The Internet at (around) 50 - Mid-life crisis or New Realism?

HENNING SCHULZRINNE
Overview

Economics – what can the Internet realistically accomplish (and not)?

- age 5-15: “You can be president/movie star/astronaut when you grow up”
- age 15-25: “You have so much promise!”
- age 25+: “What pays the rent?”

Internet economics drives the architecture & constraints

Predicting the next ten years

Thoughts on Internet architecture
Innovation = Internet
“It’s finally happened. They’ve replaced the nightly news with cat videos.”
Internet as the consensus answer

Health care costs → Internet-based EHR! Tele medicine!
Income inequality → Internet for job searches! Learn coding!
Cost of education → MOOCs!
Global warming → Replace business travel by video conferencing!
Political oppression → Twitter & FB as citizen organizers!
Natural disasters & terrorism → Change FB profile picture!
Global conflict → Get to know your (former) enemy via social media!
Traffic congestion → Smart cities!

*Any difficult problem* → Internet app!

→ Positive effects often not quantified or shown
Lots of talk about innovation...

Google n-gram
MIRACLES YOU’LL SEE

Drop in by rocket plane on Totten-ville, the smokeless garden city where you’ll live in scientific comfort in A.D. 2000. You’ll cook by solar heat, shop by television in the world just around the corner.

for cutting tools and for massive machinery. The light metals have largely displaced it. Ways have been found to change the granular structure so that a metal is ultrasonic in a desired direction and weaker in other directions. As a result, the framework of an industrial or office building or apartment house is an almost lace-like lattice.

Thanks to these alloys, to plastics and to other artificial materials, houses differ from those of our own time. The Dobson house has light-metal walls only four inches thick. There is a sheet of insulating material an inch or two thick with a casing of sheet metal on both sides.

This Dobson air-conditioned house is not a prefabricated structure, though all its parts are mass-produced. Metal, sheets of plastic and scutched clay (clay filled with bubbles so that it resembles petrified sponge) are cut to size on the spot. In the center of this eight-room house is a unit that contains all the utilities—air-conditioning apparatus, plumbing, bathrooms, showers, electric range, electric outlets. Around this central unit the house has been pieced together. Some of it is poured plastic—the floors, for instance. By 2000, wood, brick and stone are ruled out because they are too expensive.

It is a cheap house. With all its furnishings, Joe Dobson paid only $5000 for it. Though it is galeproof and weatherproof, it is built to last only about 25 years. Nobody in 2000 sees any sense in building a house that will last a century.

Everything about the Dobson house is...
A Declaration of the Independence of Cyberspace

BY JOHN PERRY BARLOW

1996

Governments of the Industrial World, you weary giants of flesh and steel, I come from Cyberspace, the new home of Mind. On behalf of the future, I ask you of the past to leave us alone. You are not welcome among us. You have no sovereignty where we gather.

We have no elected government, nor are we likely to have one, so I address you with no greater authority than that with which liberty itself always speaks. I declare the global social space we are building to be naturally independent of the tyrannies you seek to impose on us. You have no moral right to rule us nor do you possess any methods of enforcement we have true reason to fear.

Why Learning To Code Won't Save Your Job

Brushing up on your tech skills might only make for temporary job security at best.
The Internet increases citizen engagement (if you don’t care what kind)
Industrial revolutions

Classical economics: Labor ($ output/hour worked) & total factor (includes capital invested) productivity

- → higher income (on average)
- Improved quality of life (health, education, opportunities, ...)

IR#1: 1760-1830
- Spinning jenny (1764), steam engine (1770), power loom (1780), Fulton steam boat, Liverpool rail road (1830), Macadam road (1820), Bessemer steel (1850)

IR#2: 1875-1900
- Telephone, radio, automobile, record player, air craft, ...

IR#3: 1985-2010
- Mainly information technology: personal computers & Internet
The inventions of Innovation Revolution #2 were so important and far-reaching that they took a full 100 years to have their main effect. The third revolution (IR #3) is often associated with the invention of the web and the Internet around 1995. But in fact, electronic mainframe computers began to replace routine and repetitive clerical work as early as 1960. The treatment below of IR #3 includes examples of the many electronic labor-saving inventions and convenience services that already were widely available before 1995.

