Communications Network Design

lecture 02

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Computer Networks

Computer networks are a recent invention (in human history), but they have been around for longer than some of you may think. In this lecture we consider the underlying drivers in computer networks, and how this subject fits with the ongoing development of those networks.

This lecture provides a brief computer network history

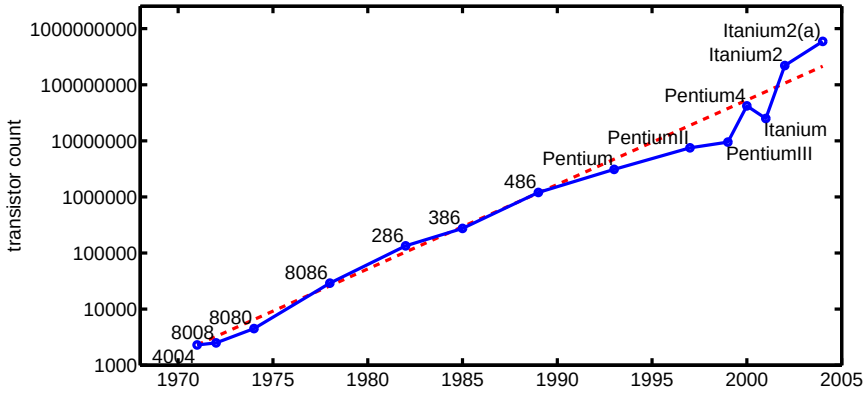
20th century

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 ...

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 [1].



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

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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`

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Gilder's Law

Gilder's law: theoretical transmission capacity of a link increases by a factor of two every 12 months.

- `http://www.seas.upenn.edu/~gaj1/promise.html`
- `http://www.dtc.umn.edu/~odlyzko/doc/tv.internet.txt`
- `http://telecomvisions.com/articles/beyondip/`
- transmission capacity is still behind storage
  - 2000, backbones in US carried 144 PB/year, total disk capacity 3000 PB
    - it would take 20 years to carry all the data
  - 2005, 100 GB disk is common, 1.5 Mbps
    - it would take 6 days to carry all the data
  - network is catching up?

Networking drivers

- Moore's law drives PC business
- Gilder's law drives networks
  - something suss here – lets discuss later
- Metcalfe's law also drives the Internet
  - The value of a network is proportional to the square of the number of users.
  - hence the failure of many "video-phone" trials
    - but success of most recent "camera phones"

"I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet bread to the wise, nor yet riches to men of understanding, nor yet favor to men of skill; but time and chance happeneth to them all."

Ecclesiastes 9:11

The race is not always to the swift, nor the battle to the strong, but that's the way to bet.

Anon

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The Internet

- Leonard Kleinrock at MIT published the first paper on **packet switching** theory in, July 1961 [2].
- J.C.R. Licklider of MIT wrote memos "Galactic Network", and later convinced DARPA to fund, 1962.
- Baran defence proposal for robust network was a packet switched network, 1962 [3].
- Thomas Merrill, Larry Roberts, first network 1965
- Roberts's plan for the "ARPANET", published 1967
- IMP's (built by BBN) connected 1968-69
- 1972: First public demo, e-mail invented
- Vinton Cerf and Robert Kahn, TCP/IP, 1973

http://www.isoc.org/internet/history/brief.shtml

The Early Internet

Kleinrock's insight [2]

- 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

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

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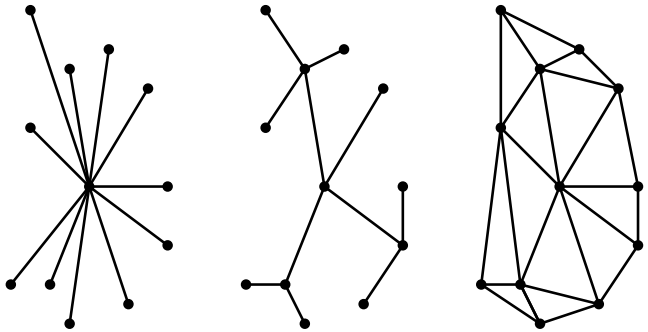
The Early Internet

Paul Baran, 1960s, envisioned a comm.s network that would survive a major enemy attack. The sketch shows three network topologies described in [3].

