Administrativa

- Midterms returned
  - Mean: 53, std dev = 7
  - FYI: HW1 (mean: 51, std = 8) HW2 (mean: 35, std = 5)

- Project #2 assignment up late this afternoon
  - Implement client functionality of Gnutella (v0.4 protocol)
  - Able to connect to Gnutella network; send queries and receive responses
  - Transfer content via HTTP
  - Don’t need to implement flooding etc…
Lecture Overview

- How much can caching help performance?

- Web caching
  - HTTP lecture briefly covered cache functionality
  - In this lecture, we go into detail
    » Why do it
    » Where to do it
    » How it performs

- P2P caching
  - How do P2P use distributions differ?
  - How does this impact caching in P2P systems?
Why Web Caching?

- **Cost**
  - Original motivation for adopting caches (esp. internationally)
  - Caching saves bandwidth (bandwidth is expensive)
  - 50% byte hit rate cuts bandwidth costs in half

- **Performance**
  - User: Reduces latency
    » RTT to cache lower than to server
  - Server: Reduces load
    » Caches filter requests to server
  - Network: Reduces load
    » Requests that hit in the cache do not travel all the way to server
Caching in the Web

- Performance is a major concern in the Web
- Proxy caching is one of the most common methods used to improve Web performance
  - Duplicate requests to the same document served from cache
  - Hits reduce latency, b/w, network utilization, server load
  - Misses increase latency (extra hops)
Where to Cache?

- Answer: Everwhere
- Browser (user)
  - Small: 1MB memory, 7MB disk (Netscape)
    » Note recursive caching (memory vs. disk)!
  - 20% hit rate
- Organization (client-side proxy)
  - Large: Gigabytes (with disk)
  - 50% hit rate (for large client populations)
- In front of server (server-side accelerator)
  - Large (gigabytes)
- Server itself (in memory)
Proxy Cache Implementations

- Squid proxy cache most popular free cache
  - Research project
- Apache web server can be configured as cache
- Many cache products
  - NetworkAppliance, Inktomi, Infolibria, etc.

- At this point
  - Web caches are frequently used
  - Issues well understood
- Let’s see how and why they work
  - Remember, it’s all about performance
Cache Performance

- Ideally, we want ~100% cache hit rate
  - In practice, we get around 50%
- Cache effectiveness is determined by the workload
- **Sharing** is the most important aspect of the workload
  - Requests hit in cache because object previously requested
  - Requests to popular objects hit in cache (only first is miss)
- Sharing obeys Zipf’s law
  - # requests $n$ to an object is inversely proportional to its rank $r$
  - $n = r^{-a}$, where $a$ is a constant close to 1
Object Popularity

![Graph showing object popularity](image)

- The x-axis represents the object number (log scale).
- The y-axis shows the number of accesses (log scale).
- The graph illustrates a decreasing trend, with a few objects having a disproportionately high number of accesses.
Implications

- The implications of the object popularity distribution are interesting
- Cache hit rate grows logarithmically with
  - Cache size
  - Number of users
  - Time
- Easy to get most of the benefit of caching
  - Beginning of the distribution
- Hard to get all
  - Tail of the distribution
Number of Users

![Graph showing Hit Rate (%) vs Population for different caching scenarios: Ideal (UW) and Cacheable (UW).]
Cache Misses

- There are a number of reasons why requests miss
- Compulsory (50%)
  - Object uncacheable (20%)
  - First access to an object (30%)
- Capacity (<5%)
  - Finite resources (objects evicted, then referenced again)
- Consistency (10%)
  - Objects change (“.../today”) or die (deleted)
Uncacheable Objects

- Caches cannot handle all types of objects
  - Pages constructed from server-side programs
    - “My Yahoo”, E-commerce
  - Changing data
    - Stock quotes, sports scores, page counters
  - Queries
    - Web searches
  - Marked uncacheable
    - Server wants to see requests (e.g., hit counting)

- Challenges
  - Difficult to solve, not one culprit
Effect of Uncacheability
Uncacheability

Reasons for Uncacheability

- Overall Uncache (v1): 40.0%
- Overall Uncache (v2): 39.4%
- Response Status: 22.8%
- Query: 13.9%
- Pragma: 7.7%
- CGI: 6.2%
- Cache Control: 5.7%
- Cookie: 4.4%
- Method: 1.4%
- Auth: 1.0%
- Vary: 0.3%
- Push Content: 0.0%
- Single Reason: 23.5%
- Two Or More Reasons: 16.4%

% of All Requests
Caching More

- Approaches to caching more types of web content
  - Caching active data: Data sources may be dynamic, but not continuously (e.g., sports scores (Olympic web sites))
    » Snapshots generated from databases
    » Requires cooperation of server and database
  - Cache server-side program inputs and outputs
    » Need to recognize program+inputs
  - “Active caches”: Run programs (e.g., Java) at caches to produce data
    » Can handle almost anything dynamic
    » Need data sources, though...starts to become distributed server
  - Consistency mechanisms (more later)
Prefetching

- Let’s say we make everything cacheable
- We still have a high compulsory miss rate (30+%)
  - Initial requests to objects
- What to do?
  - We can guess that objects will be requested in future
  - And request them now: prefetch
  - Fancy algorithms (markov models with conditional probs.)
  - Simple algorithms (only embedded)
    » Effective: 50% reduction in page latency
- Tradeoffs
  - Can increase cache hit rate, reduce latency
  - But, can be tough to determine what will be accessed
  - Accuracy (waste bandwidth), stale data
Cache Capacity

