Modern Internet architecture, technology & philosophy

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Spring 2015
02/02/2015

Lecture 1: Key concepts

- The Internet as core civil infrastructure
  - similarities & differences to other infrastructures
- The notion of an interface
  - what makes interfaces important and when/how do they last?
- How does money flow into and out of the Internet?
- Which applications and key requirements did the Internet combine?

IP AS A CORE INFRASTRUCTURE INTERFACE

The great infrastructure

- Technical structures that support a society → “civil infrastructure”
  - Large
  - Constructed over generations
  - Not often replaced as a whole system
  - Continual refurbishment of components
  - Interdependent components **with well-defined interfaces**
  - High initial cost

water

energy

transportation

The Internet as core civil infrastructure

- Involved in all information exchange
  - (in a few years)
- Crucial to
  - commerce
  - governance
  - coordination
  - inter-personal communication
- Assumed to just be there
  - “plumbing”, “pipes”, …

The Internet as core civil infrastructure

For Immediate Release February 12, 2013

Executive Order -- Improving Critical Infrastructure Cybersecurity

EXECUTIVE ORDER

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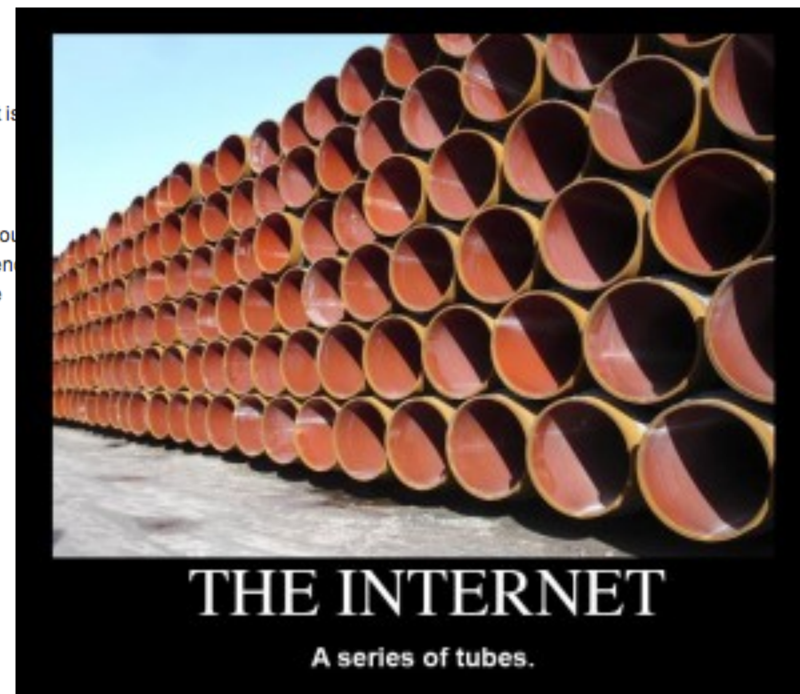
IMPROVING CRITICAL INFRASTRUCTURE CYBERSECURITY

By the authority vested in me as President by the Constitution and the laws of the United States of America, it i hereby ordered as follows:

Section 1. Policy. Repeated cyber intrusions into critical infrastructure demonstrate the need for improved cybersecurity. The cyber threat to critical infrastructure continues to grow and represents one of the most seriou national security challenges we must confront. The national and economic security of the United States depen on the reliable functioning of the Nation's critical infrastructure in the face of such threats. It is the policy of the



What's different?

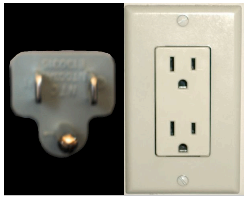
What	Utilities (gas, water, electricity)	Internet	Consumer electronics
Geographic scope	regional	local, national, international	mostly international
Economics	enabler	entry, competition, enabler	Trade, patents
Impact on culture	minimal	foundational	rarely (Walkman, iPhone)
Impact on domestic politics	in LDCs	jobs, education, health, transportation, copyright, income inequality	health & education (smartphones)
Impact on international politics	water rights?	trade, espionage, propaganda, cyberattacks, copyright, …	trade

What problems do networks solve?