With the timing of the three revolutions in place, we can now interpret history with a graph that links together many decades of dedicated research by economic historians to provide data on real output per capita through the ages. Figure 1 displays the record back to the year 1300 and traces the "frontier" of per-capita real GDP for the leading nation. The blue line represents the U.K. through 1906 (approximately the year when the U.S. caught up) and the red line the U.S. from then through 2007. Heroic efforts by British economic historians have established a rough estimate that the U.K. grew at 0.2 percent per year for the four centuries through 1700. The graph shows striking absence of the lack of progress; there was almost no economic growth for four centuries and probably for the previous millennium.

Robert Gordon 2014

Growth in GDP per capita (~productivity)
How Did Innovation in the Past Compare with the Past 40 Years?

10-Year Average Annual Growth in Total Factor Productivity, 1900-2012

Robert Gordon 2014
Let’s Think About How Minor the Progress Was in IR #2 vs. IR #3.

- The introduction of GPS navigation screens on autos compared to the invention of the auto itself.
- The introduction of the cell phone compared to the invention of the phone itself and the telegraph.
- The invention of home-streaming of movies to the invention of the motion picture itself.
- The invention of the ipod to the invention of the phonograph.
- The invention of the microwave oven to the replacement of cooking on the open hearth by the enclosed cast iron stove and later the kitchen range.
- Icemakers in refrigerators compared to the invention of the refrigerator or even the icebox.
- The conversion of card catalogues in libraries to electronic screens with the invention of electric light that made it possible to read books at night.
Transition in the labor force

Notes:
- White collar includes professional and technical, managerial, sales and clerical jobs.
- Blue collar includes machine operators, assembly, manual labor and construction jobs.
- Service includes food service, health care and personal service jobs.

Source: PUMS-USA, University Of Minnesota
Credit: Quoc Hung Bui/NIFF
The Great Prosperity: 1947–79

Pay Rose With Productivity...

Wages and overall compensation, for production and non-supervisory workers (now about 82 percent of the private sector work force), tracked steadily upward alongside gains in productivity.

The rising value of goods and services per worker meant rising pay. But that relationship ended in the 1970s.
# Employment – old vs. new social network

<table>
<thead>
<tr>
<th></th>
<th>Revenue (2015, $B)</th>
<th>Employees</th>
<th>Revenue/employee</th>
</tr>
</thead>
<tbody>
<tr>
<td>USPS</td>
<td>$68.9</td>
<td>491,863</td>
<td>$0.14M</td>
</tr>
<tr>
<td>Facebook</td>
<td>$17.9</td>
<td>12,691</td>
<td>$1.4M</td>
</tr>
</tbody>
</table>
Innovation did not disappear

Clearly, nobody would trade 2016 computer + smartphone for 1990 versions
- or a 1990s car
- or forego Amazon, FB, Google search & maps

But impact of Internet-related innovation did not fundamentally change work place
- for most occupations, at least
  - we still use LaTeX (*1985)!

Hunch: networks & IT are often just needed to compete for the same output
- e.g., high-speed trading (& overall financial sector)
- college applications

or to enable higher-complexity systems
- health insurance, taxes, advertising, ...
Change may seem sudden, but is visible

Early lab prototypes
- see “mother of all demos” (Doug Engelbart, 1968)

IPv6:
- discussion started in 1992
- standardized in 1996
- 10-25% deployment 20 years later

VoIP:
- tech demos 1978, revived early 1990s
- standards mid-1990s
- 2014: 40% deployment

Smartphone:
- first version 1994
- iPhone 2007

“The future has arrived — it’s just not evenly distributed yet.” (attributed to W. Gibson, 1992)
“We wanted flying cars, instead we got 140 characters”

Innovation on the cheap
  ◦ “we can’t build a transcontinental railroad any more, so we’ll write an app”
  ◦ that tells you how late Amtrak will be today

What tends to improve productivity
  ◦ reduce transportation lag (& cost)
  ◦ reduce labor for agriculture & manufacturing at scale
  ◦ reduce processing & coordination overhead for information-centric jobs

Economic impact
  ◦ tends to amplify differences in productivity

Can the Internet (or a better Internet) address
  ◦ global climate change?
  ◦ income inequality?
  ◦ chronic health conditions (obesity, dementia)
Some Internet economics
The great infrastructures

Technical structures that support a society → “civil infrastructure”

- Large
- Constructed over generations
- Not often replaced as a whole system
- Interdependent components with well-defined interfaces

Mostly noticed if absent

- water
- energy
- transportation
- communication
Innovations matter when they become infrastructure

Many of the fundamental advances matter only at scale

- public health & sanitation
- clean drinking water
- roads & railroads
- electricity
- telephone service

Not for all: medical, military, research tools, 3D printing, ...

