The Internet has come of age:

or has it?

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Douglas Adams on technology

1. everything that's already in the world when you're born is just normal;

2. anything that gets invented between then and before you turn thirty is incredibly exciting and creative and with any luck you can make a career out of it;

3. anything that gets invented after you're thirty is against the natural order of things and the beginning of the end of civilisation as we know it until it's been around for about ten years when it gradually turns out to be alright really.

`http://www.douglasadams.com/dna/19990901-00-a.html`

► Give the start date of the Internet as 1997
  ▷ the year my Mum heard of the Internet

► by Adams' argument, the Internet will come of age next year!
  ▷ should we start planning the party?

Me?

So what am I doing here talking to you about the Internet?

► worked for AT&T in the US
  ▷ arguably ran the largest single chunk of what we call the Internet
    `http://www.att.com/news/2003/12/11-12627`

► I spent my time trying to measure the Internet
  ▷ traffic
  ▷ performance
  ▷ routing/topology

An outline

How do we decide if the Internet has come of age

- ▶ size?
- ▶ stability?
- ▶ maturity?

Oh, and somewhere in here, I'd better tell what the Internet is.

Does size matter?

Customer: I've been enjoying the Internet, and I wanted to show my Mum. Can I buy a copy of the Internet, please?

Sales: No, it won't fit on a disk.

Customer: Oh! How many disks will I need then?

Sales: about 200,000

Customer: (strange strangling sound)

Traffic volumes

- ► April 2003, in one day AT&T carried 1 petabyte of traffic a day in North America alone
- ► 1 petabyte
  - ▷ 10^{15} bytes
  - ▷ 2000 × 500 Gbyte disks
  - ▷ 180 × the US library of congress
  - ▷ estimated 2 petabytes as the contents of all U.S. academic research libraries

How big is it?

- ► Internet size estimate
  - ▷ 1 petabytes

```
http://www.circuitcellar.com/library/
priorityinterrupt/194.htm
```

- ► Google reported to have
  - ▷ 4 petabytes memory

```
http://glinden.blogspot.com/2006/06/
four-petabytes-in-memory.html
```

- ► Wayback Machine (archive of the WWW)
  - ▷ 2 petabytes

```
http://www.archive.org/about/faqs.php
```

```
http://www.findarticles.com/p/articles/mi_m0NUH/is_7_37/ai_103382430
```

```
http://ayub.blogspot.com/search/label/Internet
```
The Library of Congress in Washington D.C. is said to be the world's largest library with over 28 million volumes

```
http://robotfuturenews.blogspot.com/2006_07_30_robotfuturenews_archive.html
```

More references
```
http://en.wikipedia.org/wiki/Petabyte
http://www.techworld.com/opsys/features/index.cfm?fuseaction=
displayfeatures&featureid=467&page=1&pagepos=6
```

Dollars and sense

- ► Google+Yahoo!+eBay+Yahoo!Japan + Amazon.com
  - ▷ pre-2000: $2B
  - ▷ Nasdaq peak (2000), $178B
  - ▷ Nasdaq trough (2002), $32B
  - ▷ Nov.2006, $259B
- ► 8% of total US advertising online
  - ▷ estimate 13% in 5 years

Morgan-Stanley, Nov 2006

http://www.morganstanley.com/institutional/techresearch/webtwopto2006.html

Outline

How do we decide if the Internet has come of age

- ► size → clearly the Internet is big enough
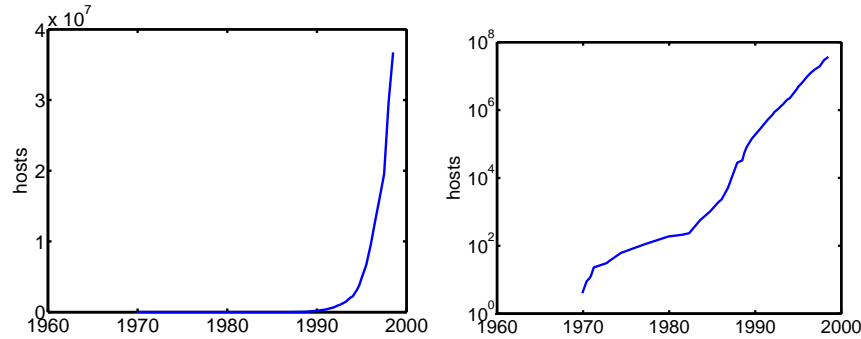- ► **stability?**
- ► maturity?

Early Internet Growth

http://www.zakon.org/robert/internet/timeline/#1990s

Date (mm/yy)	hosts
08/1981	213
01/1992	727,000
01/1997	19,540,000

Internet Traffic Growth

Traffic roughly doubles every year [10].

Traffic in TB per month
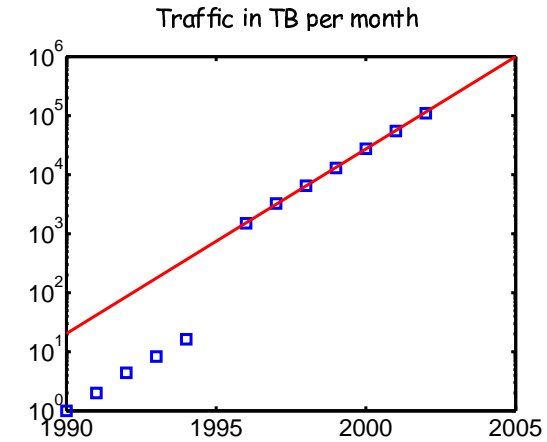
Combination of new users and higher bandwidth!

Internet traffic was believed to overtake telephone traffic around 2002.

Extrapolated Internet growth from 90's data.
http://www.cc.gatech.edu/gvu/stats/NSF/Extrap.GIF

Drivers of growth

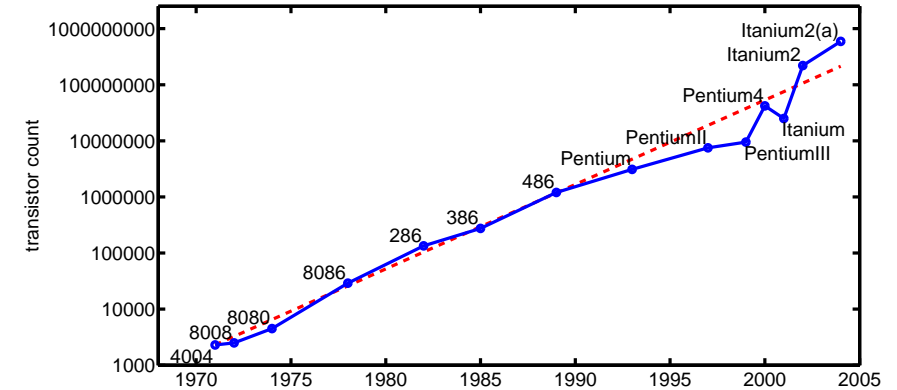- ▶ Moore's Law
- ▶ Gilders Law (and Nielson's)
- ▶ Metcalfe's Law

Moore's Law

Moore's law: the speed of digital hardware increases by a factor of two every 18 months, or the number of transistors on a chip doubles, or the cost halves [4].

