What's wrong with HTTP (and why it doesn't matter)

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HTTP is *the* killer application protocol

- 75% of the bytes on Internet backbone
- $Billions of value for .com stocks
- Even my mom uses the Web

The HTTP protocol design is a mess

- Complex and often confusing specification
- Many basic concepts are wrong
- Numerous inefficiencies
- Even a spelling error

This talk will

- Explain the flaws in the HTTP design
- Explain why it still succeeds

Why this talk?

Better understanding of HTTP

- The good and the bad

Lessons for future protocol designers

- Mistakes to avoid
- Areas for future improvement
- Procedural issues

Disclaimer

This talk is entirely my own opinion!

I do not speak for

- The IETF's HTTP Working Group (HTTP-WG)
- Other authors of the HTTP/1.1 specification
- Compaq or its partners

and I expect some of these people will violently disagree with what I say.

Outline

History of HTTP

Overview of HTTP and HTTP/1.1

Fundamental mistakes

Procedural problems in the HTTP-WG

Why the bugs in HTTP don’t matter

A Brief history of HTTP

Pre-history:

- Hypertext dreams (but no protocol)
- Gopher protocol (but no hyperlinks)
- WAIS

At CERN:

- 1990: original deployment (Tim Berners-Lee)
- Jan. 1992: first known spec (on www-talk)
  - Only "GET" method
  - No documented headers
  - Generally known as ‘‘HTTP/0.9’’
- Dec. 1992: first www-talk mention of upgrade
  - MIME-compatible
  - HTTP headers

History continued

Internet Engineering Task Force (IETF):

- Mar. 1993: first Internet-Draft for HTTP/1.0
- Nov. 1993: revised Internet-Draft for HTTP/1.0
- Dec. 1994: first HTTP-WG meeting (‘‘BOF’’)
- May 1996: RFC1945: HTTP/1.0
  - Not an IETF standard
  - Reflected consensus of implementors
  - Generally recognized as problematic

HTTP/1.1 timeline:

- Nov. 1995: first Internet-Draft issued
- Jan. 1997: RFC2068 (‘‘Proposed Standard’’)
  - Actually finished in July 1996
- Nov. 1998: final HTTP/1.1 Internet-Draft
  - ‘‘Draft Standard’’ status approved
  - In RFC Editor’s queue since March 1999

Overview of HTTP and HTTP/1.1

Basics:

- Request-response protocol
  - No response without a request
  - No callbacks
- ASCII headers
  - MIME-like syntax
  - Special format for first line
- Binary data in optional *body*
  - HTTP treats body as bag-of-bits
- A request applies a *method* to a *resource*
  - Methods include: GET, PUT, POST
- HTTP uses TCP as transport (almost always)

Example: HTTP/1.0 exchange

Client sends:

```
GET /home.html HTTP/1.0
Accept: text/html, image/*
```

Server replies:

```
HTTP/1.0 200 OK
Date: Sat, 01 Aug 1998 06:59:59 GMT
Content-type: text/html

<HTML>
<HEAD><TITLE>
This is a title
</TITLE></HEAD>
This is an example.
</HTML>
```

Other HTTP/1.0 features

HTTP/1.0 included support for:

- Caching
  - `Expires`, `Last-Modified`, `If-Modified-Since`
- Internationalization
  - `Accept-Language`, `Accept-Charset`, etc.
- Authentication
  - with cleartext passwords!

HTTP/1.1: fixing(?) HTTP/1.0

Persistent connections & pipelining
- Multiple requests per connection
- No need to wait for preceding reply
- Requires explicit end-of-message mechanism

Clean up caching
- More careful model
- Entity tags
- Explicit control using `Cache-control`
- `Vary` header for negotiated resources
- `Warning` header for non-fatal errors

Partial transfers (‘‘`Range`’’ requests)
- For grabbing prefixes
- For resuming after an error

Extensibility
- `Via` header for hop-by-hop version info
- More careful rules for proxies and servers

HTTP/1.1, continued

Digest authentication
- Avoid cleartext passwords
- Some end-to-end message integrity

IP address conservation
- Send server hostname in `Host` header

Content negotiation
- Actual syntax specification
- Supports ‘‘quality factors’’ (preferences)

Negotiated use of compression, etc.
- More efficient use of bandwidth
- Allows use of new coding algorithms

More detail in WWW8 paper by Krishnamurthy, Mogul, and Kristol

Fundamental mistakes

Topics:

- Data model and the MIME miasma
- Extensibility
- Caching
- Header categories
- Status and error codes
- Transport issues
- Content negotiation
- Cookies & other social issues

My rating system

- A really annoying mistake:

- Bugs me that we didn't solve this:

- Might become trouble:

Data model and the MIME miasma

Original HTTP vision:

- ‘‘object-oriented protocol’’
- MIME-conforming and MIME-compatible
- Objects with many variants

Consequences:

- Terminology:
  - ‘‘Objects’’ and ‘‘methods’’
  - MIME ‘‘entity’’ for in-transit payload
- Possibility of ‘‘dynamic’’ resources
- MIME header rules (more or less)
- MIME content-type system
- URL does not always identify specific variant

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Object-oriented? Not!