Thus, the Internet matters as infrastructure, not technology as such
Communication models – ca. 1980

TV (& radio) broadcast

CATV

largely distributors

Telephone service (voice, modem data, fax)

one-to-one largely conduit
Internet economic models - now

Google Chatroulette
Google

Level 3
IP

Level 3
content and applications

Level 3
fiber or copper loop ("Homes with tails")

Level 3
vs.

Level 3
content production (*)

Level 3
advertising

Level 3
content distribution

Level 3
CDN

Level 3
broadband access

Level 3
local infrastructure

Level 3
regional and national backbone

Level 3
vs.

Level 3
AT&T + DirectTV

Level 3
Comcast/NBC (*)

Level 3
Verizon + AOL
The residential Internet is still getting faster

Akamai entrance of DOCSIS 2+ in several countries
VDSL in others
Broadening participation: the problem

Exhibit 6

Expenditures as a Share of After-Tax Income by Quintile (2013)

Source: Bureau of Labor Statistics Consumer Expenditure Survey, MoffettNathanson estimates and analysis
Reason for non-adoption

Table 2: Top Reasons for not Subscribing to an Internet Service at Home*

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No need</td>
<td>44%</td>
</tr>
<tr>
<td>Cost/expense</td>
<td>22%</td>
</tr>
<tr>
<td>Don’t use the Internet enough</td>
<td>10%</td>
</tr>
<tr>
<td>Lack of availability</td>
<td>6%</td>
</tr>
<tr>
<td>Access the Internet on a phone</td>
<td>4%</td>
</tr>
</tbody>
</table>

* Asked of those who do not currently get an Internet service at home and do not plan to subscribe in the next six months

= economics & policy
Internet usage by income

<table>
<thead>
<tr>
<th>Household income</th>
<th>Computer ownership</th>
<th>Internet use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than $25,000</td>
<td>62.4</td>
<td>48.4</td>
</tr>
<tr>
<td>$25,000 to $49,999</td>
<td>81.1</td>
<td>69.0</td>
</tr>
<tr>
<td>$50,000 to $99,999</td>
<td>92.6</td>
<td>84.9</td>
</tr>
<tr>
<td>$100,000 to $149,999</td>
<td>97.1</td>
<td>92.7</td>
</tr>
<tr>
<td>$150,000 and more</td>
<td>98.1</td>
<td>94.9</td>
</tr>
</tbody>
</table>

Note: About 4.2 percent of all households reported household Internet use without a paid subscription. These households are not included in this figure.
Barriers to Internet adoption

Non-Internet users face four categories of barriers

<table>
<thead>
<tr>
<th>Barriers directly affecting consumers</th>
<th>Incentives</th>
<th>Low incomes and affordability</th>
<th>User capability</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of awareness of Internet or relevant use cases</td>
<td></td>
<td>Low income or consumer purchasing power</td>
<td></td>
<td>Lack of digital literacy</td>
</tr>
<tr>
<td>Lack of relevant (e.g., local, localized) content and services</td>
<td></td>
<td>Total cost of ownership for device</td>
<td></td>
<td>Lack of language literacy</td>
</tr>
<tr>
<td>Lack of cultural or social acceptance</td>
<td></td>
<td>Cost of data plan</td>
<td></td>
<td>Lack of adjacent infrastructure (e.g., grid electricity)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consumer taxes and fees</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Root causes (e.g., providers, government/regulatory, industrial)

- High content and service provider costs and business model constraints
- Low awareness or interest from brands and advertisers
- Lack of a trusted logistics and payments system
- Low ease of doing business
- Limited Internet freedom and information security
- Challenging national economic environment
- High device manufacturer costs and business model constraints
- High network operator costs and business model constraints
- High provider taxes and fees
- Unfavorable market structure
- Under-resourced educational system
- Limited access to international bandwidth
- Underdeveloped national core network, backhaul, and access infrastructure
- Limited spectrum availability
- National ICT strategy that doesn’t effectively address issue of broadband access
- Under-resourced infrastructure development (e.g., FDI limits)