Actually looks more like a factor of 2 every 2 years.

Intel's pages on Moore's law:
http://www.intel.com/technology/mooreslaw/index.htm
ftp://download.intel.com/research/silicon/moorespaper.pdf

Other links to Moore's law:
http://en.wikipedia.org/wiki/Moore's_law
http://www.thocp.net/biographies/papers/moores_law.htm
http://www.firstmonday.org/issues/issue7_11/tuomi/
http://www.hyperdictionary.com/computing/moore's+law
http://www.physics.udel.edu/wwwusers/watson/scen103/intel.html
http://www.ziplink.net/~lroberts/Forecast69.htm
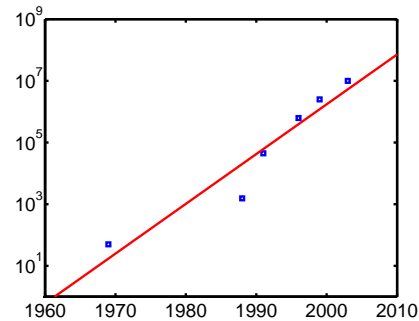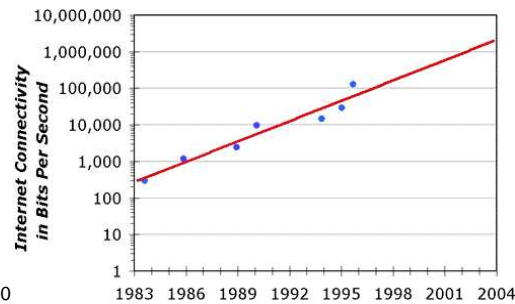
Gilder's law: theoretical transmission capacity of a link increases by a factor of two every 12 months.

- ► backbone link capacity approx. doubling in 2 years
- ► access links likewise (Nielsen's Law)

Backbone link bandwidth in kbps

Access link bandwidth

- ► The value of a network goes as $O(N^2)$
- ► Metcalfe's law also drives the Internet
  - ▷ hence the failure of many "video-phone" trials
    - ⋆ but success of most recent "camera phones"
- ► Actually probably more like $O(N \log N)$
  `http://spectrum.ieee.org/jul06/4109`

```
http://www.seas.upenn.edu/~gaj1/promise.html
http://www.dtc.umn.edu/~odlyzko/doc/tv.internet.txt
http://telecomvisions.com/articles/beyondip/
http://www.useit.com/alertbox/980405.html
```

Backbone link speeds
- ► 1969: 50kbps
- ► 1988: NSFNET backbone upgraded to T1 (1.544Mbps)
- ► 1991: NSFNET backbone upgraded to T3 (44.736Mbps)
- ► 1996: MCI upgrades Internet backbone 622Mbps
- ► 1999: MCI/Worldcom begins upgrading the US backbone to 2.5 Gbps (OC48)
- ► circa 2003: 10 Gbps (OC192)

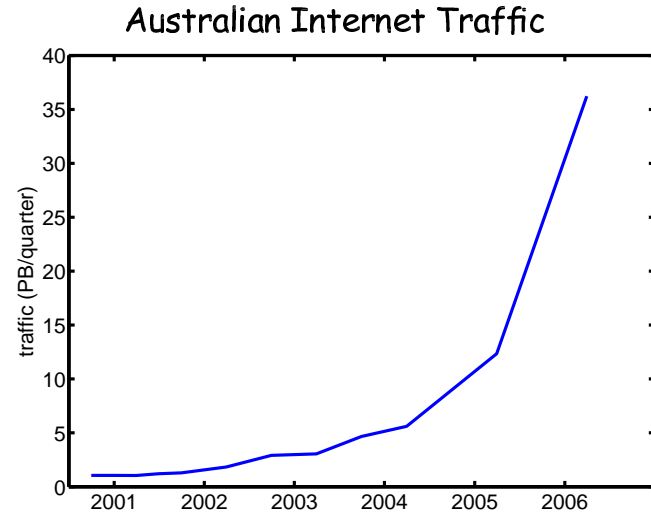Backbone speeds are behind limits of transmission tech.
`http://www.zakon.org/robert/internet/timeline/`

Exponential growth

Australian Internet Traffic

Exponential Growth

Australian Internet Traffic
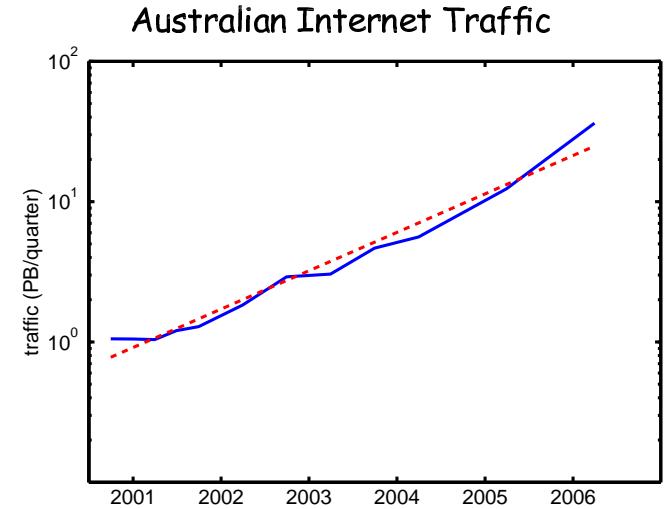
Doubles in roughly 400 days

Measurements taken from the Australian Bureau of Statistics: see
http://www.abs.gov.au/AUSSTATS/abs@.nsf/allprimarymainfeatures/
6445F12663006B83CA256A150079564D?opendocument

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http://www.abs.gov.au/AUSSTATS/abs@.nsf/allprimarymainfeatures/
6445F12663006B83CA256A150079564D?opendocument

See Andrew Odlyzko's page for more on the growth of traffic,
http://www.dtc.umn.edu/~odlyzko/

Will it ever stabilise?