HTTP transfers current resource response

- Not the resource itself

Cached values don’t work like dynamic resources

No cache coherency for updatable resources

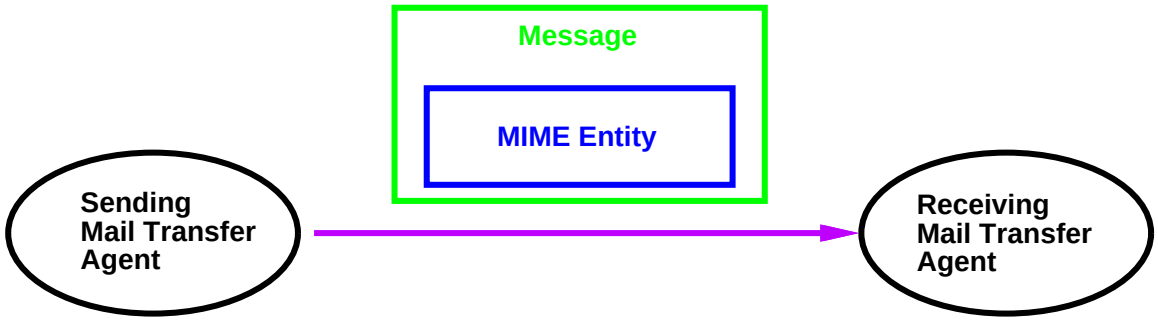
HTTP/1.1 no longer described as ‘‘objected oriented’’

So now what?

Entities and resources and instances, oh my!

Crucial mistake: false analogy with MIME entities

MIME model:

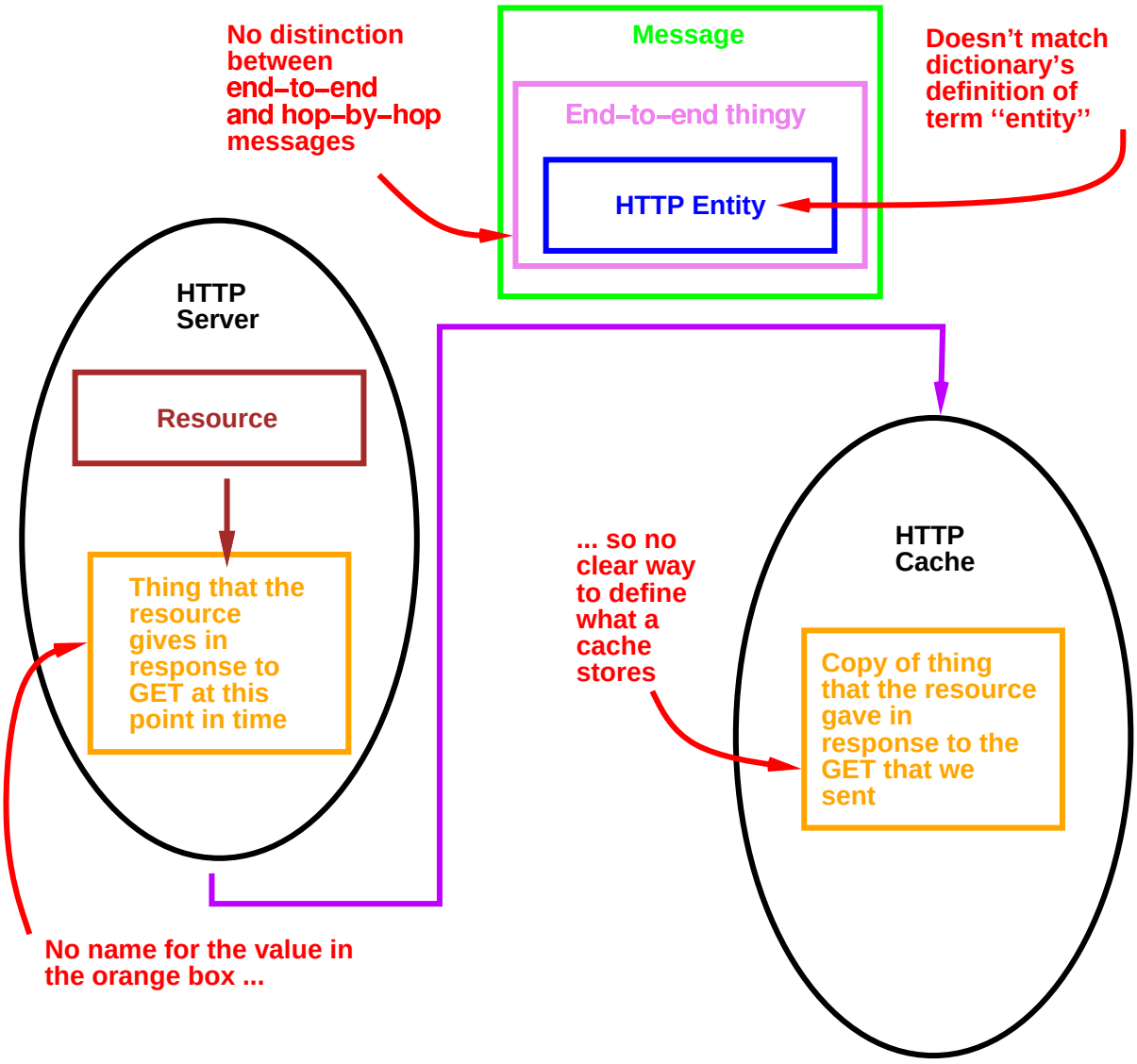


Note:

- No data types besides entities and messages
- End-to-end message = hop-by-hop message
  - Except for ‘‘Received-by’’ & warnings

MIME analogy falsely extended to HTTP

Official HTTP model:



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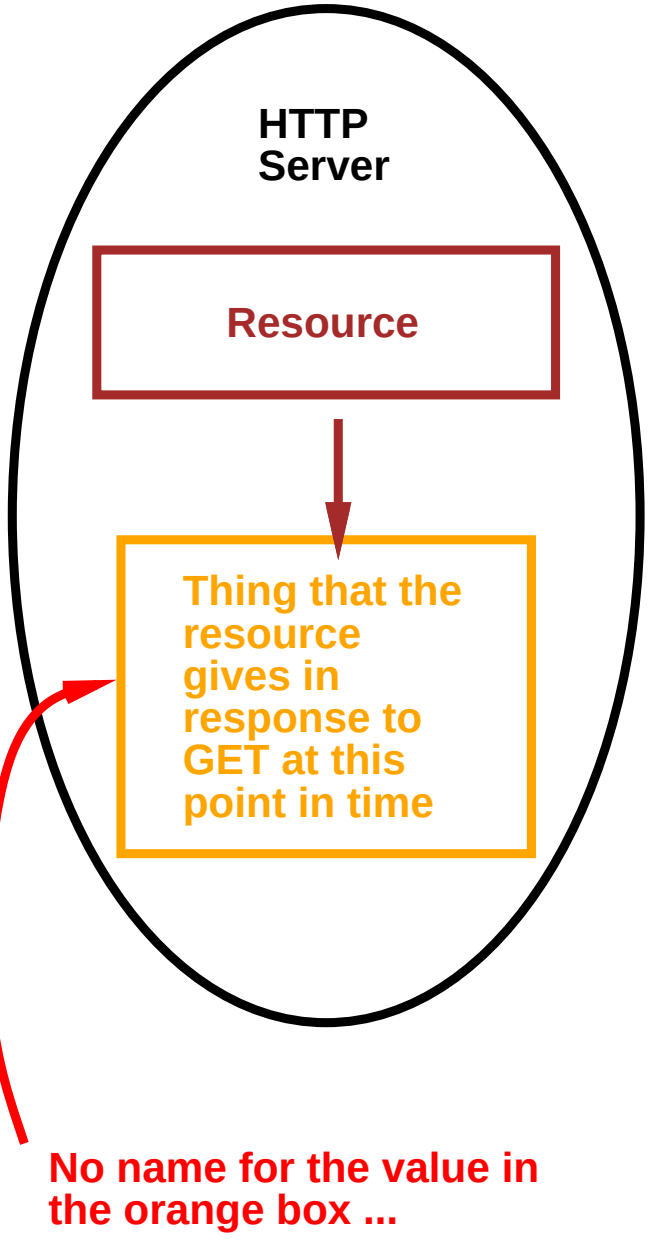