SOURCE: Literature review; expert interviews; McKinsey analysis
Internet industries have network effects

→ new Internet industries dominated by one or two players
  ◦ was partially true for broadcasting (“The Big Switch”)
  ◦ even more for Internet at all layers
    ◦ government monopolies: intellectual property (copyright, patents), spectrum
    ◦ scale effects (platforms)
    ◦ network effects (social networks)
    ◦ natural monopolies (infrastructure) → rarely more than two competitors

→ rent seeking behavior
The lighter the blue, the fewer the options. You get the point. The bar on the left reflects the availability of wired broadband using the FCC's current broadband definition of 4 Mbps. But let's be clear, this is "yesterday's broadband." Four megabits per second is not adequate when a single HD video delivered to home or classroom requires 5 Mbps of capacity. This is why we have proposed updating the broadband speed required for universal service support to 10 Mbps. But even 10 Mbps doesn't fully capture the increasing demand for better wired broadband, of which downstream speed is, of course, only one component. It's not uncommon for a U.S. Internet-connected household to have six or more connected devices—including televisions, desktops, laptops, tablets, and smartphones. When these devices are used at the same time, as they often are in the evenings, it's not hard to overwhelm 10 Mbps of bandwidth. And consumer demand is growing; today over 60% of peak-time downloads are streaming audio and video. While today that video may be for entertainment, other applications are right behind. For instance, if we are to tackle healthcare costs, high-speed broadband video for remote examination, diagnosis and even surgery is important. If our students are to get a 21st Century education, high-speed broadband to the classroom is essential. And, increasingly, that high-speed will be in both directions. As is proved here daily at 1776, high-speed connections are crucial not only for the kind of innovation that will educate our children and deliver quality health care, but also improve energy efficiency, fill the employment ranks, and maintain the United States as the world's innovation leader for the 21st Century.

* These data reflect speeds of 3 Mbps up / 768 kbps down, which the FCC uses as the best proxy for 4 Mbps / 1 Mbps. See, e.g., FCC, Eighth Broadband Progress Report, FCC 12-90, ¶ 29 (2010).

Competition models

Unbundled loops (asymmetric regulation)
- regulated pricing for dominant provider
- mainly for copper DSL (e.g., Germany, Italy, UK)

Two infrastructures → duopoly
- historical accident: copper + cable (in urban areas)
- Netherlands, US, Canada, W Germany

Fiber sharing
- works well in countries with lots of MDUs
- e.g., Korea, Japan

No country with more than two PHY providers for wireline
- economics for 2^{nd} and 3^{rd} overbuilder very hard
- except maybe for municipal networks competing with DSL
US industry structure

Until recently, periodic regulatory interventions changed industry structure. With more frequent updates being consistent with an increasing pace of change, an overhaul of the 1996 Act seems long overdue (but probably won’t happen).

This equilibrium is characterized by:

1. Three sustainably dominant supply-side firms (AT&T, Verizon, and Comcast): The dominant trio offer wireless-and-wireline services and are accompanied by a chorus of smaller companies (Bubbles of the Week #1) that may be more-or-less sustainable and/or investable, but whose role – like a classical Greek chorus – is largely limited to commenting on actions driven by the major players, whether regulatory (e.g., AT&T driving the D.C. debate about the IP transition), technological (e.g., Verizon driving LTE over WiMAX), or strategic (e.g., Comcast driving the sale of SpectrumCo and the rollout of cable Wi Fi).

2. Saturated demand for connectivity: With the progression from fixed voice to fixed broadband to mobile voice to mobile broadband largely complete, there are few high-value subscribers who do not have their full complement of connectivity. The demand-side endgame is therefore marked by a shift from rapid increases in penetration to inertial decisions about switching between providers or spending an increased proportion of wallet (e.g., by adding more connected devices and/or spending more per device). As such, organic changes in the share of value captured by different connectivity providers are likely to be relatively small.