Moore's law failure predictions have always failed
But

► the number of users is finite

► the amount of time they can spend on the web is finite

► so growth should at least slow to growth of access line speeds?

► maybe it will even drop back to linear growth?
  ▷ most other technologies saturate the market at some point

► maybe it will still grow?
  ▷ machine to machine traffic

Outline

How do we decide if the Internet has come of age

► size → clearly the Internet is big enough

► stability → clearly not!

► **maturity?**

Maturity

Lets have a brief history of networking

1. pre-industrial

2. 19th century

3. early 20th century

4. computer networks

5. early 21st century (now)

More detailed telephony timelines can be found at
```
http://www.telephonetribute.com/timeline.html
http://www2.fht-esslingen.de/telehistory/
```
Histories of computing and computer networks
```
http://en.wikipedia.org/wiki/Computing_timeline
http://www.isoc.org/internet/history/
```
Australian telecoms history
```
http://www.caslon.com.au/timeline.htm
http://www.anu.edu.au/people/Roger.Clarke/II/OzIHist.html
```

Pre-industrial

- ▶ Jungle drums

- ▶ Signal fires
  1184 BC, fall of Troy [1]
  1588 AD, Arrival of Spanish
  Armada

- ▶ Carrier pigeons
  700 BC, Olympic games

- ▶ Smoke signals
  150 AD, Romans

- ▶ Semaphore
  1791 AD, Chappe brothers
  later used by Napoleon

Marathon: One of the more famous events in early telecommunications occurred in September 490 BC. The Greeks defeated a much larger Persian army (numbering in the hundreds of thousands as compared to the Greeks who had more like 10,000 soldiers). An Athenian herald, Pheidippides, ran from Marathon to Athens to deliver the message "We were victorious!", following which he immediately died.

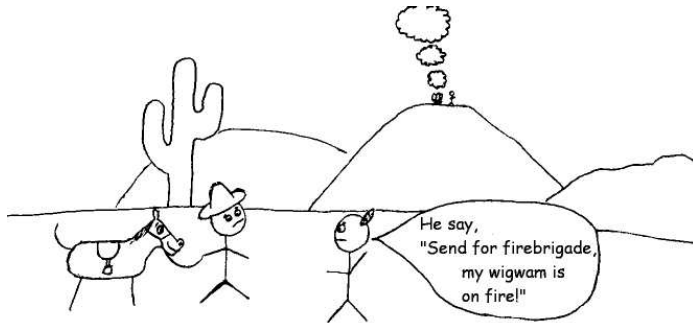Most telecommunications providers would prefer not to die :-)

Pre-industrial

These had limitations

- ► **Carrier pigeons:** `1 short message per pigeon`
- ► **Signal fires:** `one bit per fire`
- ► **Semaphore:** `15 characters per minute.`

19th century

Electronic communication:

- ► telegraph
  - ▷ invented 1753
  - ▷ Morse code 1835
  - ▷ take off 1838
  - ▷ 1st transatlantic line 1866
- ► radio (Marconi, 1896)
- ► telephone
  - ▷ A.G. Bell
  - ▷ filed patent Feb. 14, 1876, 3 hours before Elisha Gray

In 1876, Bell and his financial backer, G.G. Hubbard, offered Bell's patent to the ancestor of Western Union. Their committee to investigate the patent reads in part:

"The Telephone purports to transmit the speaking voice over telegraph wires. We found that the voice is very weak and indistinct, and grows even weaker when long wires are used between the transmitter and receiver. Technically, we do not see that this device will be ever capable of sending recognizable speech over a distance of several miles.

"Messer Hubbard and Bell want to install one of their "telephone devices" in every city. The idea is idiotic on the face of it. Furthermore, why would any person want to use this ungainly and impractical device when he can send a messenger to the telegraph office and have a clear written message sent to any large city in the United States?

"The electricians of our company have developed all the significant improvements in the telegraph art to date, and we see no reason why a group of outsiders, with extravagant and impractical ideas, should be entertained, when they have not the slightest idea of the true problems involved. Mr. G.G. Hubbard's fanciful predictions, while they sound rosy, are based on wild-eyed imagination and lack of understanding of the technical and economic facts of the situation, and a posture of ignoring the obvious limitations of his device, which is hardly more than a toy... .

"In view of these facts, we feel that Mr. G.G. Hubbard's request for $100,000 of the sale of this patent is utterly unreasonable, since this device is inherently of no use to us. We do not recommend its purchase."
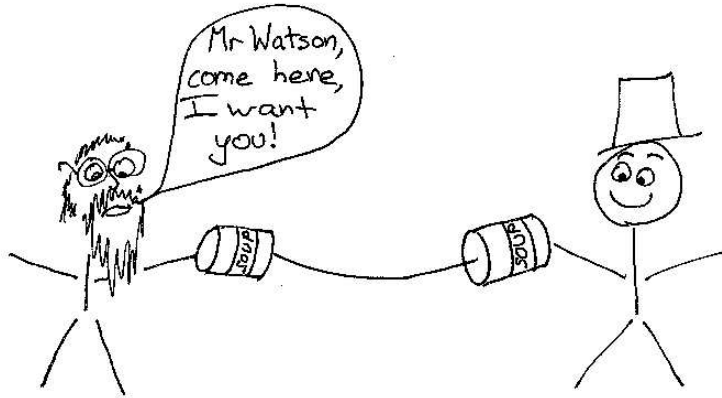
The amusing thing about this letter, in retrospect, is that Bell obtained controlling interest in Western Union by 1882!

19th century

Simple telephone: connects two points with a wire

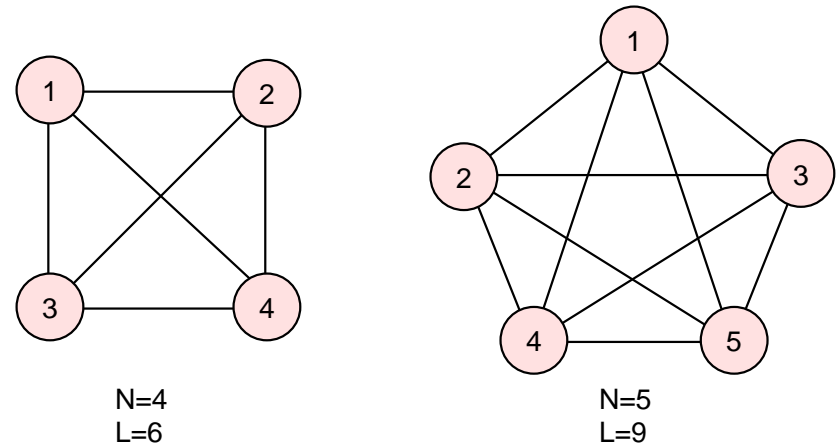Reportedly, the first words over the telephone came when Bell spilled some acid on his pants, whereupon he call "Mr. Watson, come here, I want you!"