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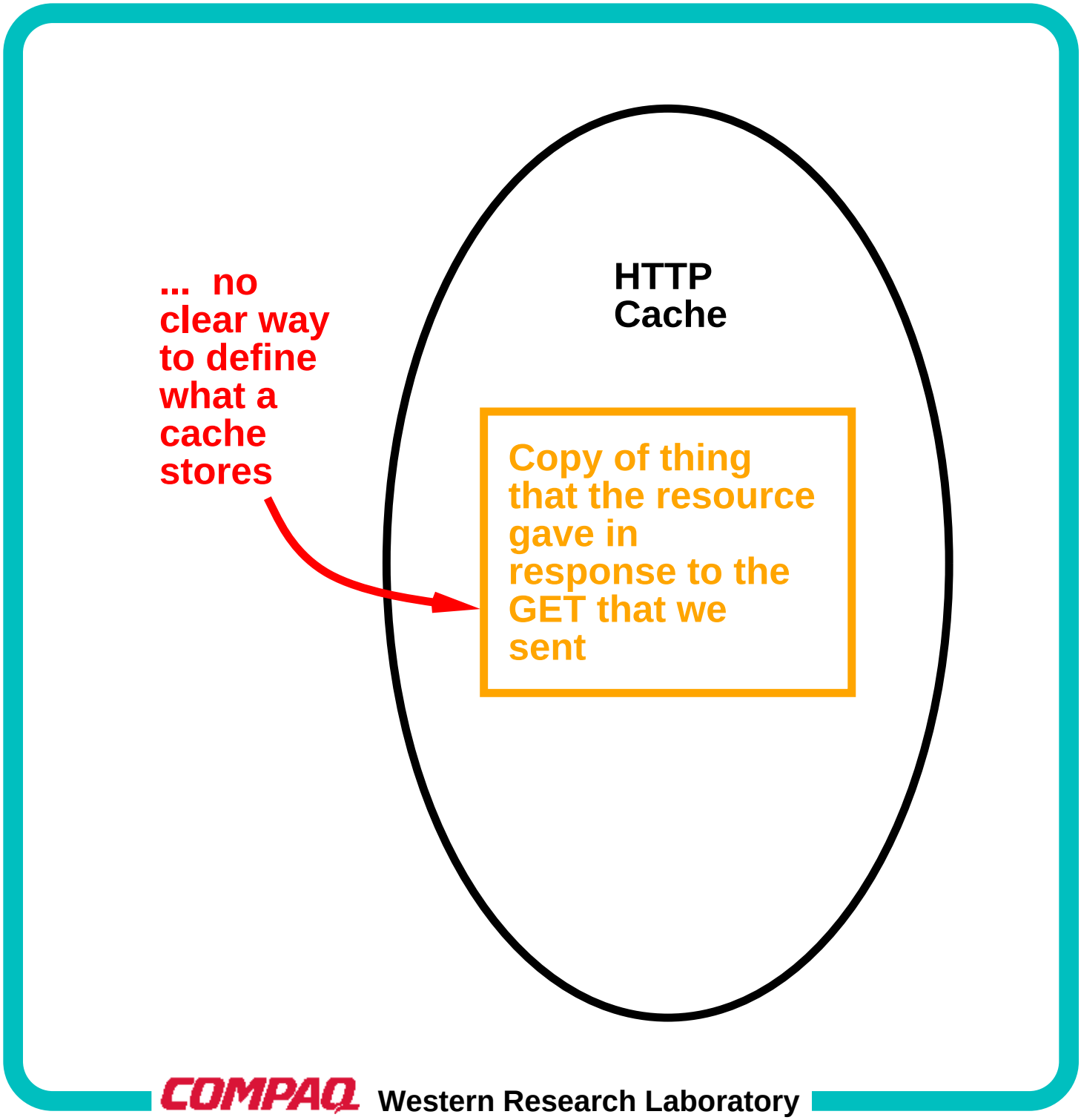
... no clear way to define what a cache stores
HTTP Cache
Copy of thing that the resource gave in response to the GET that we sent
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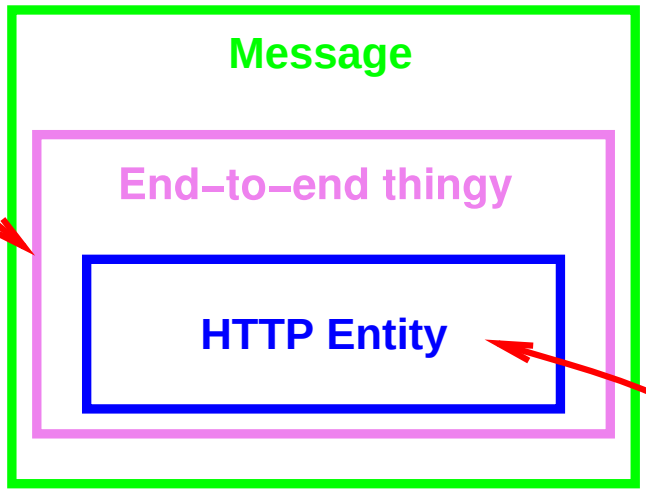
No distinction between end–to–end and hop–by–hop messages



Doesn’t match dictionary’s definition of term ‘‘entity’’