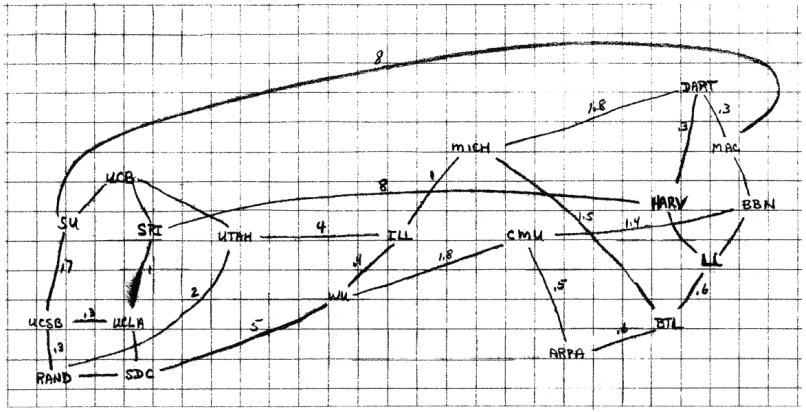


centralized **decentralized** **distributed**

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 [4, p.50].



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

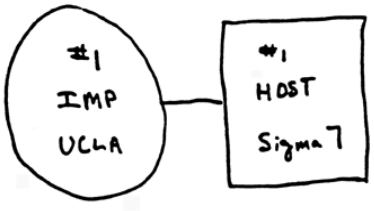
The centralized network is highly vulnerable to damage to it central node, and other nodes will be detached from the network by link failures

The distributed network structure has best survivability.

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

The first node on ARPANET at University California Los Angeles (UCLA) on the 2nd of September 1969 [5].

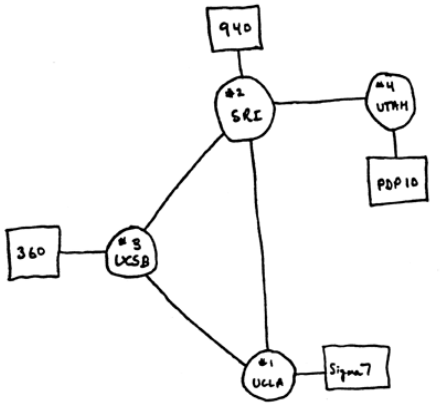


IMP = Interface Message Processor
what we would call a router
TIP = Terminal IMP
IMP to which terminals can directly connect
Host = computer (which provides services)

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

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) [5].



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

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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

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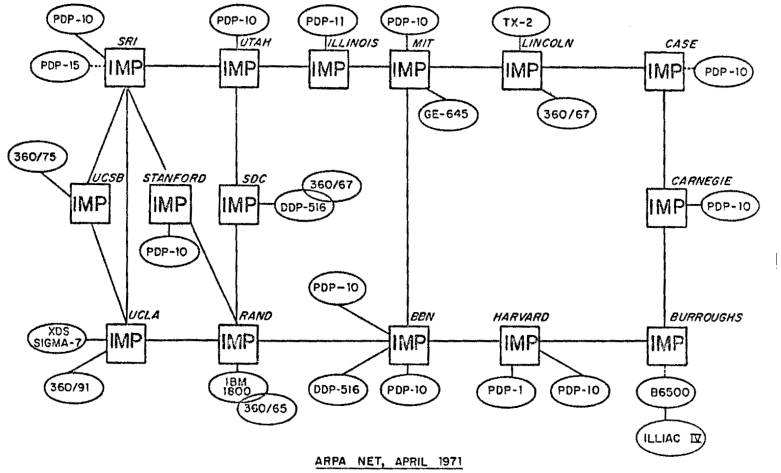
The Early Internet

- a lot of effort went into design of the protocols, and architecture
- the actual network was designed more by constraints: geographic, cost, political, (i.e. who had funding to participate)
  - some formal optimization (Howard Frank in particular)
- you can design a network on the back of an envelope when it has 4 nodes.
  - not so easy with 100