Dumb network design

One link between every pair who wish to speak

N=4
L=6

N=5
L=9

N nodes, then we have L=N(N-1)/2 links

Dumb network design

Pratt, Kansas
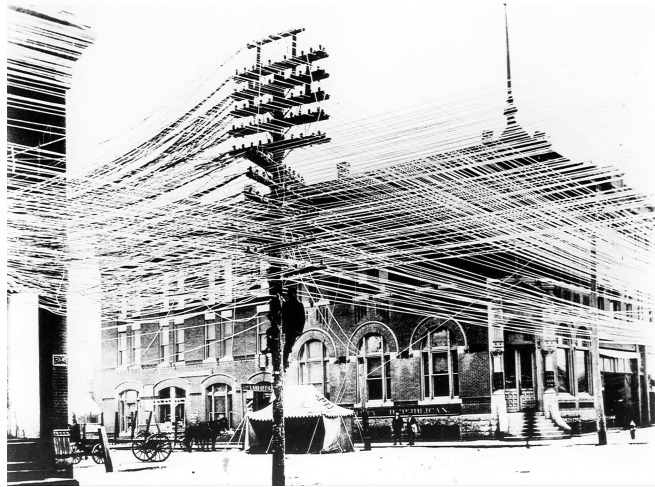
`http://www.bellsystemmemorial.com/oldphotos_6.html`

A switch

What if each person has one wire to a **switch**.
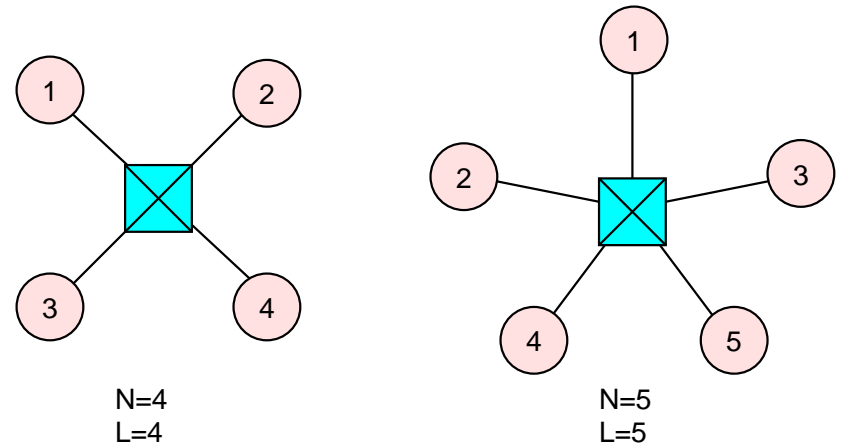
N=4
L=4

N=5
L=5

N nodes, then we have L=N links

Switchboards

So switches are great, but what is a switch?

http://www.bellsystemmemorial.com/oldphotos_6.html

Electromechanical switch

Almon Strowger was an undertaker in Kansas City in the late 1800's

► http://www.strowger.com/history.html

► Company 'Strowger Automatic Telephone Exchange' in October 1891

► step-by-step electromechanical switch [2]
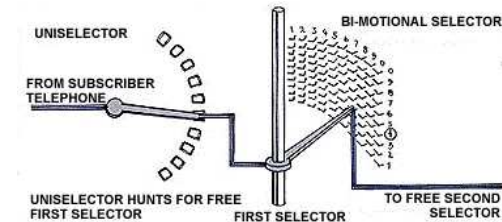
http://www.sigtel.com/tel_tech_sxs.html

More pictures with commentary
http://www.technology.niagarac.on.ca/people/mcsele/TelephoneSwitch.html

More history
http://www.telephonetribute.com/switches_survey_intro_chapter_1.html
http://www.strowger.com/history.html

Towards modern telephony

- ► switches get more complicated and sophisticated
  - ▷ electronic switch (instead of electromechanical)
  - ▷ 4ESS (like a building)

    `http://www.att.com/history/nethistory/switching.html`
- ► networks become hierachical
  - ▷ long distance versus local
- ► reliability and redundancy become important
  - ▷ alternate routing
- ► billing systems
  - ▷ harder than you think!

911

- ► 1889 (Britain) postal officials reprimand subscriber who used his phone to notify the firebrigade of a nearby fire. Directed to confine usage to his own affairs. [3]
- ► Great Britain (999), in 1937
- ► Australia (000), 1961
- ► investigated in US in 1958, legislation 1967
- ► 1st 911 call in 1968

More detailed telephony timelines can be found at
```
http://www.telephonetribute.com/timeline.html
http://www2.fht-esslingen.de/telehistory/
http://www.webbconsult.com/hist-time.html
http://www.ieee.org/organizations/history_center/comsoc/timelines.html
http://williamstallings.com/Extras/Telecom.html
http://aronsson.se/hist.html
```

Histories of computing and computer networks
```
http://en.wikipedia.org/wiki/Computing_timeline
http://www.isoc.org/internet/history/
http://www.isoc.org/internet/history/brief.shtml
http://www.dei.isep.ipp.pt/docs/arpa.html
http://www.zakon.org/robert/internet/timeline/
http://en.wikipedia.org/wiki/History_of_the_Internet
http://goldenink.com/computersandnetworks.shtml
http://www.davesite.com/webstation/net-history.shtml
http://www.computerhistory.org/exhibits/internet_history/
http://www.tranquileye.com/cyber/
```

Australian telecoms history
```
http://www.caslon.com.au/timeline.htm
http://www.anu.edu.au/people/Roger.Clarke/II/OzIHist.html
```

```
http://en.wikipedia.org/wiki/9-1-1
http://www.911dispatch.com/911/history/
http://inventors.about.com/library/inventors/bl911.htm
```

911

► Skype has 113 million users (Sept. 2006)

`http://about.skype.com/2006/09/skype_introduces_video_calling.html`

  ▷ 54 million, Sept. 2005

► 7% of long-distance minutes (Morgan-Stanley)

► Skype's licence

> 7.4 No Emergency Services. You expressly agree and understand that the Skype Software is not intended to support or carry emergency calls to any type of hospital, law enforcement agency, medical care unit or any other kind of Emergency Service. Skype, its Affiliates or Skype Staff are in no way liable for such emergency calls.