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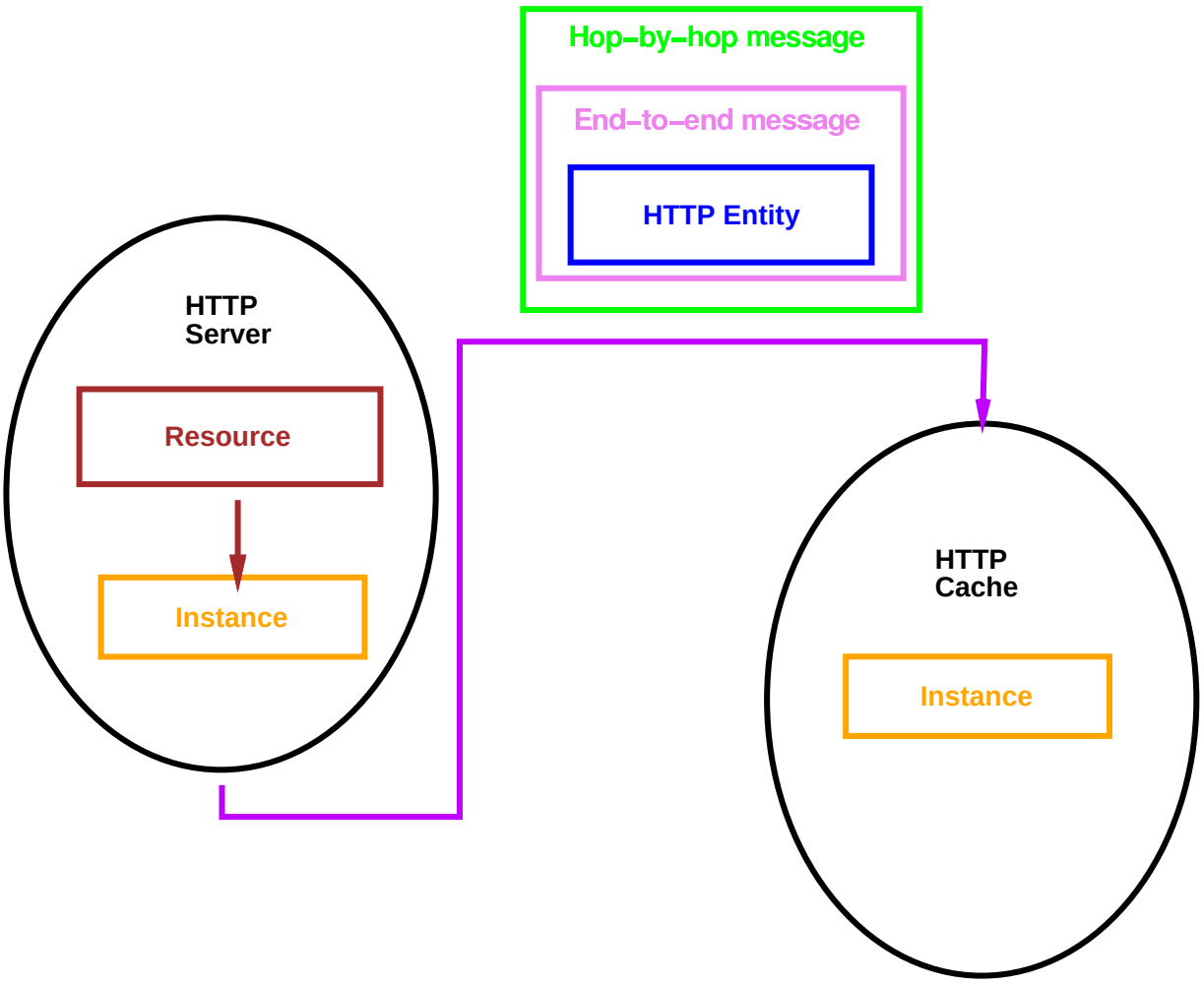
Clarified HTTP model: introduce ‘‘instances’’



Now we can discuss

- Transformations on instances
- What caches store

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Data model - importance

Why is this important?

- Poor terminology leads to fuzzy thinking
- Poor terminology leads to underspecification
  - E.g., relationship between compression and byte-ranges
- Much confusion over whether headers apply to:
  - Server (or proxy)
  - Resource
  - Variant
  - Instance
  - Entity
  - End-to-end message
  - Hop-by-hop message

  with some headers filling several roles

Note: MIME's content-type system is fine with me.

Data model - example

Scenario:

1. Client loads first part of file, using `Range`
   - in response message #1
2. Client loads rest of file, using `Range`
   - in response message #2
3. Client assembles result from #1 & #2

Question: can we determine if result is correct?

What about `Content-MD5` header:

- Defined as ‘‘Digest of the entity-body’’
- ... so only applies to *message* #1 or #2

What we need:

- Digest of instance
- Not available in HTTP
  - because the concept wasn’t clear

Extensibility

Facts of life

- HTTP evolves
- Compatibility is mandatory
- ‘‘Flag days’’ are impossible

So: HTTP must be extensible:

- Interoperate with past implementations
  - Without degrading their behavior
- Interoperate with future implementations
  - No matter what the future brings
- Ambiguity kills

Three key issues

1. Protocol version numbering
2. Probing for extensions
3. The POST hole

HTTP Version numbers

HTTP version numbers verge on meaningless

- ‘‘HTTP/1.0’’ never really specified
- ‘‘HTTP/1.1’’ systems deployed before spec is finished
- Some proxies use the wrong version number
- Version number is officially hop-by-hop
  - though `Via` gives end-to-end version
- Optional features aren’t indicated by version

Basic problems:

- Distinction between hop-by-hop, end-to-end
- Lack of precision
  - optional features (MUST vs. SHOULD)
  - minor updates
  - ‘‘Proposed’’ vs. ‘‘Draft’’ vs. ‘‘standard’’
- Lack of formal binding to a specification

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Version numbers - alternative?