- Diversity in technologies
  - wired vs. terrestrial wireless vs. satellite
  - trade-off capacity vs. cost vs. distance
- Variation in load
  - intermittent demand → shared networks
  - cannot design capacity for top 5 minutes of load
- “Noise”
  - electric noise
  - radio interference
- Human adversaries
  - denial-of-service attacks
  - information theft
  - impersonation

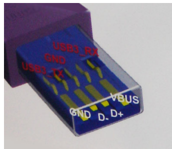
Interfaces: Energy

110/220V



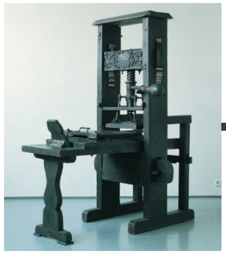
1904

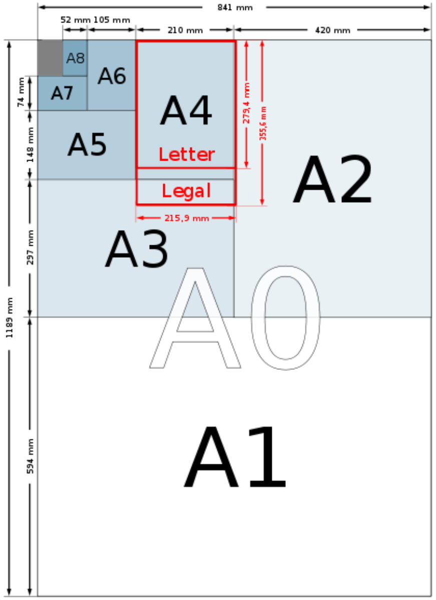
- Lots of other (niche) interfaces
- Replaced in a few applications



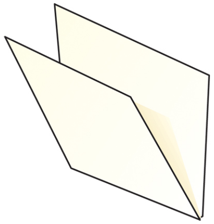
1901

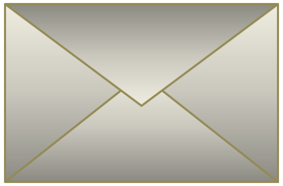
Interfaces: Paper-based information



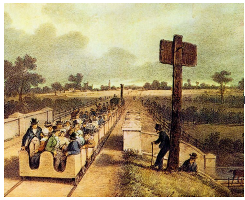


1798, 1922 (DIN)





Interfaces: Transportation



About 60% of world railroad mileage

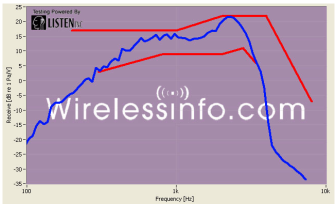
1435 mm

1830 (Stephenson)
1846 UK Gauge Act

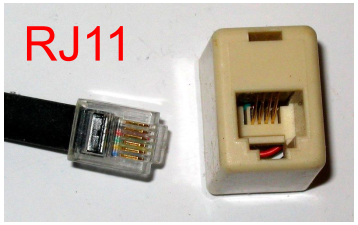
12’

Interfaces: Phone system

1949
Modular: 1975-

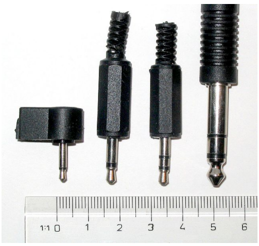


4 kHz spectrum
48 V off-hook
275 mV audio



1970s

Other long-lived interfaces



1878

Cigarette lighter
(1956)

1993

fuel nozzle

1982

1992

SQL
1974

What makes interfaces permanent?

- Widely distributed, uncoordinated participants
- Capital-intensive
  - depreciated over 5+ years
  - see Y2K problem
- Allocation of cost vs. savings
  - ISP saves money, end user pays
- Hard to have multiple at once
  - “natural monopoly”