Computer networks

► First generation of electrical digital computers 1940s

► Second generation – late 1950s and early 1960s
  ▷ transistor invented in 1947 (at AT&T)
  ▷ direct networks: peripherals such as printers directly attached to computers

► Third generation, post-1964
  ▷ integrated circuits
  ▷ real computer networks start

► 1965, Moore's law discovered
  ▷ computers get better and better ...

7.4.1 Alternative Arrangements. By agreeing to this Agreement You understand that additional arrangements must be made to access Emergency Services. To access Emergency Services, You acknowledge and accept Your responsibility to purchase, separately from Skype Software, traditional wireless or wireline telephone service that offers access to Emergency Services. 7.4.2 No Compulsion to Offer Emergency Services. You recognize and agree that Skype is not required to offer Emergency Services pursuant to any applicable local and or national rules, regulation or law. You further recognize that Skype is not a replacement for Your primary telephone service.

The "Internet"

What is the Internet?

- ► physical infrastructure
- ► protocols
- ► software
- ► services/applications
- ► standards
- ► architecture
- ► operational practices
- ► principles

All of the above, but lets think about its principles.

The Early Internet

Paul Baran, 1960s, envisioned a comm.s network that would survive a major enemy attack. The sketch shows three network topologies described in [6].
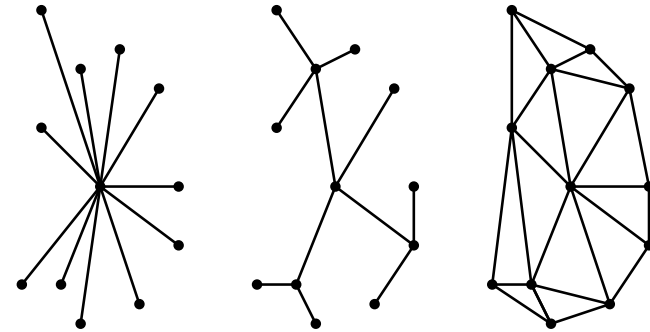
centralized　　　**decentralized**　　　**distributed**

Original available at
`http://www.cybergeography.org/atlas/historical.html`

The Early Internet

A rough sketch map of the possible topology of ARPANET by Larry Roberts. Drawn in the late 1960s as part of the planning for the network [7, p.50].

`http://www.cybergeography.org/atlas/historical.html`

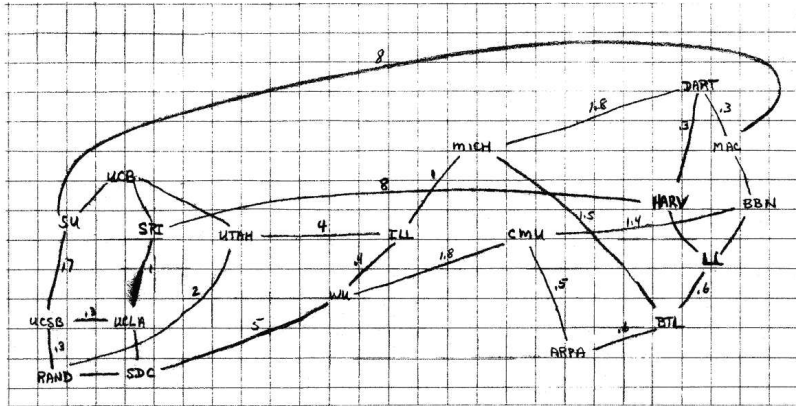# The Early Internet

The first node on ARPANET at University California Los Angeles (UCLA) on the 2nd of September 1969 [8].
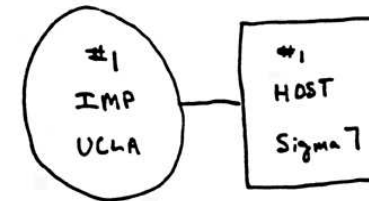
IMP = Interface Message Processor
        what we would call a router
TIP = Terminal IMP
        IMP to which terminals can directly connect
Host = computer (which provides services)

Available at
`http://www.cybergeography.org/atlas/historical.html`

Early on, the ARPANET was small enough to design on the back of an envelope. This is rarely possible for todays networks.

The Early Internet

Dec 1969 "ARPA NETWORK". 4 nodes: Uni. of California Los Angeles (UCLA), Uni. of California Santa Barbara (UCSB), Uni. of Utah and the Stanford Research Institute (SRI) [8].

Available at
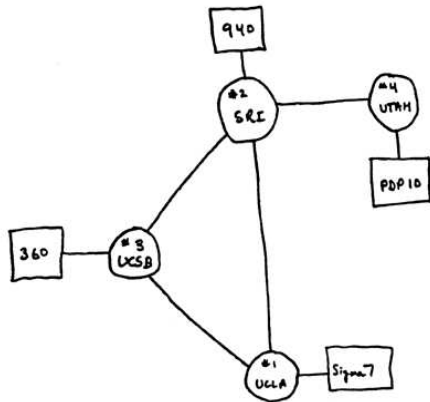http://www.cybergeography.org/atlas/historical.html

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The Early Internet

The map above shows the logical topology of ARPANET in April 1971. (computers connect direct to IMPs) [8].
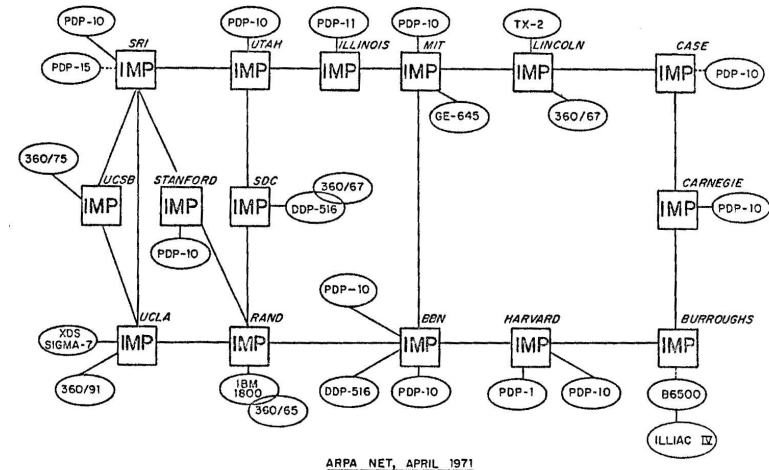
ARPA NET, APRIL 1971

The first letters transmitted on the Internet were "lo", transmitted between SRI and UCLA on October 29, 1969. The letters were the beginning of "login" of which only the first two letters were sent before the system crashed.

http://www.lk.cs.ucla.edu/first_words.html

The Early Internet

ARPANET grew rapidly as more sites are connected [8].

