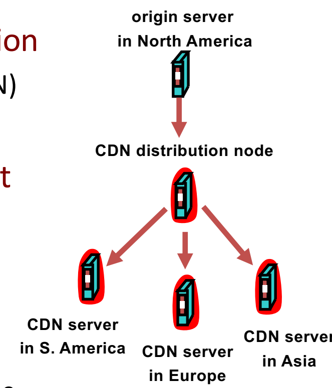
Content Distribution Networks

Content Distribution Network

- Proactive content replication
  - Content provider (e.g., CNN) contracts with a CDN
- CDN replicates the content
  - On many servers spread throughout the Internet
- Updating the replicas
  - Reactive by TTL or updates pushed to replicas when the content changes



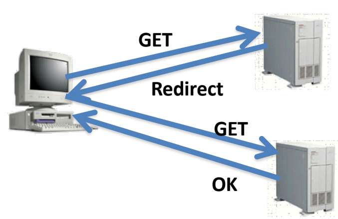
Server Selection Policy

- Live server
  - For availability
- Lowest load
  - To balance load across the servers
- Closest
  - Nearest geographically, or in round-trip time
- Best performance
  - Throughput, latency, …
- Cheapest bandwidth, electricity, …

Requires continuous monitoring of liveness, load, and performance

Server Selection Mechanism

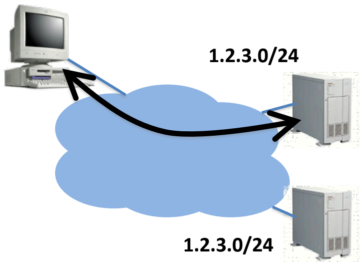
- Application
  - HTTP redirection



- Advantages
  - Fine-grain control
  - Selection based on client IP address
- Disadvantages
  - Extra round-trips for TCP connection to server
  - Overhead on the server

Server Selection Mechanism

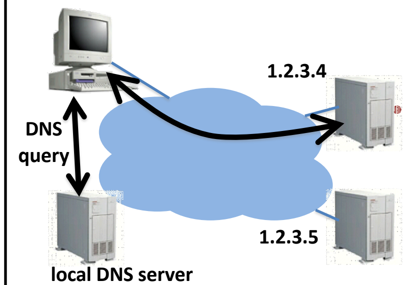
- Routing
  - Anycast routing



- Advantages
  - No extra round trips
  - Route to nearby server
- Disadvantages
  - Does not consider network or server load
  - Different packets may go to different servers
  - Used only for simple request-response apps

Server Selection Mechanism

- Naming
  - DNS-based server selection



- Advantages
  - Avoid TCP set-up delay
  - DNS caching reduces overhead
  - Relatively fine control
- Disadvantage
  - Based on IP address of local DNS server
  - “Hidden load” effect
  - DNS TTL limits adaptation

How Akamai Works

Akamai Statistics

- Distributed servers
  - Servers: ~275,000
  - Networks: 1,500
  - Countries: 136
- Many customers
  - 50% of Fortune Global 500
- Network
  - Up to 50 Tbps daily
  - 2019 Cricket World Cup: 25.3M concurrent viewers
  - 85% Internet is one network hop from Akamai servers

https://www.akamai.com/us/en/about/facts-figures.jsp

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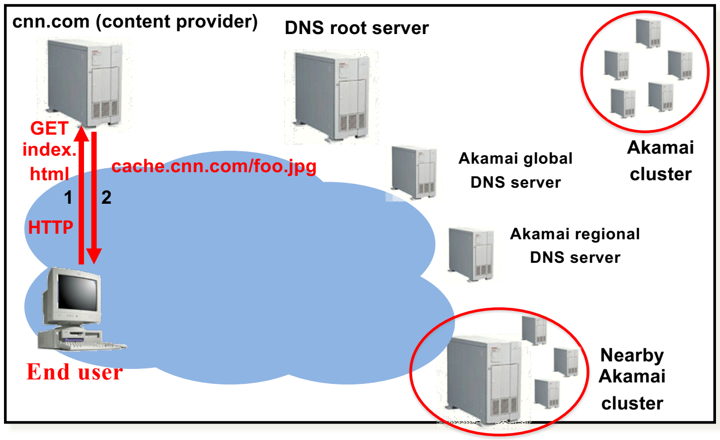
How Akamai Uses DNS



