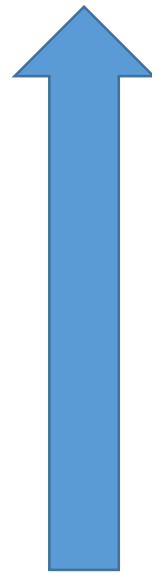
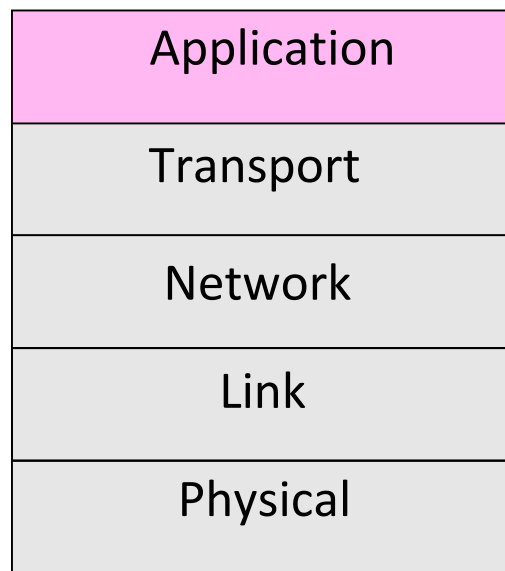


Applications!

Where we are in the Course

- Started from the bottom
 - Now we're here

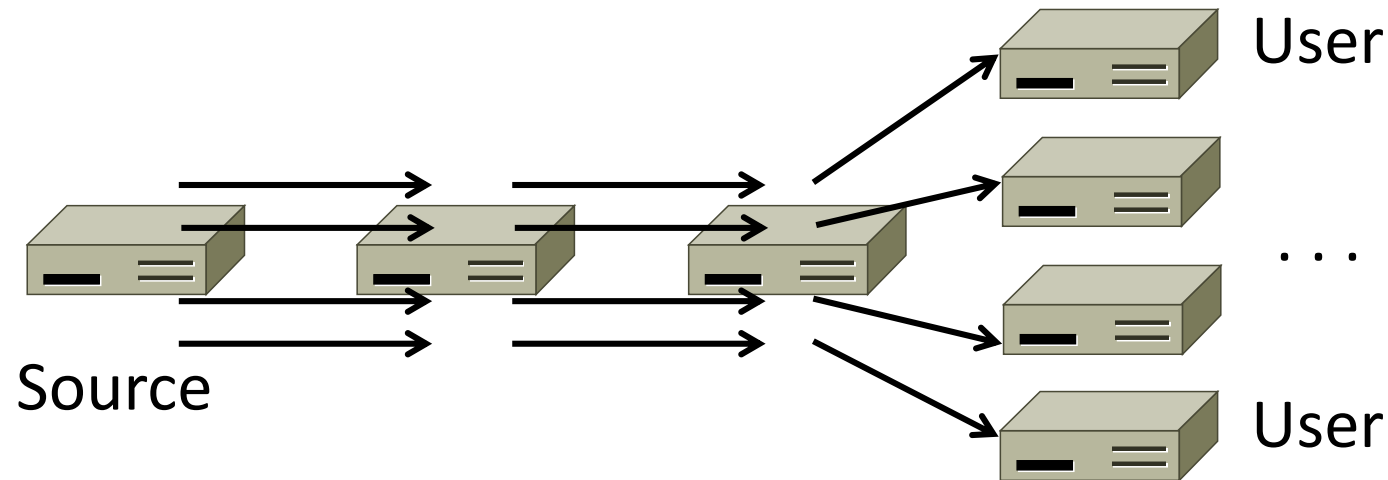


Content Delivery Networks

- As the web took off in the 90s, traffic volumes grew and grew. This:
 1. Concentrated load on popular servers
 2. Led to congested networks and need to provision more bandwidth
 3. Gave a poor user experience
- Idea:
 - Place popular content near clients
 - Helps with all three issues above