THE ARPA NETWORK
August 1972
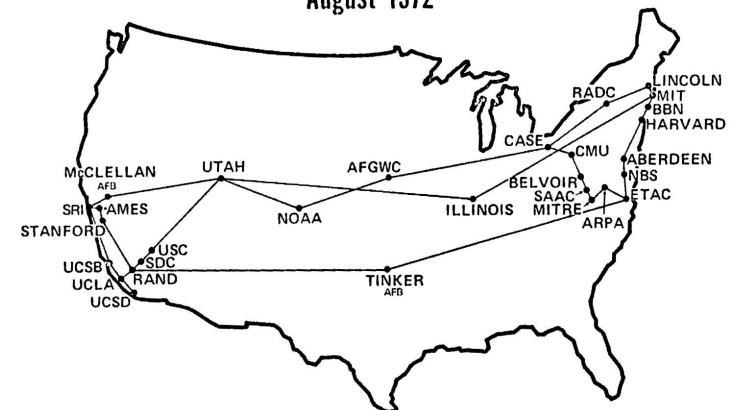
The Early Internet

ARPANET grew rapidly as more sites are connected [8].

ARPA NETWORK, GEOGRAPHIC MAP

JUNE 1975

The Early Internet

ARPANET grew rapidly as more sites are connected [8].

ARPANET GEOGRAPHIC MAP, OCTOBER 1980

http://www.cybergeography.org/atlas/historical.html

The Internet: the 80's

► new developments
  ▷ Personal Computers (PCs)
    ⇒ lots more computers to network
  ▷ Ethernet (1973, Robert Metcalfe) creates LANs

► the Internet
  ▷ TCP/IP provides a way to hook up the LANs and PC over wide areas (standard in 1980)
  ▷ scale gets bigger
    ⋆ numbers increase
    ⋆ becomes international
  ▷ partitioning
    ⋆ ARPANET splits into MILNET and ARPANET in early 80's, followed by further additions

The Internet: the 80's

ARPANET/MILNET [8].

ARPANET/MILNET GEOGRAPHIC MAP, APRIL 1984
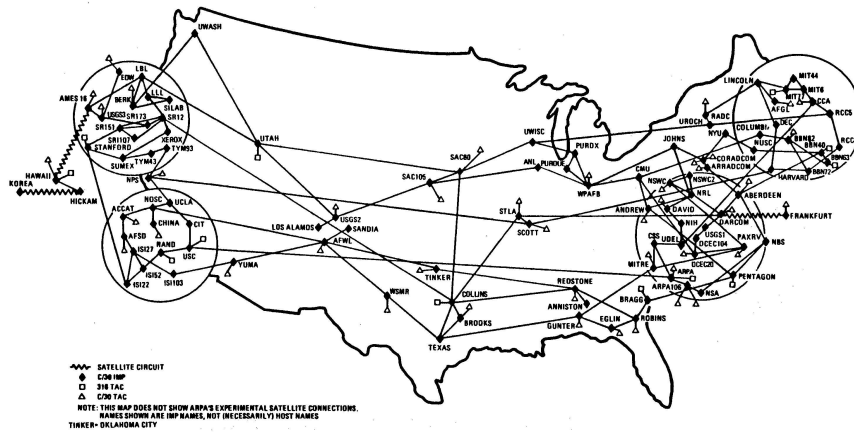
The Internet: the 90's

► ARPANET decommissioned 1990
  ▷ NSF Backbone connects many other networks
    ⋆ Australia connected in 1990 [9]

```
It was the first, and being first, was best,
but now we lay it down to rest.
Now pause with me a moment, shed some tears.
For auld lange syne, for love, for years and years
of faithful service, duty done, I weep.
Lay down thy packet, now, O friend, and sleep.
```
Vinton Cerf, 1989

► commercial Internet services evolve
  ▷ 1995 NSFNET terminated (replaced by vBNS)
  ▷ effectively fully privatised Internet
  ▷ links through exchange points

FEBRUARY, 2005: The Association for Computing Machinery (ACM) awarded Internet pioneers Vinton Cerf and Robert Kahn the Turing Award (often considered the Nobel Prize of Computing) for "pioneering work on internetworking, including the design and implementation of the Internet's basic communications protocols, TCP/IP, and for inspired leadership in networking."
`http://www.acm.org/awards/turing_citations/cerf_kahn.html`

The Internet: the 90's

Australia's network 1991

Australian Academic and Research Network

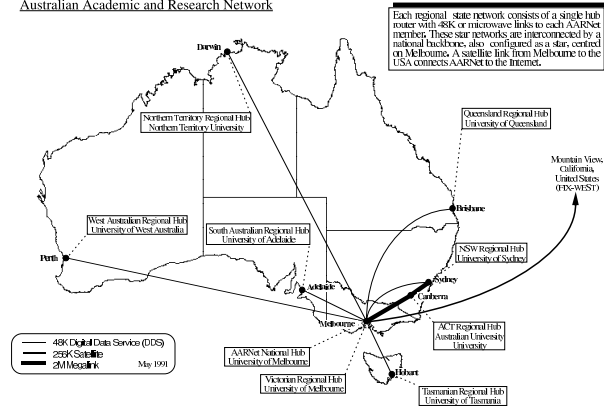Each regional state network consists of a single hub router with 48K or microwave links to each AARNet member. These star networks are interconnected by a national backbone, also configured as a star, centred on Melbourne. A satellite link from Melbourne to the USA connects AARNet to the Internet.