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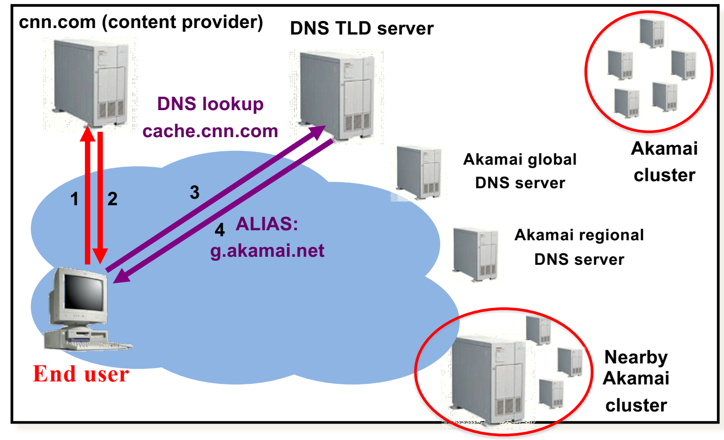
How Akamai Uses DNS



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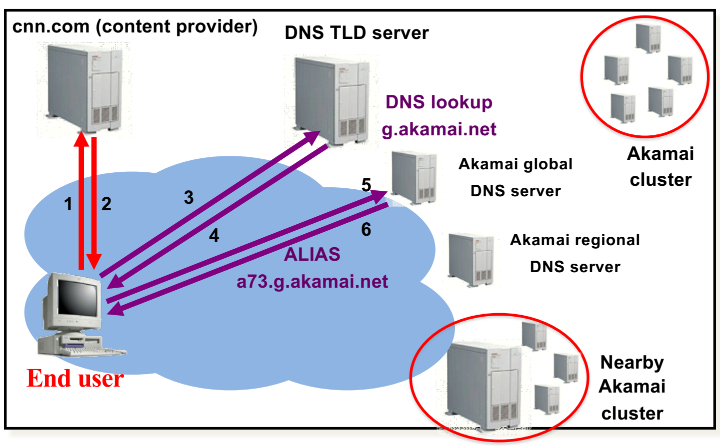
How Akamai Uses DNS



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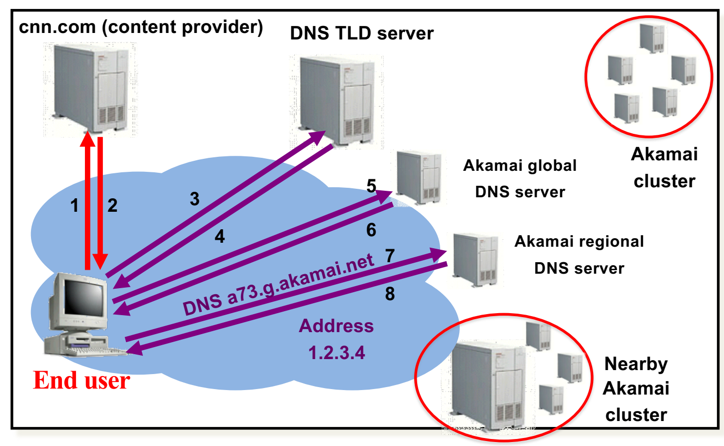

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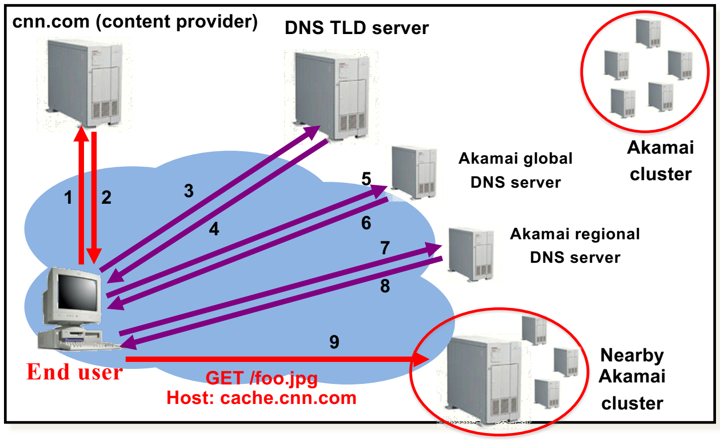

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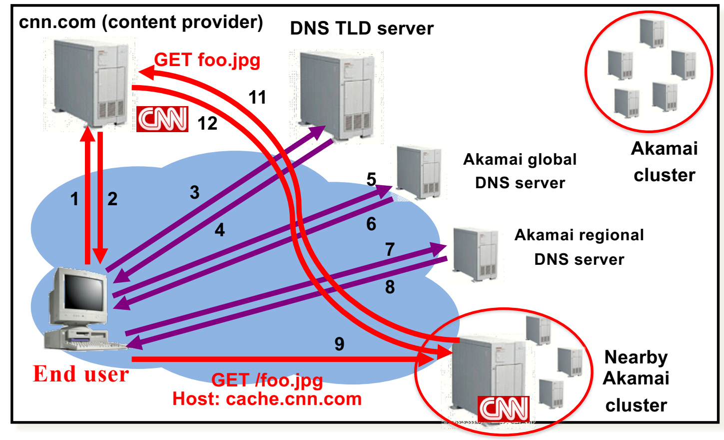