Extrapolating from history

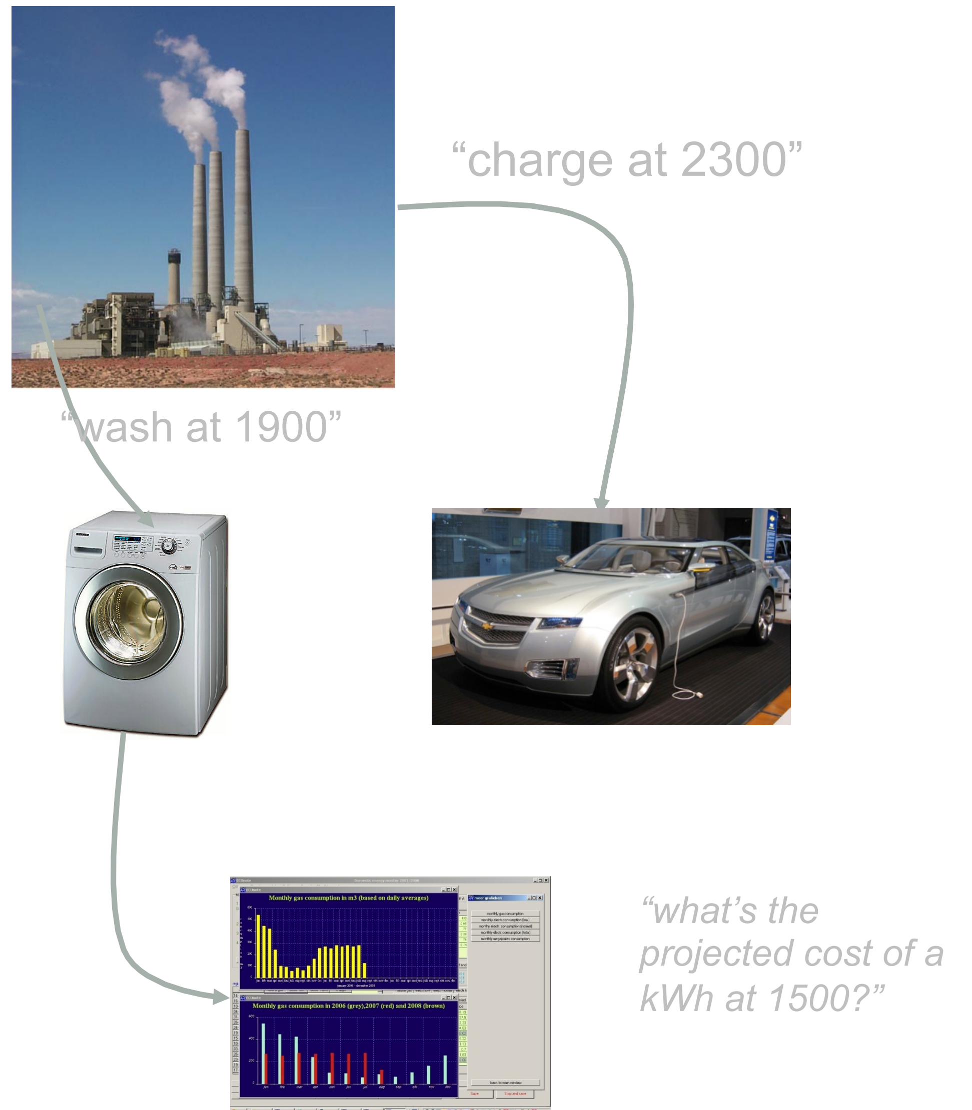
- IP now “the” data interface
- Unclear that any packet-based system can be
  - ≥ 10 times cheaper
  - ≥ 10 times more functionality
  - ≥ 10 times more secure
- Replacing phone system due to generality, not performance
  - IP offers general channel
- → We’re stuck with IPv4/IPv6
  - except for niche applications (car networks, BlueTooth, USB, …)

Integrating infrastructures: Energy

- Much of the improvement in civil infrastructure needs networks → information networks complement other networks
  - transportation
  - energy
- Energy time management
  - Plug-in hybrid is notified when it should charge
  - Dishwasher, water heater run after midnight
  - “when can I get 100 kW?”
- Utility requests load reduction
  - “please reduce load by 1 MW”
- Energy management
  - “Dear fridge, how many kWh have you used?”