Northern Territory Regional Hub
Northern Territory University

Queensland Regional Hub
University of Queensland

Mountain View,
California,
United States
(FIX-WEST)

West Australian Regional Hub
University of West Australia

South Australian Regional Hub
University of Adelaide

NSW Regional Hub
University of Sydney

Brisbane

Perth

Adelaide

Sydney
Canberra

Melbourne

ACT Regional Hub
Australian National University

48K Digital Data Service (DDS)
256K Satellite
2M Megalink   May 1991

AARNet National Hub
University of Melbourne

Victorian Regional Hub
University of Melbourne

Hobart

Tasmanian Regional Hub
University of Tasmania

`http://www.ucs.ed.ac.uk/fmd/unix/edftp/pub/maps/`

New network
`http://www.aarnet.edu.au/engineering/aarnet3/`

The Internet: the 90's

`http://www.w3.org/History.html`

► 1990: World Wide Web
   Tim Berners-Lee created HyperText Markup Language, or HTML. Along with URL (Uniform Resource Locators), and HTTP (HyperText Transfer Protocol), created the web. Based on earlier work at CERN (1980).

► 1993: Mosaic (Marc Andreesen, NCSA)
   Mosaic became the first popular web browser. It was not only easy to use to access the World Wide Web, but it was also extremely easy to download and install!

► Killer app => the Internet takes off in a big way

These days

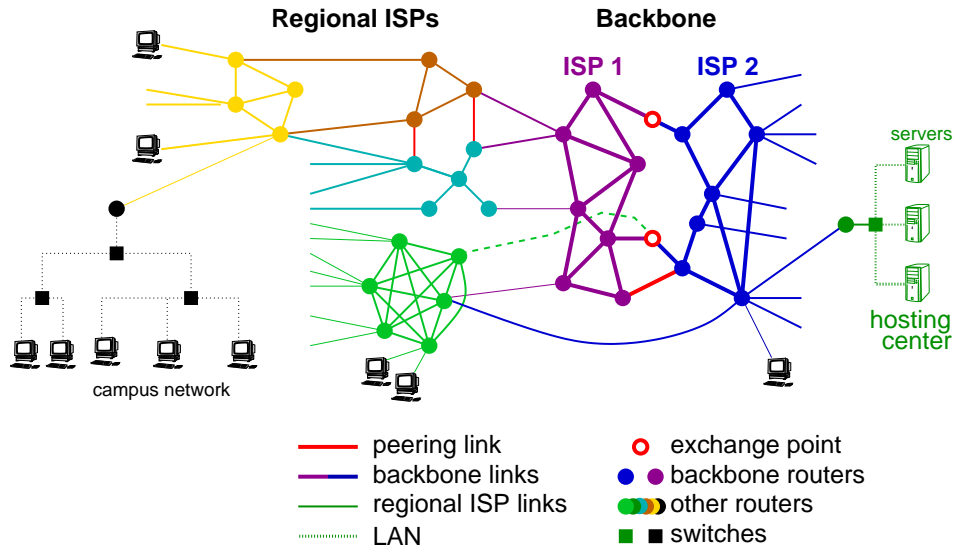The Internet is broken into around 20,000 Autonomous Systems (ASs)

- ► AS is a separately managed network
- ► within an AS may use different routing, technology, management, ...
- ► may be a LAN, WAN, or combination
- ► example ASs:
  - ▷ ISP (Internet Service Provider)
  - ▷ Campus network
  - ▷ Enterprise network
  - ▷ Hosting center
- ► interior details of an AS are not exposed
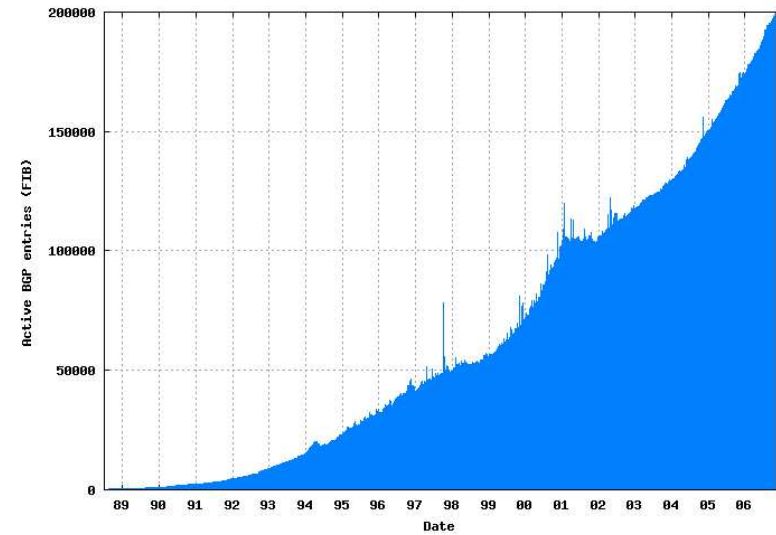
a network of networks
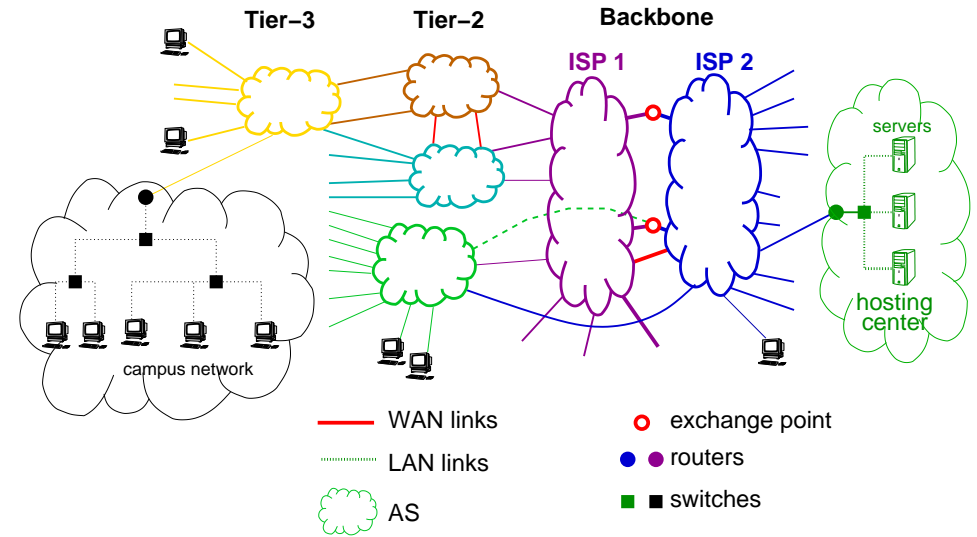
a network of networks

Regional ISPs   Backbone

ISP 1   ISP 2

servers

hosting center

campus network

—— peering link	◯ exchange point
—— backbone links	●● backbone routers
—— regional ISP links	◐◑ other routers
⋯⋯ LAN	■ switches

Number of subnets

http://www.cidr-report.org/

A Juniper router in use.