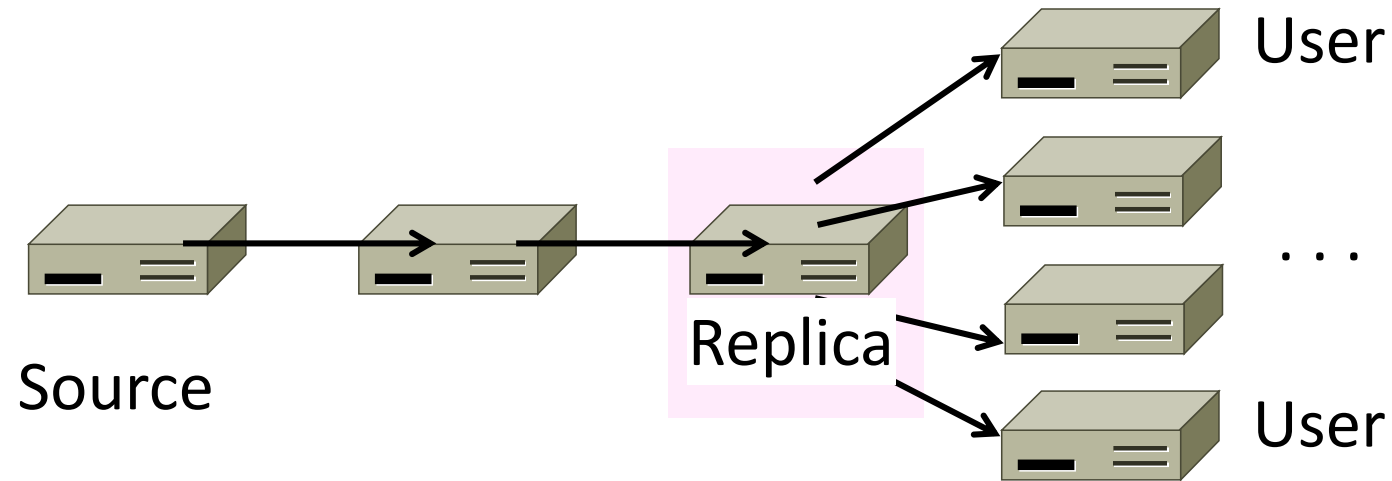
Before CDNs

- Sending content from the source to 4 users takes $4 \times 3 = 12$ “network hops” in the example



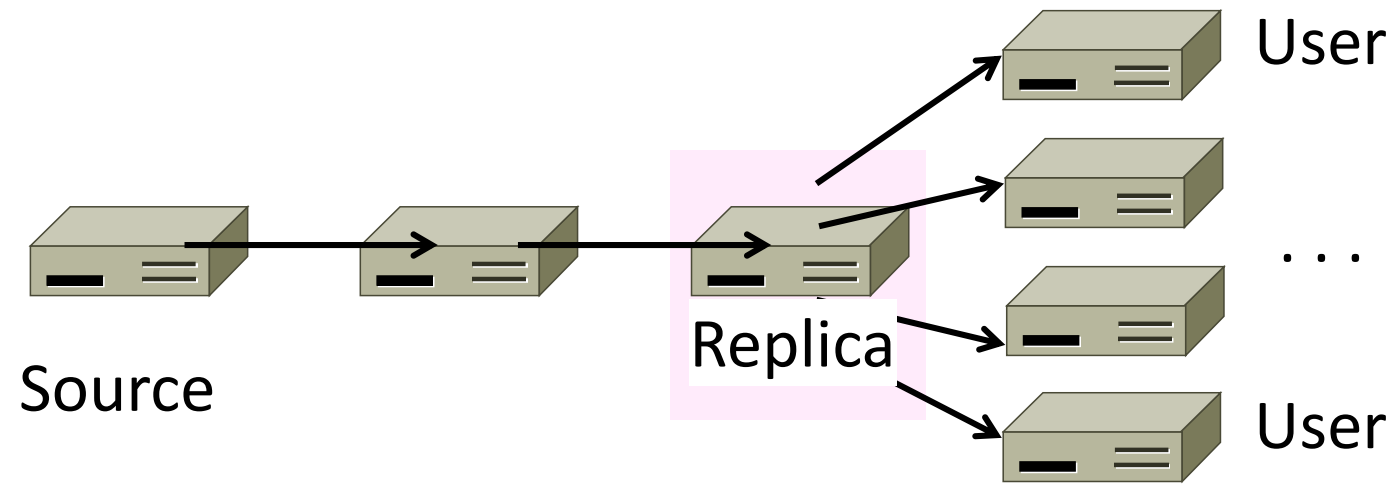
After CDNs

- Sending content via replicas takes only $4 + 2 = 6$ “network hops”