The Early Internet

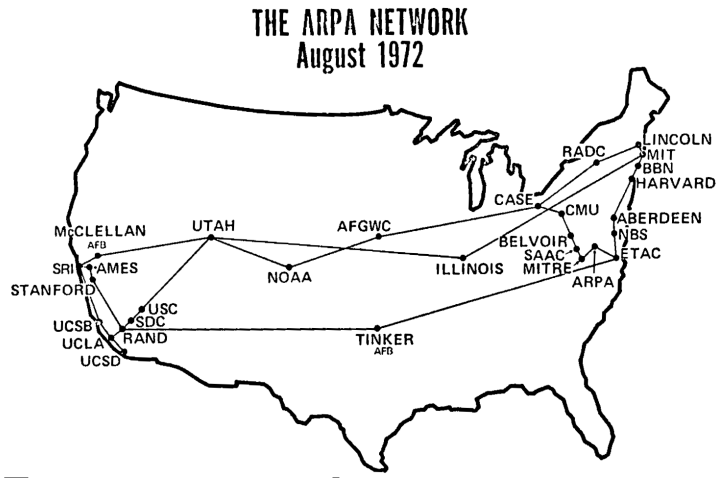
The map above shows the logical topology of ARPANET in April 1971. (computers connect direct to IMPs) [5].



Formal optimization of computer networks reputedly first appeared in "Optimal Design of Centralized Computer Networks", H.Frank, I.T.Frisch, R.Van Slyke, and W.S.Chou, Networks, Vol.1, No.1, pp.43–58, 1971, but I haven't been able to obtain a copy as yet.

The Early Internet

ARPANET grew rapidly as more sites are connected [5].



The Early Internet

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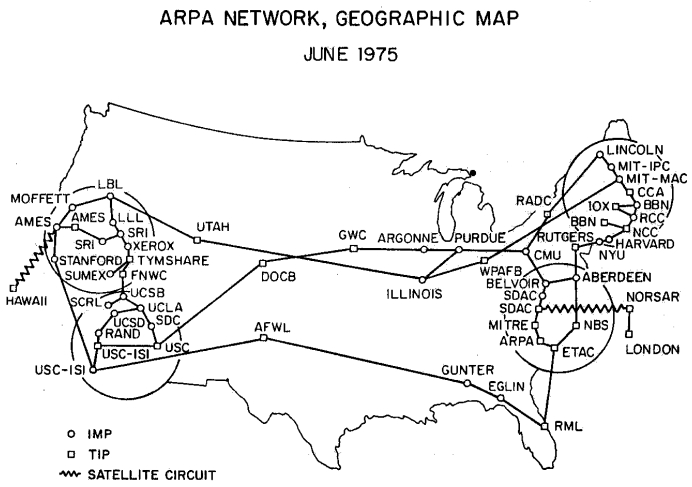

The Early Internet

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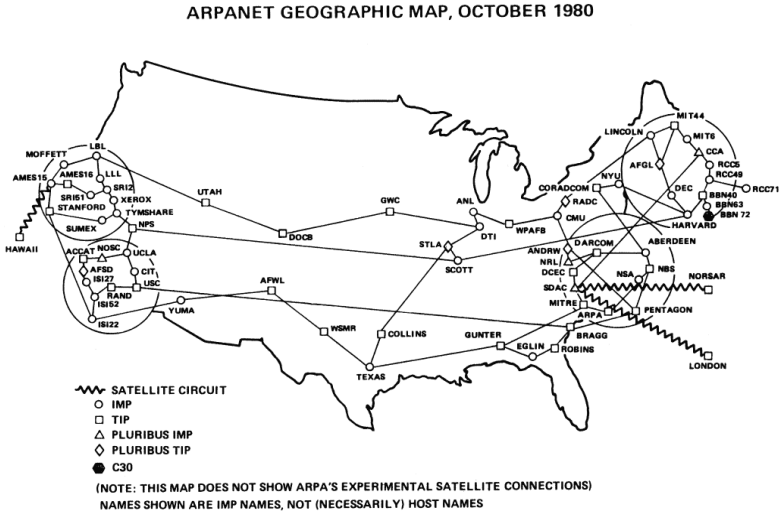

http://www.cybergeography.org/atlas/historical.html

The Internet: the 80's

- new developments
  - Personal Computers (PCs)
    $\Rightarrow$ 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