► pre-2001:
  ▷ investment money relatively easy to obtain
  ▷ people would throw ridiculous amounts on money into foolish ventures
  ▷ NASDAQ peak 10th May 2000
► tech-wreck (2001-2002)
  ▷ bubble burst, tech. stocks dropped rapidly
  ▷ many people laid off
  ▷ NASDAQ bottoms in Oct 2002 (large % drop)
► post tech-wreck:
  ▷ investments in networks must be **very** well justified
  ▷ but its still growing strongly

Internet characteristics

The Internet

- ► highly dynamic (exponential growth)
- ► highly heterogeneous (20,000 Autonomous Systems, different technologies, and applications)
- ► 100's of thousands of subnets
- ► many millions of hosts
- ► (largely) decentralised
- ► (largely) stateless
- ► (largely) self-configuring

In many ways it resembles some kind of living thing!

The Great Big Jellyfish
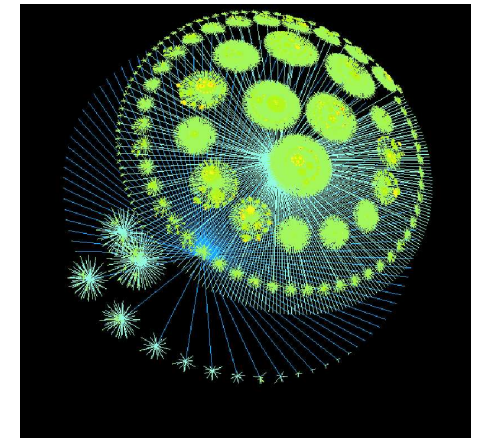
Created by Ashley Flavel using Walrus.

Distributed control

- ► Distributed control is the key to making this work
  - ▷ its one of the fundamental principles of the Internet's design
- ► But its not all roses and jellyfish
  - ▷ how do you design/optimize something like this?
    - ⋆ you can't (at least not easily)
      - ◇ tragedy of the commons
      - ◇ multiple objectives of different ASs
      - ◇ unwillingness to co-operate
    - ⋆ no guarantees of convergence when you try!

Internet Design Principles

- ► **distributed control:** as compared to centralized, or decentralized [14].
- ► **packet switching not circuit switching:** Don't reserve bandwidth for a connection.
- ► **layered model:** with a thin waist.
- ► **robustness principle:** Be liberal in what you accept, and conservative in what you send [11, 12].
- ► **end-to-end principle:** Smart terminals, dumb network [13, 14].
- ► **general issues:** simplicity, modularity, performance [12].
- ► **deployment issues:** scale, incremental deployment, heterogeneity [12].

The Early Internet

Kleinrock's insight [5]

- ► computer traffic is bursty (it comes in spurts)
- ► more efficient to transmit packets of data on-demand than to reserve circuits between computers
  - ▷ setting up a circuit takes time (high latency)
  - ▷ keeping up a circuit set up is inefficient
    - ⋆ not used most of the time
  - ▷ all you want to do is send one little chunk of data
    - ⋆ example: typing – one character at a time
    - ⋆ even a whole email is quite small
  - ▷ alternative: send data as packets

Packets vs circuits

- ► Bell-heads vs Net-heads
  - ▷ Bell-heads from old Bell system (AT&T included)
  - ▷ Net-heads: new generation, who grew up on the ARPANET/Internet
- ► Bell-heads believe you need a dedicated circuit
  - ▷ like a phone line (but higher speed)
  - ▷ said the ARPANET would never work
- ► Net-heads think circuits are a waste of time
  - ▷ poor use of resources when traffic is bursty [15].
  - ▷ invented the ARPANET/Internet
- ► this is a theological debate

http://www.wired.com/wired/archive/4.10/atm.html

packets are not all good

Some things IP packets don't do well

- ▶ billing
  - ▷ circuits are easy to bill
  - ▷ packets are not
    - ⋆ most Internet charging is flat rate
    - ⋆ Australia is an exception
  - ▷ does this really matter? [17].
- ▶ QoS (Quality of Service)
  - ▷ e.g. network not design to provide voice quality
  - ▷ maybe it can be fixed? Lots of research.
- ▶ security (crypto doesn't fix DoS, Worms, ...)

MPLS

Multi-Protocol Label Switching

- ▶ MPLS creates virtual circuits between end-points
  - ▷ connections are not between end-users though
  - ▷ allows **multiplexing** of traffic inside a connection
  - ▷ multiplexed traffic is less bursty
- ▶ MPLS seems to be changing the underlying infrastructure of the Internet.

- ► 2 steps forward, 1 step back
  - ▷ Strowger
    - ⋆ bigger, faster networks
    - ⋆ lost operators' local information
  - ▷ distributed control
    - ⋆ robustness
    - ⋆ cost of optimality
  - ▷ packets
    - ⋆ cheap, efficient, high-rate data
    - ⋆ poor billing and QoS
  - ▷ wireless telephony
    - ⋆ mobility
    - ⋆ loss in quality

- ► step back is often perceived as bad
- ► has it always been that bad?
  - ▷ Strowger
    - ⋆ aren't phone directories better than operators?
  - ▷ distributed control
    - ⋆ optimality doesn't matter as much as robustness
  - ▷ packets
    - ⋆ flat rate billing isn't such a bad thing
  - ▷ wireless telephony
    - ⋆ quality wasn't as important as once thought
- ► really, there are tradeoffs

Fundamental Changes

Rather too many to go into today

- ► Wireless Internet
- ► Network convergence
- ► Net neutrality
- ► IPv6
- ► real Worldwide governance
- ► TCP landspeed
- ► Knowledge plane
- ► Asia-Pacific – the new engine of growth

Has the Internet come of age?

- ► size → clearly the Internet is big enough
- ► stability → clearly not!
- ► maturity →
  - ▷ we're still arguing about some basic issues
  - ▷ but there are some good signs along the way
- ► perhaps best charactered as a "teenager"
  - ▷ going through a bit of a growth spurt
  - ▷ rebellious
    - ⋆ its going through its "packets" phase
  - ▷ spends a bit too much time in the bedroom
  - ▷ likes loud music a bit too much

Conclusion

Has the Internet come of age?

- ► Douglas Adam's may be off by a couple of years

- ► When will I say its come of age?
    - ▷ I still have LPs, but when I'm giving a class and want to talk about them to students, I have to show them one to explain
    - ▷ When I have to do that for the Internet, then whatever it has become will have come of age.

- ► Finally: will people please stop talking about Internet enabled fridges.

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