Example: SmartGrid

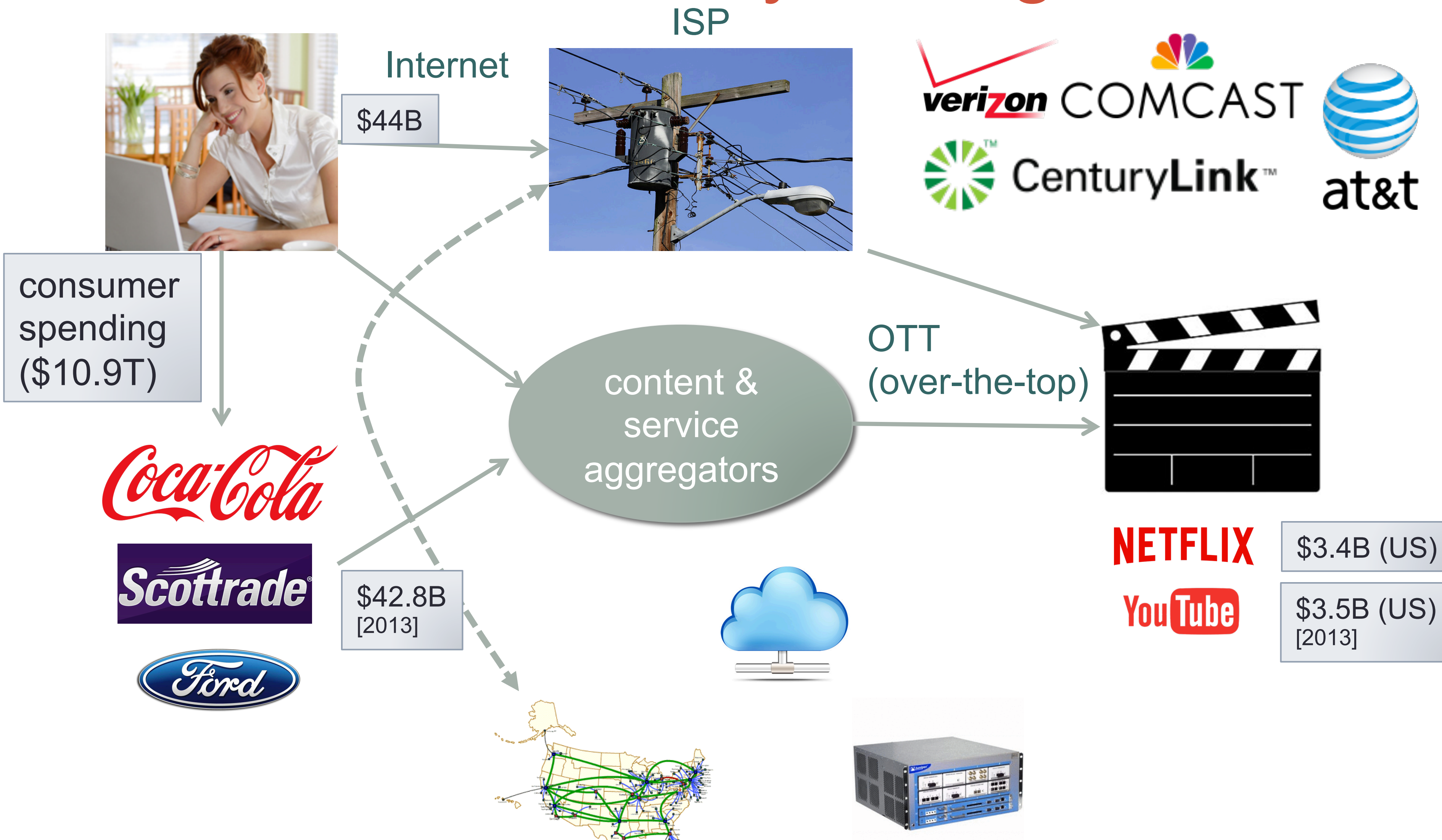
- Discover controllers and elements
  - Utility (gas, electric)
  - Local controllers
- Authenticate
  - Prices and actions may depend on customer contract
- Control
- Information



What has changed?

1980s/1990s	2000s+
Rapid technology evolution in network core	Relatively stable core technology
Internet exceptionalism (no distance! no borders!)	National laws & customs
Internet utopianism	“Big Switch”, harms & limitations
Performance!	Reliability?
Cost-insensitive (and “free” phone access)	Deployment cost barriers
Separated from commercial media (newspaper, magazines, radio, TV)	Affects all media
Self-revealed data (email, BBS)	Intimate data (information access, behavioral)
Little economic impact	One of the largest US exports