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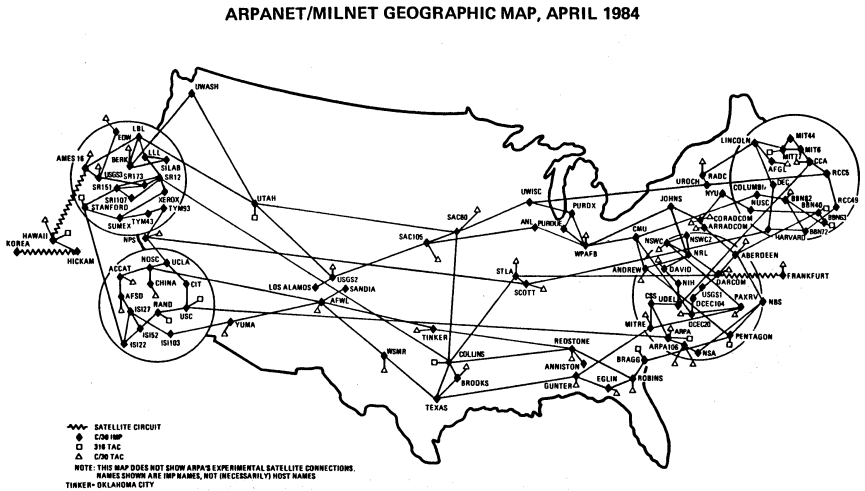
The Internet: the 80's

ARPANET/MILNET [5].



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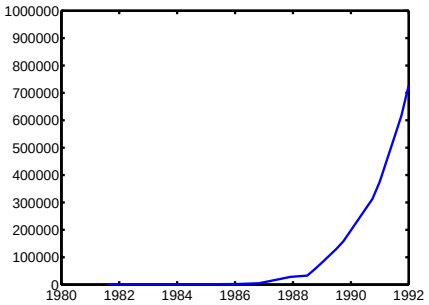
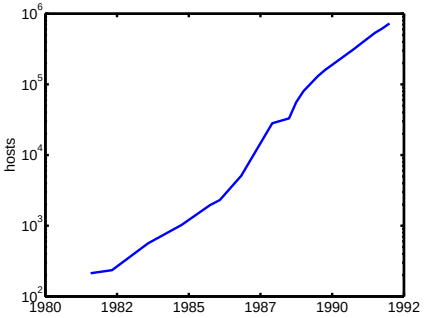
Early Internet Growth





RFC 1296 `ftp://ftp.isi.edu/in-notes/rfc1296.txt`

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

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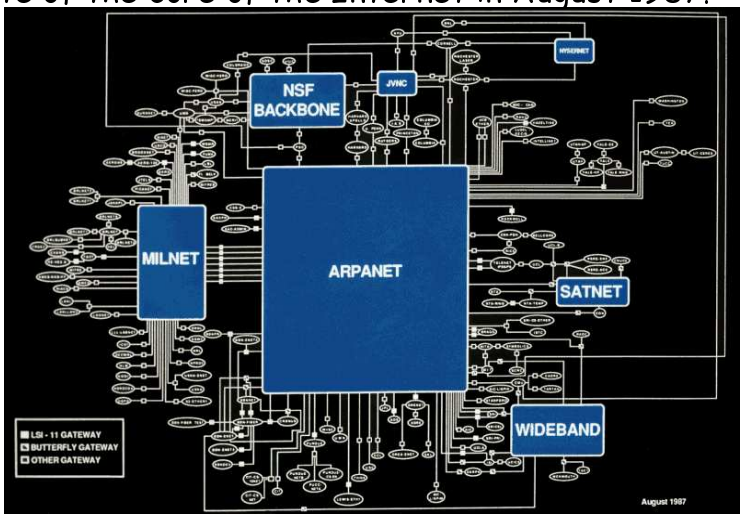
The Early Internet