Possible alternative approach:

- Use RFC #s instead of sequential versions
  - RFCs are immutable
  - Should be well-defined
- Create special ‘‘profile’’ RFCs as necessary
- Parameter indicates ‘‘conditional’’ compliance
- Use header (not first line) to carry info
  - Separate headers for e-2-e, hop-by-hop
  - Proxies leave audit trail (like `Via`)

Example:

```
HTTP/1.1 200 OK
Server-Version: RFC=2068, RFC=9914
Proxy-version: RFC=6234;cond
```

Maybe next time ...

Probing for extensions

Question:

- Does peer implement an extension?

Goals:

- Discover this reliably
- Fall back to standard protocol
- Don’t add too many round trips

One good thing: ‘‘ignore unknown headers’’ rule

- See if peer responds to new header
- Especially useful for optimizations

Complex extensions not adequately supported

- What precise extension (and options) is desired?
- How does this affect caching
- How are extensions named?
- What extensions do we expect, anyway?

Attempts:

- PEP (‘‘Protocol Extension Protocol’’): failed
- ‘‘HTTP Extension Framework’’: jury is still out

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The POST hole

HTTP's POST method

- Sends bits to server
- ... but does not simply store into resource
- Basically, an arbitrary RPC
  - Typical use: complex HTML forms

A well-specified standard would ...

- allow ends to evolve without agreement
- allow proxies to intermediate

POST is just a big loophole

- No standard
- Too tempting to use instead of a true extension
- Problematic for security firewalls

Caching

Caching and proxies in HTTP/1.0:

- An afterthought, at best
- No cache coherency (especially for updates)
- No extensibility to new methods
- No detection of transparency failures

Transparency:

A cache behaves transparently when the response that you get from it is essentially the same as the response you would have received from the origin server.

Without transparency:

- Caches aren't trusted (and are bypassed)
- Users get wrong answers

How HTTP caching works

Basic model of HTTP caching:

1. Client A requests resource R via Proxy P
2. Proxy P forwards A's request to server for R
3. Proxy P receives server's response for R
   - Forwards response to A
   - Stores response for later use
4. Client B requests resource R via Proxy P
5. Proxy P retrieves & returns stored response

Conditional requests:

1. Server's response includes validator
   - e.g., last-mod date or (in 1.1) entity-tag
2. Client asks server if cache entry is fresh:

```
GET /foo.gif HTTP/1.0
If-Modified-Since:
        Thu, 03 Jun 1999 20:16:34 GMT
```

3. Server responds with either:
   - `200 OK` + full response body
   - `304 Not Modified` + no body

Caching - after HTTP/1.1

HTTP/1.1 improvements:

- Detection of transparency failures
- Better transparency, in general
  - More accurate mechanisms
  - Explicit control for exceptions

but these are still problems:

- Coherency for updatable resources
- Extensibility
- Complexity of rules & implementation
- Overall performance

Caching - coherency after updates

Problem: cache cannot detect update to resource

- If update is done local to server
- If update is done by client not using this cache

Implications:

- Expiration deadlines must be conservative
- ‘‘Distributed authoring’’ must disable caches

Several potential solutions:

- Callbacks (Chengjie Liu and Pei Cao)
- Volume-based validation (Cohen et al.)
- Cache applets (Cao, Jin Zhang, & Kevin Beach)

although all have drawbacks and limitations

Security: especially difficult

- Who is allowed to modify a cache entry?

Caching - complexity

HTTP/1.1 caching specification:

- Lots of caching-related rules
- Some are subtle
- Some are contradictory

This is due to

- Evolutionary design
- Competing notions of goodness

Cache implementations are complex:

- Because of complex specification
- Because of complex lookup mechanisms
- Because of inevitable engineering issues

Not clear how to resolve this

Caching - performance

Three reasons for caching

1. Faster response time
2. Lower bandwidth requirements ($$$)
3. Availability during disconnection

But

- Observed cache hit ratios are below 50%
- Byte-weighed hit ratios are even lower
- Lack of coherent ‘‘collection’’ concept

So simple caching has pretty much hit its limits

Can’t we do better?

Caching - paths to improved performance

Possible approaches:

- Prefetch, to hide latency
- Exploit (better) the bits already in the cache
- Decompose pages into static & dynamic parts
- Support coherent snap-shots

All require some level of HTTP enhancements

Also interesting: cache management issues

- Replacement hints
- Balancing the cost of disk I/O
- Cache cooperation
- Privacy considerations
- Hit-metering/ad-placement

would be nice to resolve these ...

Content negotiation

Important original broad goal:

- Make the Web international (multilingual)

Semi-failure, because of fuzziness about:

- Specific goals; especially, who's in charge?
  - User's preference
  - Site designer's preference
- Naming issues
- Confusion between negotiation axes:
  - content
  - presentation
  - implementation parameters
- Caching
- Importance of avoiding round-trips

Negotiation problem: deploying new codings

How to deploy new codings?