- Caches have finite resources
  - Eventually, something is going to have to be evicted
- Choice is made by the cache replacement algorithm
  - Cache replacement is probably the most popular single web cache research topic
- It also probably has the least impact
  - Capacity misses comprise <5% of miss rate
  - Greatest benefit you could hope for is a 5% improvement
  - Basically, want an algorithm incorporating frequency and size
- General problem
  - Fancy algorithms evaluated with small, unrealistic cache sizes
Consistency

- Consistency ensures that objects are not stale
  - Always want version on server and in caches to be the same
- Objects have lifetimes (TTL)
  - Requests to expired objects have to go back to server If-Modified-Since (304)
  - If object hasn’t changed, return from cache
  - Otherwise server sends back changed object
  - Even if not modified, still suffer extra latency and server load
- TTLs tend to be conservative
  - Shorter TTLs to reduce potential for staleness
  - Results in many requests back to server (10-20%)
Server-Driven Consistency

- Servers know when objects change
- We can have them tell caches when they change
  - Send invalidations
- Leases used to synchronize caches and server
  - Object leases: Short, per-object TTLs
    - Record cache has copy to send invalidations
  - Volume leases: Long, per-site TTLs
    - Amortize lease renewal for many objects
- Key issues
  - State to keep track of objects in proxy caches (can scale)
  - Load induced by bursts of invalidations (pace them)
Cooperative Caching

- Sharing and/or coordination of cache state among multiple Web proxy cache nodes
  - NLANR cache hierarchy most widely known
Cooperative Caching

- Idea: Increase number of users using caching system
  - Have caches “cooperate” and share content, users
  - Caches send their misses to other caches (e.g., to a parent cache in a hierarchy)
  - Can greatly increase number of users in system (and hit rate)
- Cooperative caching has also been a popular topic
  - I’ve even worked on it (part of my thesis)
- Many interesting issues: architecture, request routing, updates, scalability
- Utility depends on scale
  - Works well for small scales (depts.), but not very necessary
  - Some benefit for medium-scale (large city)
  - Large scale (national) not worth the complexity
Summary of Web Caching

- **Web caching**
  - Used every step of the way
  - Proxy caches give us about 50% hit rate
  - Many techniques for improving cache effectiveness
  - But cannot be the only answer

- What about P2P systems? Would caching work as well there?
Analysis of Content Distribution
(Sariou et al)

- Thirst for data continues to increase (more data & users)
- New types of data have emerged – audio, video
- People use new means to exchange this data

- The result – Internet is now seeing a mixture of old and new content delivery systems:
  - Conventional Web servers and Web clients
  - CDNs: Akamai, Digital Island, Speedera
  - P2Ps: Kazaa, Gnutella, Napster, Audio Galaxy

- High-level questions:
  - What is the (bandwidth) impact of these systems on the Internet?
  - What are the characteristics of the new delivery systems?
What applications use the most bandwidth?

- From University of Washington Trace
- Web = 14% of TCP; P2P = 43% of TCP
- P2P now dominates Web in bandwidth consumed!!!
## Bandwidth use asymmetry...

<table>
<thead>
<tr>
<th></th>
<th>WWW</th>
<th>Kazaa</th>
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<tbody>
<tr>
<td></td>
<td>inbound</td>
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<td>Bytes Xferred</td>
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Outbound bandwidth usage

- P2P has diurnal cycle, like the Web
- P2P peaks later at night
What kind of data is being sent?

Web = text + images
Akamai = images
Kazaa = video
Gnutella = video + audio
Object size

P2P objects are 3 orders of magnitude bigger than Web objects
## Most bandwidth consuming object

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## Top 5 bandwidth consuming objects

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<td>0.009</td>
<td>1.4 mil.</td>
<td>694.4</td>
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<tr>
<td>2</td>
<td>0.002</td>
<td>3 mil.</td>
<td>702.2</td>
</tr>
<tr>
<td>3</td>
<td>333</td>
<td>21</td>
<td>690.3</td>
</tr>
<tr>
<td>4</td>
<td>0.005</td>
<td>1.4 mil.</td>
<td>775.6</td>
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<tr>
<td>5</td>
<td>2.23</td>
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A few clients and servers exchange big, popular objects
# How is bandwidth distributed?

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Object Popularity

1,000 Kazaa objects (out of 111K) responsible for 50% of bytes transferred
Small number of clients account for large portion of traffic

- 200 Web+Akamai = 13% of traffic
- 200 Kazaa = 50% of traffic (20% of all incoming HTTP)
20 servers supply 80% of Web traffic

334 servers (10%) supply 80% of Kazaa traffic
The Internet is being used in a *completely* different way:
- P2P traffic is now the largest bandwidth consumer
- Peers consume significant bandwidth in both directions
- P2P objects are 1,000 times larger than Web objects
- Small number of huge objects are responsible for an enormous fraction of bytes transferred
  - 300 Kazaa objects consumed 5.6TB bandwidth!
- Few P2P peers are causing much of the traffic
- Caching isn’t going to help much here…