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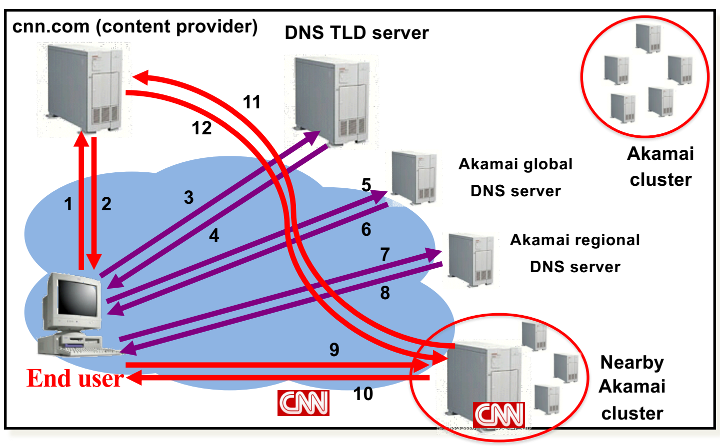
How Akamai Uses DNS



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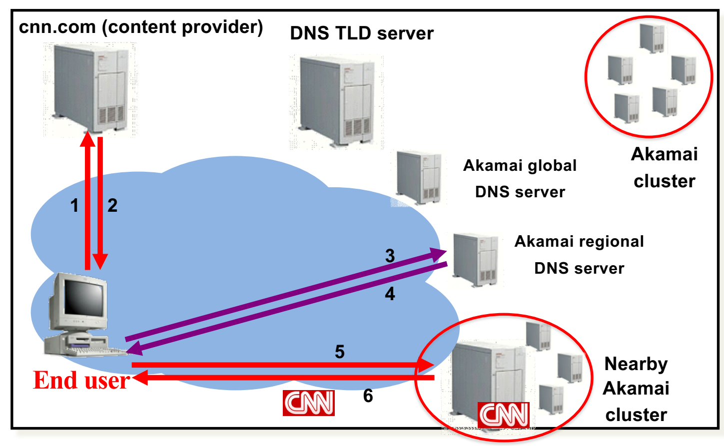
How Akamai Works: Cache Hit



Mapping System

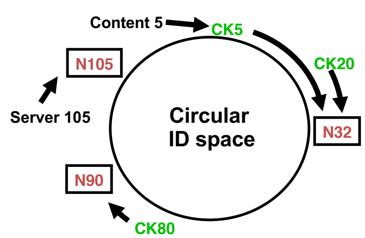
- Equivalence classes of IP addresses
  - IP addresses experiencing similar performance
  - Quantify how well they connect to each other
- Collect and combine measurements
  - Ping, traceroute, BGP routes, server logs
    - E.g., over 100 TB of logs per days
  - Network latency, loss, and connectivity

Routing Client Requests within Map

- Map each IP class to a preferred server cluster
  - Based on performance, cluster health, etc.
  - Updated roughly every minute
    - **Short, 60-sec DNS TTLs** in Akamai regional DNS accomplish this
- Map client request to a server in the cluster
  - Load balancer selects a specific server
  - E.g., to **maximize** the cache hit rate

Selecting server inside cluster

- "Consistent hashing"
  - content_key = hash(URL) mod N
  - node_key = hash(server ID) mod N
  - Content belongs to server's node_key is "closest" to URL's content_key



Adapting to Failures

- Failing hard drive on a server
  - Suspends after finishing "in progress" requests
- Failed server
  - Another server takes over for the IP address
  - Low-level map updated quickly
- Failed cluster or network path
  - High-level map updated quickly
- Failed path to customer's origin server
  - Route packets through an intermediate node

Akamai Transport Optimizations

- Bad Internet routes
  - Overlay routing through an intermediate server
- Packet loss
  - Sending redundant data over multiple paths
- TCP connection set-up/teardown
  - Pools of persistent connections
- TCP congestion window and round-trip time
  - Estimates based on network latency measurements

Akamai Application Optimizations

- Slow download of embedded objects
  - Prefetch when HTML page is requested
- Large objects
  - Content compression
- Slow applications
  - Moving applications to edge servers
  - E.g., content aggregation and transformation
  - E.g., static databases (e.g., product catalogs)

Conclusion

- Content distribution is hard
  - Many, diverse, changing objects
  - Clients distributed all over the world
- Moving content towards client is key
  - Reduces latency, improves throughput, reliability
- Contribution distribution solutions evolved
  - Reactive caching, load balancing, to
  - Proactive content distribution networks