E.g.: client that groks ‘‘squish’’ compression sends:

```
Accept-encoding:gzip,compress,squish
```

Problem: must choose between

- Request header bloat

or

- Sluggish deployment of new codings

Underlying problem: no way for

- Client to ask server what it supports
- Server to tell client ‘‘*X* unsupported’’

Bad hacks:

- Server keys off of `User-agent` header
- Client sends `Accept: */*`

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Status and error codes

HTTP responses carry one 3-digit status code; e.g.

```
HTTP/1.0 200 OK
HTTP/1.0 304 Not Modified
HTTP/1.0 404 Not Found
HTTP/1.0 501 Not Implemented
```

Problems:

- Some ambiguity in specification
  - ‘‘Which code should I use here?’’
- Only one code
  - What about non-fatal errors at proxies?
- Complex interaction with caching
- Not really extensible

Status codes - improvements

HTTP/1.1 adds `Warning` header; e.g.

```
HTTP/1.1 200 OK
Warning: 110 proxy.a.com
         "Response is stale"
Warning: 214 proxy.b.com
         "Transformation applied"
```

First digit controls cache behavior on revalidation

What might have been better:

- Status code as separate header(s)
- Specific indications for severity, caching
  - Consider automated clients
- Better multilingual support

Transport issues

Goal: efficient and reliable message transport

Issues:

- Inefficiency of ASCII header encoding
- Bias against compression
- Lack of clean connection-abort mechanism
- No buffer size limits/negotiation
- No multiplexing
- No multi-resource operations
- No atomic grouping of operations

Transport issues - HTTP/1.1 fixes

HTTP/1.1 has some improvements:

- Persistent connections, pipelining
- Compression negotiation
- Chunked encoding + careful rules
- "`100 Continue`" + `Expect` mechanism
  - This is complex, might be unreliable
- Weak form of atomic read-modify-write
  - Single resource only
  - Not really tested

Transport - efficiency

Inefficiency of ASCII header encoding

- Way too verbose, e.g.:

```
If-UnModified-Since: Thu, 03 Jun 1999 20:16:34 GM
```

  Mean header sizes (from traces):
  - Requests (with URLs): ca. 300 bytes
  - Responses: ca. 160 bytes

- Requires complex parser
- Could be simpler:
  - One or two bytes of header ‘‘name’’ code
  - Tokens with type, length code bytes
  - Binary codes for dates, integers, enums
- Could also be optional; either
  - Negotiated switch from ASCII to binary
  - Short abbrevs for header names, enums
- For example: replace header above by

```
IU: 3756E239
```

Transport - efficiency, continued

Bias against compression

- Default is uncompressed
  - images, media usually pre-compressed
- Poorly defined interation with other features
  - e.g., Range retrievals

Transport - reliability

Lack of clean connection-abort mechanism:

- If user hits Stop button, then:
  - TCP connection(s) lost
  - Possible loss of buffered data

No buffer size limits/negotiation

- Basic principle violated:
  - Can't send more than receiver can buffer
  - but HTTP has no explicit limits
- Specific bug found in HTTP/1.1 spec:
  - Involves proxies, chunking, HTTP/1.0
  - Required last-minute spec change
- HTTP should have
  - End-to-end, hop-by-hop limits
    - Reasonable default
    - + Negotiation mechanism?

Transport - message structure

No multiplexing

- Slow response stalls all others on connnection
- Would require some kind of transaction ID

No multi-resource operations

- Cannot operate on multiple resources, e.g.:
  - Multiple cache re-validations
  - GET-LIST of images on a page
- Can kludge using message headers
  - Not interoperable with extant proxies

No atomic grouping of operations, e.g:

- Get consistent set of resources
- Rename (via GET, PUT, DELETE)

(but WEBDAV adds this)

Cookies

Originally Netscape's *ad hoc* extension

RFC2109 proposed a standard

Problems:

- interoperation w/ non-standard cookie implementations adds complexity
- Privacy concerns

Conflict between technology, policy, & profit:

- IETF requires ‘‘Security Considerations’’
- but there's no consensus on how far to go
- Ad-supported sites have a lot to lose
    - Software vendors tend to play along

Other social issues

Copyright

- Is a cache liable for copyright violation?
- How can a proxy know what is legal?

Advertising

- Accurate counting without excess overhead
- Trust issues:
  - Are counts honest?
  - Are proxies surreptitiously replacing ads?
- Balance between:
  - Users want to refuse ads
  - Content-providers need ad revenue

Procedural problems in the HTTP-WG

- Length of process
- Porous criteria for feature inclusion
- Premature deployment
- Lack of resources for tedious work
- Some good points

HTTP-WG procedures

Length of process

- HTTP/1.1 took 4.5 years
- Lots of players joined relatively late
  - Or moved on (or got rich)
- Tendency to rush decisions
  - ... and then the process drags on
- Architectural issues tend to drift

Porous criteria for feature inclusion

- ‘‘Demonstrated necessity’’
- ... but sometimes based only in theory
- ‘‘Wait for HTTP-2.x’’ (or for HTTP/1.2)
- Multi-stage process might have helped