Basic Internet money routing

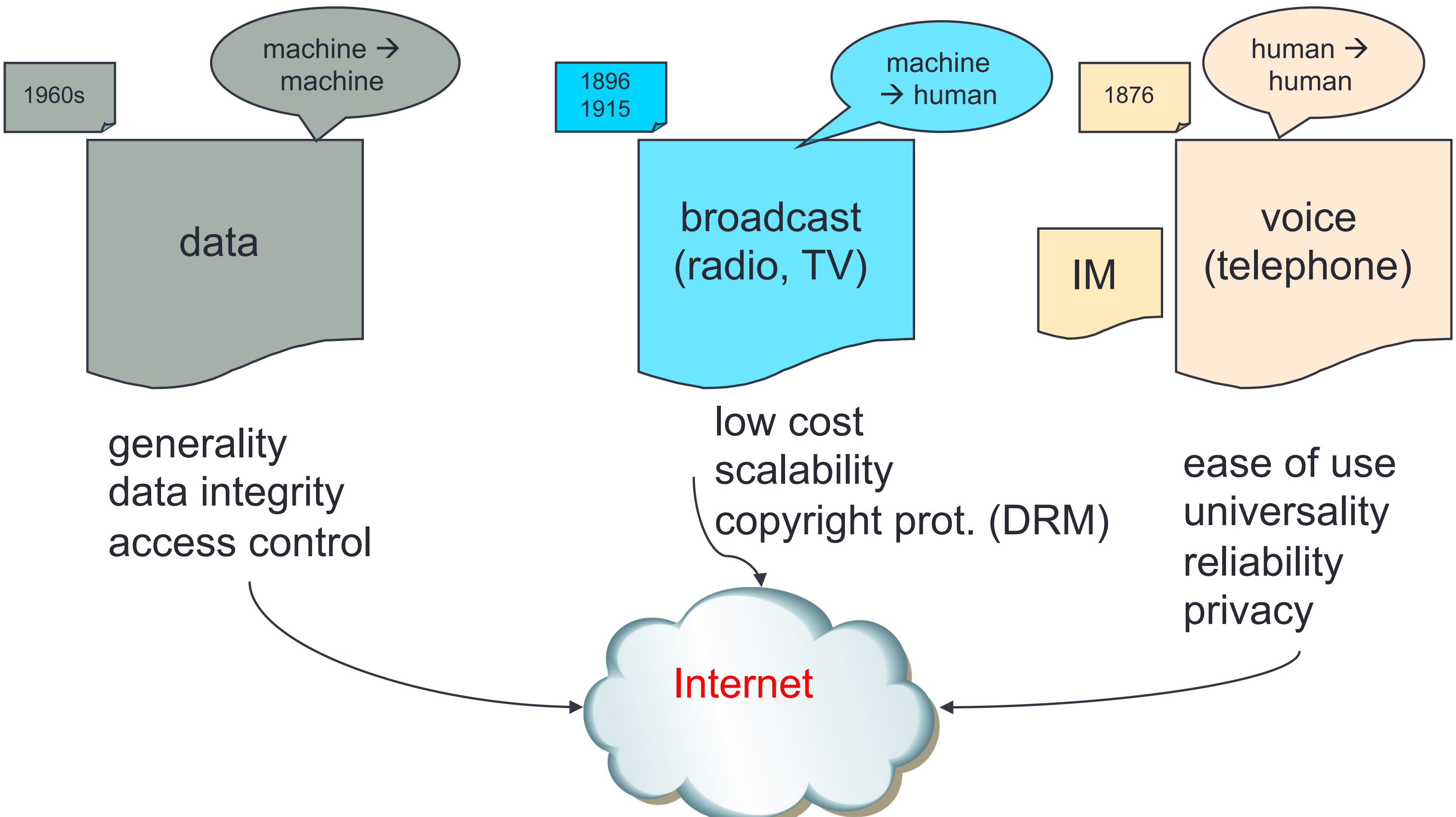


all $ figures US 2014, unless otherwise noted

INTERNET APPLICATIONS

Converging communities

since 1900: separate networks, companies, professions



Internet applications

- Variations on three themes: messaging, retrieval, continuous media
    - distinguish protocol vs. application behavior
- Messaging
    - datagram model → no direct confirmation of final receipt
    - e.g., email (optional confirmation now) and IM
    - emphasis on interoperation (SMS, pagers, …)
    - delays measured in *minutes*
- Retrieval & query (request/response)
    - "client-server"
    - e.g., ftp, HTTP
    - RPC (Sun RPC, DCE, DCOM, Corba, XML-RPC, SOAP)
    - emphasis on fast & reliable transmission
    - delays measured in *seconds*

Internet applications, cont'd

- Continuous media
  - generation rate ~ delivery rate ~ rendering rate
  - audio, video, measurements, control
    - Internet telephony
    - Multimedia conferencing
  - related: streaming media →slightly longer timescales for rate matching
    - video-on-demand
  - emphasis is on *timely* and low-loss delivery → *real-time*
  - delays measured in milliseconds