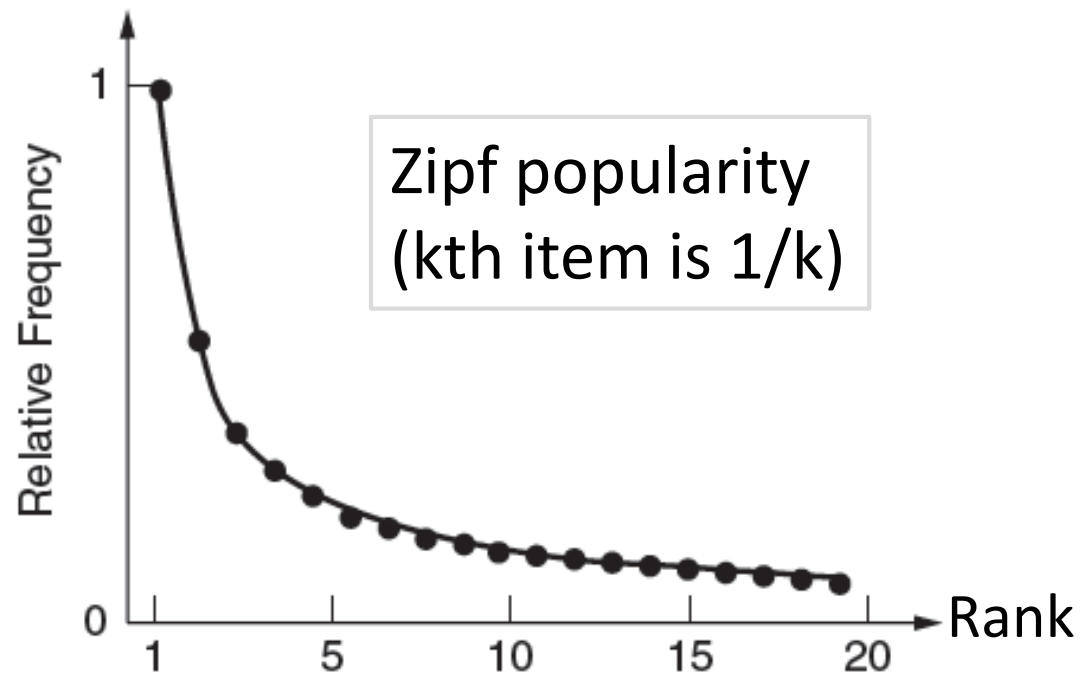
After CDNs (2)

- Benefits assuming popular content:
 - Reduces server, network load
 - Improves user experience (PLT)



Popularity of Content

- Zipf's Law: few popular items, many unpopular ones; both matter



George Zipf (1902-1950)