3. Little chance of major disruption from new entrants, technology, or regulation: Unlike some sectors, in which the threat of disruptive forces makes any equilibrium unstable, in telecom barriers to entry are high (given the cost and operational complexity of deploying large-scale networks), technological change is incremental (largely about improved data-transmission protocols), and the chances of a major regulatory interventions are low, given the eroding jurisdiction of the FCC, the difficulty in pursuing antitrust violations arising from network-based...
US industry is dominated by ~12 providers

<table>
<thead>
<tr>
<th>Cable Companies</th>
<th>Subscribers at End of 2015</th>
<th>Net Adds in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comcast</td>
<td>23,329,000</td>
<td>1,367,000</td>
</tr>
<tr>
<td>Time Warner Cable</td>
<td>13,313,000</td>
<td>1,060,000</td>
</tr>
<tr>
<td>Charter</td>
<td>5,572,000</td>
<td>497,000</td>
</tr>
<tr>
<td>Cablevision</td>
<td>2,809,000</td>
<td>49,000</td>
</tr>
<tr>
<td>Suddenlink</td>
<td>1,223,000</td>
<td>73,900</td>
</tr>
<tr>
<td>Mediacom</td>
<td>1,085,000</td>
<td>72,000</td>
</tr>
<tr>
<td>WOW (WideOpenWest)</td>
<td>712,500</td>
<td>(15,300)</td>
</tr>
<tr>
<td>Cable ONE</td>
<td>501,241</td>
<td>12,787</td>
</tr>
<tr>
<td>Other Major Private Companies*</td>
<td>6,725,000</td>
<td>190,000</td>
</tr>
<tr>
<td><strong>Total Top Cable</strong></td>
<td><strong>55,269,741</strong></td>
<td><strong>3,306,387</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Telephone Companies</th>
<th>Subscribers at End of 2015</th>
<th>Net Adds in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
<td>15,778,000</td>
<td>(250,000)</td>
</tr>
<tr>
<td>Verizon</td>
<td>9,228,000</td>
<td>23,000</td>
</tr>
<tr>
<td>CenturyLink</td>
<td>6,048,000</td>
<td>(34,000)</td>
</tr>
<tr>
<td>Frontier*</td>
<td>2,444,000</td>
<td>101,500</td>
</tr>
<tr>
<td>Windstream</td>
<td>1,095,100</td>
<td>(36,500)</td>
</tr>
<tr>
<td>FairPoint</td>
<td>311,130</td>
<td>(8,785)</td>
</tr>
<tr>
<td>Cincinnati Bell</td>
<td>287,400</td>
<td>17,500</td>
</tr>
<tr>
<td><strong>Total Top Phone</strong></td>
<td><strong>35,191,630</strong></td>
<td><strong>(187,285)</strong></td>
</tr>
<tr>
<td><strong>Total Top Broadband Providers</strong></td>
<td><strong>90,461,371</strong></td>
<td><strong>3,119,102</strong></td>
</tr>
</tbody>
</table>
Capital investment is roughly 15% of revenues

<table>
<thead>
<tr>
<th>Company</th>
<th>Revenue</th>
<th>Capital expenditures</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comcast (US) [3Q14]</td>
<td>$11.04B</td>
<td>$1.644B</td>
<td>14.9</td>
</tr>
<tr>
<td>Telekom (DE) [3Q14]</td>
<td>€15.6B</td>
<td>$2.58B</td>
<td>16.5</td>
</tr>
<tr>
<td>Safaricom (KE) [H1FY15]</td>
<td>Ksh 79.34B</td>
<td>Ksh 12.37</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Comcast's Cable Capital Intensity

Charter Communications Inc. increased CapEx by 35% year-over-year to $570 million in the second quarter. Projects related to CPE and scalable infrastructure accounted for 70.9% of Charter's total spending; $134 million of the MSO's total CapEx was dedicated to its all-digital initiative. The company expects to spend $400 million on its all-digital initiative in 2014 out of a budgeted $2.2 billion total CapEx for the full year.

Suddenlink Communications' CapEx increased 8.7% year-over-year to $103 million in the second quarter. The company expects to spend between $410.0 million to $420.0 million in 2014, an increase of $50 million over the MSO's previous guidance. Suddenlink will begin investing $230 million in the second half of 2014 to increase HSD speeds to 1Gbps. The investment horizon of the project stretches through 2017, during which the MSO will upgrade data network headend equipment, replace any remaining deployed DOCSIS 2.0 customer premises equipment with DOCSIS 3.0 equipment, and complete its all-digital video conversion. Suddenlink expects to spend approximately $35 million of the total capital expenditures related to "Operation GigaSpeed" in the second half of 2014.

