Last Class: Concurrency Control

- Concurrency control
  - Two phase locks
  - Time stamps

- Intro to Replication and Consistency

Today: Web caching

- Case Study: web caching as an illustrative example
  - Invalidate versus updates
  - Push versus Pull
  - Cooperation between replicas
Replica Placement

- Permanent replicas (mirroring)
- Server-initiated replicas (push caching)
- Client-initiated replicas (pull/client caching)

Web Caching

- Example of the web to illustrate caching and replication issues
  - Simpler model: clients are read-only, only server updates data

```
browser  request  Web server
    response

browser  request  Web Proxy cache
    request
    response
    response

browser  request  Web server
    response
```
Consistency Issues

- Web pages tend to be updated over time
  - Some objects are static, others are dynamic
  - Different update frequencies (few minutes to few weeks)
- How can a proxy cache maintain consistency of cached data?
  - Send invalidate or update
  - Push versus pull

Push-based Approach

- Server tracks all proxies that have requested objects
- If a web page is modified, notify each proxy
- Notification types
  - Indicate object has changed [invalidate]
  - Send new version of object [update]
- How to decide between invalidate and updates?
  - Pros and cons?
  - One approach: send updates for more frequent objects, invalidate for rest
Push-based Approaches

- **Advantages**
  - Provide tight consistency [minimal stale data]
  - Proxies can be passive

- **Disadvantages**
  - Need to maintain state at the server
    - Recall that HTTP is stateless
    - Need mechanisms beyond HTTP
  - State may need to be maintained indefinitely
    - Not resilient to server crashes

Pull-based Approaches

- Proxy is entirely responsible for maintaining consistency
- Proxy periodically polls the server to see if object has changed
  - Use if-modified-since HTTP messages
- Key question: when should a proxy poll?
  - Server-assigned *Time-to-Live (TTL)* values
    - No guarantee if the object will change in the interim
Pull-based Approach: Intelligent Polling

- Proxy can dynamically determine the refresh interval
  - Compute based on past observations
    - Start with a conservative refresh interval
    - Increase interval if object has not changed between two successive polls
    - Decrease interval if object is updated between two polls
  - Adaptive: No prior knowledge of object characteristics needed

Pull-based Approach

- Advantages
  - Implementation using HTTP (If-modified-Since)
  - Server remains stateless
  - Resilient to both server and proxy failures
- Disadvantages
  - Weaker consistency guarantees (objects can change between two polls and proxy will contain stale data until next poll)
    - Strong consistency only if poll before every HTTP response
  - More sophisticated proxies required
  - High message overhead
A Hybrid Approach: Leases

- **Lease**: duration of time for which server agrees to notify proxy of modification
- **Issue lease on first request, send notification until expiry**
  - Need to renew lease upon expiry
- **Smooth tradeoff between state and messages exchanged**
  - Zero duration => polling, Infinite leases => server-push
- **Efficiency depends on the lease duration**

![Diagram of A Hybrid Approach: Leases]

Policies for Leases Duration

- **Age-based lease**
  - Based on bi-modal nature of object lifetimes
  - Larger the expected lifetime longer the lease
- **Renewal-frequency based**
  - Based on skewed popularity
  - Proxy at which objects is popular gets longer lease
- **Server load based**
  - Based on adaptively controlling the state space
  - Shorter leases during heavy load
Cooperative Caching

- Caching infrastructure can have multiple web proxies
  - Proxies can be arranged in a hierarchy or other structures
    - Overlay network of proxies: content distribution network
  - Proxies can cooperate with one another
    - Answer client requests
    - Propagate server notifications

Hierarchical Proxy Caching

Examples: Squid, Harvest
Locating and Accessing Data

Properties
• Lookup is local
• Hit at most 2 hops
• Miss at most 2 hops (1 extra on wrong hint)

CDN Issues
• Which proxy answers a client request?
  – Ideally the “closest” proxy
  – Akamai uses a DNS-based approach

• Propagating notifications
  – Can use multicast or application level multicast to reduce overheads (in push-based approaches)

• Active area of research
  – Numerous research papers available