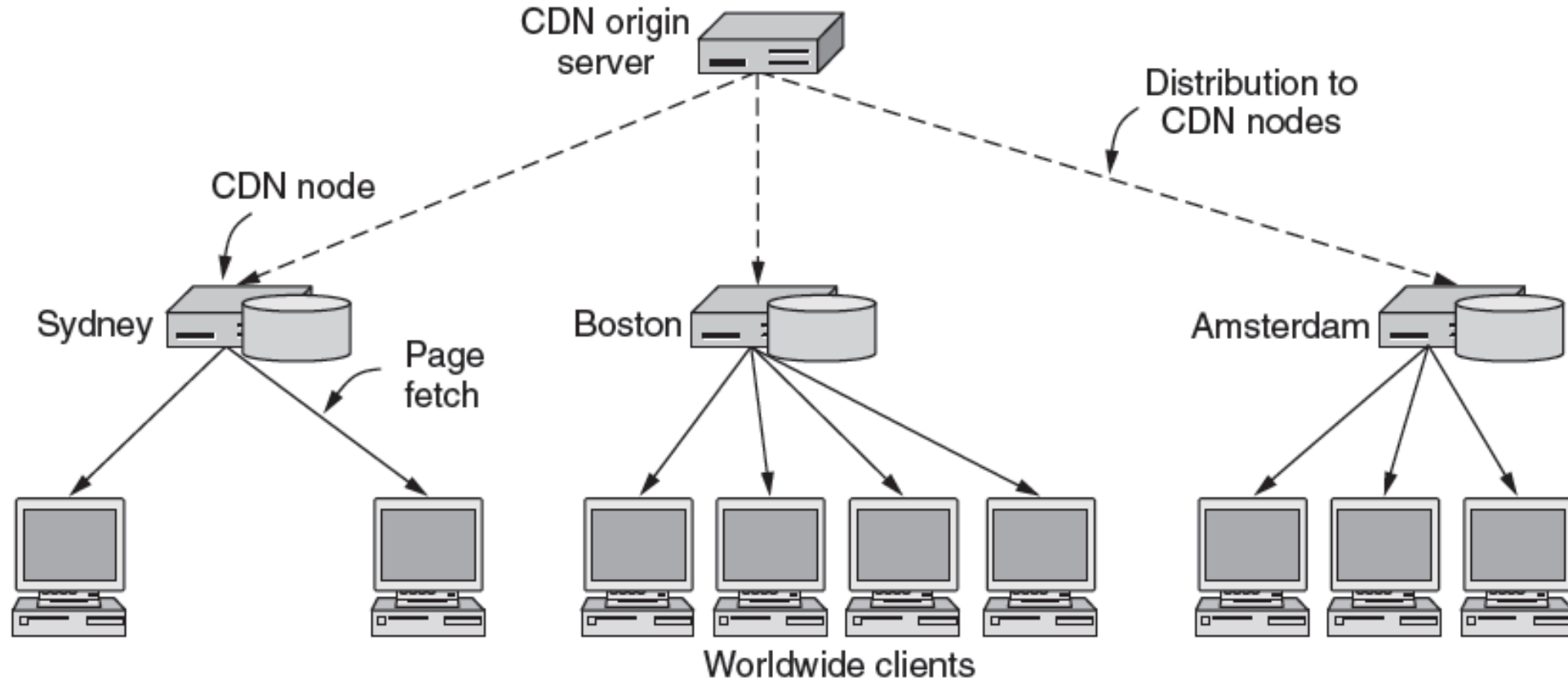


Source: Wikipedia

How to place content near clients?

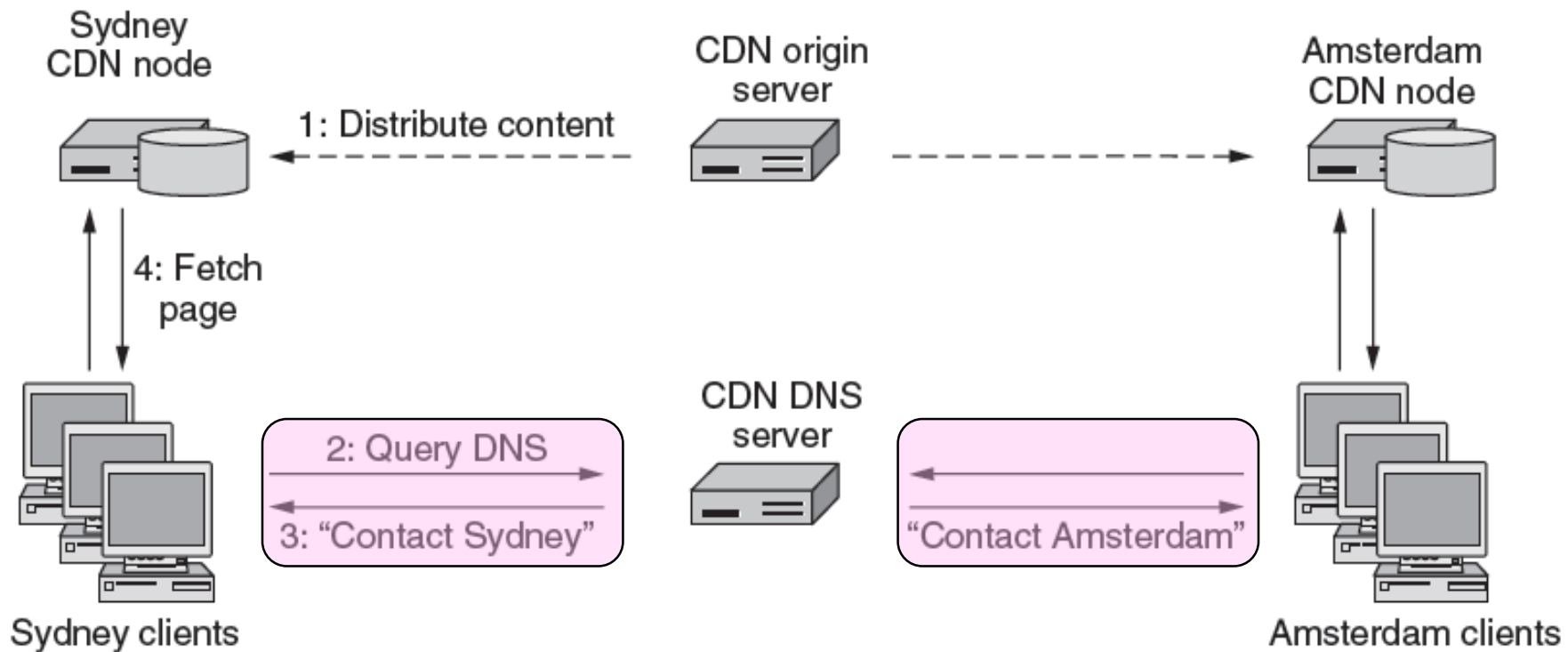
- Use browser and proxy caches
 - Helps, but limited to one client or clients in one organization
- Want to place replicas across the Internet for use by all nearby clients
 - Done by clever use of DNS