With the exception of Comcast, the three remaining cable operators that still break out the segment reported year-over-year declines in second-quarter commercial CapEx. Comcast's spending on commercial projects increased 13% year-over-year to $209 million in the three months to June 30. In aggregate, the four MSOs—Cablevision Systems Corp., Charter, Comcast and Suddenlink—reported $308 million in commercial CapEx in the quarter.

Cablevision attributed a 6.2% year-over-year decrease in CapEx to the timing of CPE purchases. CFO Gregg Seibert, however, expects no material change in total full-year CapEx compared to 2013 levels. Mediacom Communications Corp. also recorded a year-over-year decrease in CapEx to $123.4 million.

As of Aug. 2014. *Total excludes $13 million in discretionary capital. Total including discretionary spending was $1,493 mil. Source: Comcast. © 2014 SNL Kagan, a division of SNL Financial LC, estimates. All rights reserved.
Broadband cost

- 70%
- 30%
Internet architecture evolution
Networking is getting into middle years

<table>
<thead>
<tr>
<th></th>
<th>idea</th>
<th>current</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>1974 (RFC 675)</td>
<td>1981 (RFC 793)</td>
<td>35</td>
</tr>
<tr>
<td>telnet</td>
<td>1969 (RFC 15)</td>
<td>1983 (RFC 854)</td>
<td>33</td>
</tr>
<tr>
<td>ftp</td>
<td>1971 (RFC 114)</td>
<td>1985 (RFC 959)</td>
<td>31</td>
</tr>
<tr>
<td>http</td>
<td>1996 (RFC 1945)</td>
<td>1999 (RFC 2616)</td>
<td>20</td>
</tr>
<tr>
<td>SIP</td>
<td>1999 (RFC 2543)</td>
<td>2002 (RFC 3261)</td>
<td>17</td>
</tr>
</tbody>
</table>
Networks last a long time

![Graph: Mobile Network Technology Lifecycles (North America)](image)
What made the Internet successful?

- generality (cf. circuit switching)
- leverage semiconductor speed increases
- distributed service creation (with improving tools)
Still mostly intranets at layer 7

Standards progression
- Adobe Flash $\rightarrow$ HTML5, SVG, etc.

Standards regression
- instant messaging (SMS $\rightarrow$ SIP/SIMPLE + XMPP $\rightarrow$ WhatsApp)
- two identifiers (E.164 + RFC822) $\rightarrow$

Lacking (modern) standards for
- electronic health records
- interconnecting medical devices
- traffic data exchange (“this traffic light is red”)
- financial data exchange (still “wires” and manual entry of credit card numbers)
- invoices (e.g., travel reimbursement)
New Patient Intake Form

**Most common Electronic Health Record “System”**

### New Patient Intake Form

**Date of Birth:**

#### General Cardiovascular Symptoms
- Chest pain
- Cyanosis
- Sweating
- Edema (swelling)
- Exercise intolerance
- Poor appetite
- Inability to keep up with peers
- Shortness of breath at rest
- Shortness of breath w/mild exercise
- Fainting
- Dizziness
- Palpitations
- No concerning symptoms
- Other ________________________________

#### Review of Systems
- Weight change or poor appetite
  - Normal
  - Abnormal
- Bones / Joints
  - Normal
  - Abnormal
- Eyes
  - Normal
  - Abnormal
- Skin
  - Normal
  - Abnormal
- Ears
  - Normal
  - Abnormal
- Nervous system
  - Normal
  - Abnormal
- Nose
  - Normal
  - Abnormal
- Emotional/Behavioral
  - Normal
  - Abnormal
- Throat
  - Normal
  - Abnormal
- Blood / Lymph system
  - Normal
  - Abnormal
- Heart / Circulation
  - Normal
  - Abnormal
- Hormones / Glands
  - Normal
  - Abnormal
- Stomach /Digestion
  - Normal
  - Abnormal
- Allergic /Immunologic
  - Normal
  - Abnormal
- Kidneys /Bladder
  - Normal
  - Abnormal
- Allergies:
  - Yes
  - No
  - None
  - 1% Neutropenia