HTTP-WG Procedures - continued

Premature deployment

- RFC2068 (text: Aug. 96) treated as ‘‘standard’’
  - I.e., implementations deployed widely
  - Not a ‘‘standard’’ by normal IETF rules
- Precluded undoing design mistakes later on
- Special problem: RFC2068 inconsistencies
- Debate over whether to rename as ‘‘HTTP/1.2’’
  - Apparently, we won’t

Lack of resources for tedious work

- editorial work
  - checklists (required vs. recommended)
  - consistency
- test implementations
- rationale documentation

HTTP-WG Procedures - continued

Good points about the HTTP-WG process:

- The long process gave time to reflect
  - Many bugs found years after design phase
  - Overall, reached architectural consensus
- Vendors behaved themselves
  - No attempts to bias towards their code
  - Engineers cooperate better than marketers
- HTTP/1.1 much more specific than HTTP/1.0
  - Ambiguities rare
  - ... but still some ‘‘folklore’’ inferences
- Good balance of fixes vs. compatibility

Why the bugs in HTTP don’t matter

If technical excellence really mattered, then:

- FORTRAN
- Windows
- QWERTY keyboards
- VHS tapes

would be dead and buried

The bugs in HTTP don’t matter because:

- It works well enough
- It’s not the only game in town
- Revising it again would be too hard

HTTP - it works well enough

Lack of flexibility doesn't seem to be a problem

- Existence proof: zillions of Web sites

Poor cache coherence can be solved by

- Cache-busting
- ''For latest view, hit 'Shift-Reload' ''
- Not caring

Inefficiency might be irrelevant:

- Bandwidth keeps increasing
- CPU speed & RAM size follow Moore's Law
- Users are surprisingly patient
- Site designers will get a clue ... some day

''Wrong tool for the job'' argument

- Ignores human nature

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HTTP - not the only game in town

‘‘HTTP doesn’t work for my application’’

- Intrinsically bad for:
  - Two-way initiation of operations
  - Real-time
  - Deferred delivery
- Argues for new protocol, not for fixing HTTP
- No single protocol can support every feature

For example:

- RealAudio/RTSP
- IRC, USENET, SMTP, NFS (old protocols)

‘‘HTTP Envy’’ (Mark Day’s term)

- ‘‘Driven by fantasies of HTTP-like ubiquity’’
- No reason to naively use HTTP for everything
- Properly leads to non-HTTP protocols

HTTP - too hard to revise it again

HTTP/1.1 took 4+ years

- Relative minor revisions

Barriers to new revisions of HTTP:

- Incompatibility would mean:
  - Hard to deploy new version
  - No experience to guide detailed design
- Incremental benefits, at best
  - Little incentive to deploy widely
- Large installed base
  - Older code stops dying off
- Last year's ‘‘trial’’ site now ‘‘mission-critical’’
  - Less tolerance for change, instability

Summary and Conclusions

Design by evolution

- Leads to adequate design
- But not optimal design

HTTP is

- Definitely not optimal
- Probably adequate

Caching - Prefetching

Prefetching principles

- Predict one or more future references
- Initiate prefetch if spare bandwidth available
- Cache prefetched result until needed

Prefetching issues

- How to make accurate predictions
  - Observations of this or other users
  - Parsing to find links and images
  - User-specified targets
- How to avoid congestion
  - Limit to non-shared links, when idle
  - Use feedback from TCP performance
  - Prefetch before scheduled uses
  - Ignore problem
- Protocol enhancements
  - Server-supplied hints
  - Mark prefetch requests as ‘‘low priority’’

Caching - Delta-encoding & Macros

Observations:

- Many resources change frequently
- Differences between instances often small

Therefore, in these cases

- Most of the ‘‘cached bits’’ actually useful
- Need: difference (delta) between instances

Delta-encoding:

- Transmit just the delta
- Requires extensions to convey instance info

HTML macros (Douglis, Haro, Rabinovich)

- Separate HTML into constant part, parameters
- Cache can hold constant (usually larger) part
- ‘‘Parameters’’ really just a macro call (Java?)

Caching - Duplicate suppression

Many responses have different URL, same content

Implications of such ‘‘duplicates’’:

- Cache miss yields data cache already has
- Cache ends up storing multiple copies

Automatic duplicate suppression would:

- Conserve bandwidth
- Reduce latency
- Possibly conserve cache storage

Proposals (all based on MD5 or SHA-1 digests):

- Link-level (Santos and Wetherall)
- DRP (van Hoff *et al.*)
- HTTP Duplicate Suppression (van Hoff & me)

Effectiveness? still an open question

- Probably 5% - 15% bandwidth savings

Caching - Coherent snapshots

Goal: avoid intra-page incoherence

- E.g., right text, wrong photo
- Or inter-page incoherence for collections

HTTP lacks mechanism for describing collections

- and for coordinated locking

Proposals:

- DRP: uses ‘‘index’’ Content-Type
  - MD5/SHA-1 digests for integrity
  - No locking mechanism
- WEBDAV: elaborate extensions
  - 96 pages
  - Does some other stuff, too