Content Delivery Network



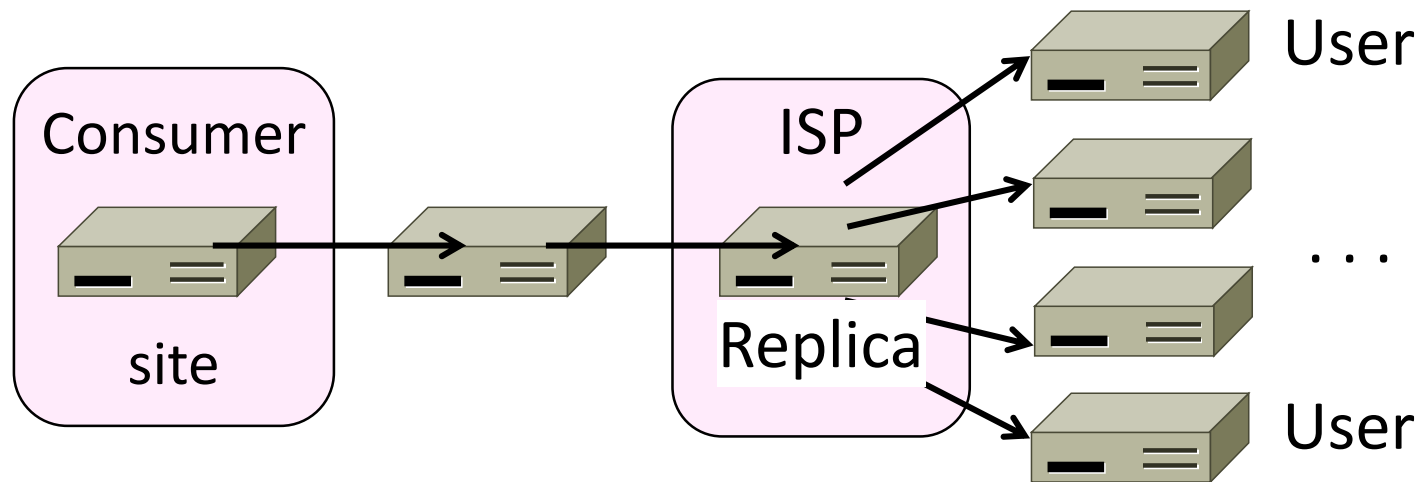
Content Delivery Network (2)

- DNS gives different answers to clients
 - Tell each client the nearest replica (map client IP)



Business Model

- Clever model pioneered by Akamai
 - Placing site replica at an ISP is win-win
 - Improves site experience and reduces ISP bandwidth usage



CDNs - Issues

- Security
 - What about private information?
 - How to cache/forward encrypted content
 - Basically can't!
- Net neutrality
 - I.org, FreeBasics -> Basically CDNs
 - But for reasons of price, not efficiency
 - Who decides who gets to place CDNs?

End-to-End principle

End-to-end

- Broad networking principle, specific to Internet-like networks
 - Not present in cellular networks, we'll talk about why later
- Idea: We are a node. We can send and receive messages with another node. This is our API. Do **as much as possible** at the ends, as the network cannot be trusted.
 - Not trusted to deliver without error (ECC)
 - Not trusted to delivery in order (TCP)
 - Not trusted to not snoop (TLS)
 - Not trusted to route at all (ARQ)

End-to-End

- What are the limitations of the End-to-End principle?