#### Immunizations up to date:
- Yes
- No
- Declined

#### Past History
- Hospitalizations, Surgeries, Major Illnesses:
  - Problem:
    - Date / Pt age:
  - Problem:
    - Date / Pt age:
  - Problem:
    - Date / Pt age:
  - Problem:
    - Date / Pt age:

#### Patient Medical History
- ADHD
  - Yes
  - No
- Rheumatic fever
  - Yes
  - No
- G-tube
  - Yes
  - No
- Asthma
  - Yes
  - No
- Sickle cell anemia
  - Yes
  - No
- Glenn
  - Yes
  - No
- Cancer
  - Yes
  - No
- Trisomy 21
  - Yes
  - No
- Mitral valve replace
  - Yes
  - No
- Chronic lung disease
  - Yes
  - No
- Tuberous sclerosis
  - Yes
  - No
- Nissen fundoplication
  - Yes
  - No
- Congenital heart disease
  - Yes
  - No
- Turner syndrome
  - Yes
  - No
- Norwood
  - Yes
  - No
- DiGeorge syndrome
  - Yes
  - No
- Arterial switch
  - Yes
  - No
- PDA ligation
  - Yes
  - No
- GERD
  - Yes
  - No
- ASD repair
  - Yes
  - No
- PE tubes
  - Yes
  - No
- Kawasaki disease
  - Yes
  - No
- AVR
  - Yes
  - No
- TOF repair
  - Yes
  - No
- Muscular dystrophy
  - Yes
  - No
- BT shunt
  - Yes
  - No
- Tonsillectomy
  - Yes
  - No
- Obesity
  - Yes
  - No
- CAVC repair
  - Yes
  - No
- Adenoidectomy
  - Yes
  - No
- Sleep apnea
  - Yes
  - No
- Coarctation repair
  - Yes
  - No
- VSD repair
  - Yes
  - No
- Prematurity
  - Yes
  - No
- Fontan
  - Yes
  - No

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**GI 2016**
What has been less than successful?

What can we learn from 40+ years of Internet research?

**Network-layer functionality**
- IP mobility
- IP multicast
  - beyond local network
- IPsec (cf. to TLS)
- QoS
  - beyond basic two-level priority
- CCN (predicting)
  - static content and deep network architecture

**Goal of maintaining low complexity has faded**
- only a handful of implementations of most network protocols
- 3 browsers, 3 web servers, 2 operating systems (Android = Linux here)
Physical network architecture

- only 3-4 realistic locations for storage → complexity may not pay off
- some video content is customized
- most HTML content is program-generated

Direct peering

P2P

Regional fiber loop (passive)

E.g., Netflix OpenConnect
Evolving towards a new architecture

Keep IPv6 as a substrate
  ◦ as well as eBGP, TCP, ...

Unlikely, but…: unified control protocols
  ◦ patterns: configuration, on-path control, route exchange
  ◦ share encoding, security, reliability, discovery, session

Generalize SDN + fog model + CCN
  ◦ any node can host (authorized) code
  ◦ some provides CDN functionality
  ◦ some control nearby switches
  ◦ provide generalized location-based discovery (rather than specialized CCN model) of resources
What’s missing?

Increasing dominance of network operations costs (cf. to capacity costs)

→ Much better autonomous management systems at scale

Network management without a human in the loop

Automated discovery of failures & performance problems

More robust network support functions (AAA, DNS, DHCP)
My 2026 predictions

Still largely the same transmission technology
  ◦ fiber, OFDM

Still largely the same lower-layer protocols
  ◦ even for 5G
  ◦ but finally mostly IPv6

Similar applications
  ◦ but scaled up & integrated

Lots of boring new applications
  ◦ electric meter reading! finding parking spots!

Fewer cords (last mile & last foot)
Could things get worse?

Technology always gets better, but society doesn’t

Risk factors:

- income stagnation → limited mass-market deployment
- geographic fragmentation
- privacy risk by integration of carrier traffic data into advertising
- “cableization” fragmentation of Internet
- political fragmentation & tribalization increased by Internet personalization
- security risks – Internet suitable only for cat pictures
- RF discovered to have significant health risks
Summary

As engineers, we should not overestimate the impact (and ignore the trade-offs)
Internet as cheap substitute for larger changes that we are unable or unwilling to make
Reflect more critically on what technical contributions have mattered and why
What are plausible architecture options and what’s missing?