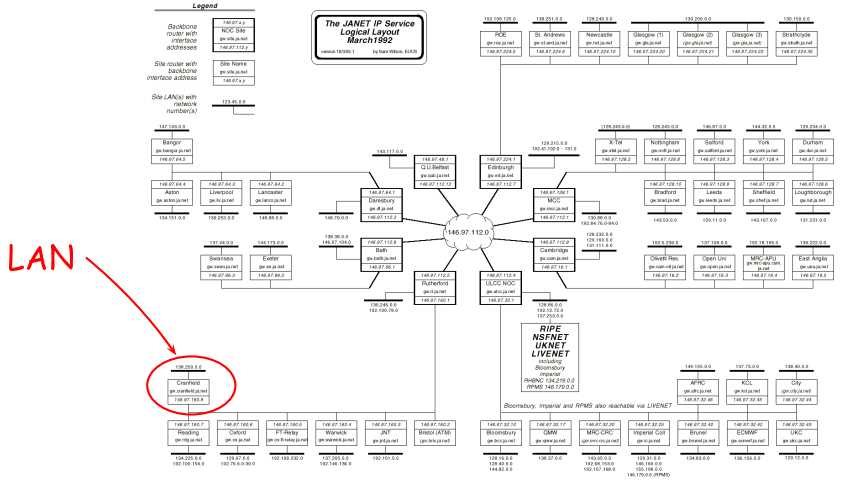
State of the core of the Internet in August 1987.



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

Networks of networks

These maps show the structure of JANET, the UK's academic and research network, in 1992.



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

The Internet: the 90's

- ARPANET decommissioned 1990
  - NSF Backbone connects many other networks
    - ⋆ Australia connected in 1990 [6]

```
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

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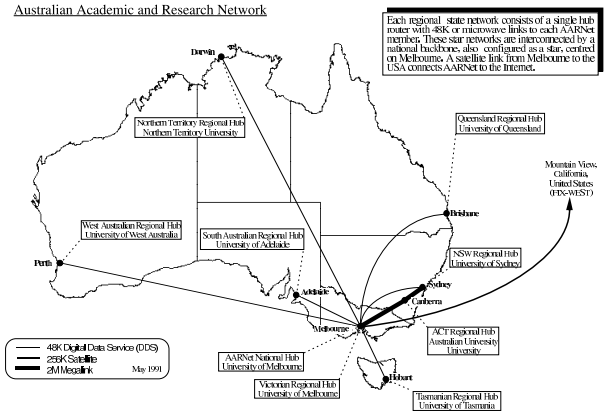
The Internet: the 90's

Australia's network 1991



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

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

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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

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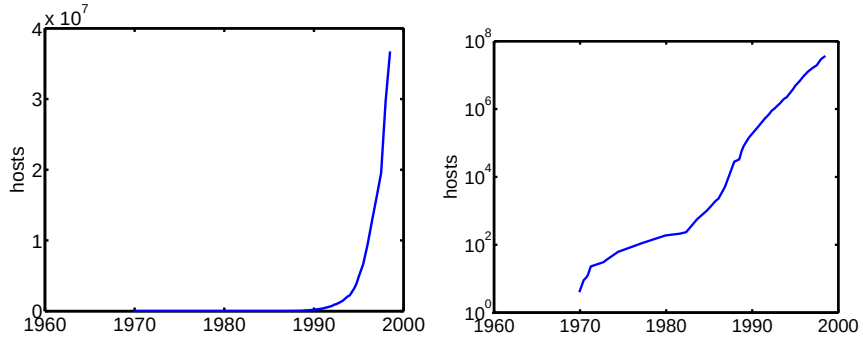
Early Internet Growth



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

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

Early Internet Bandwidth Growth

All the time **backbone** link speeds have been growing

- 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 (*OC*48)
- circa 2003: 10 Gbps (*OC*192)

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

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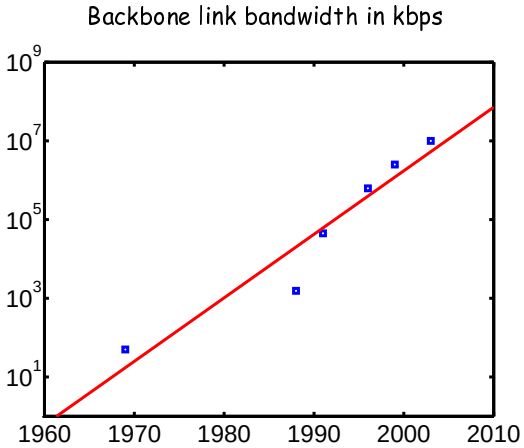
Backbone link speed growth

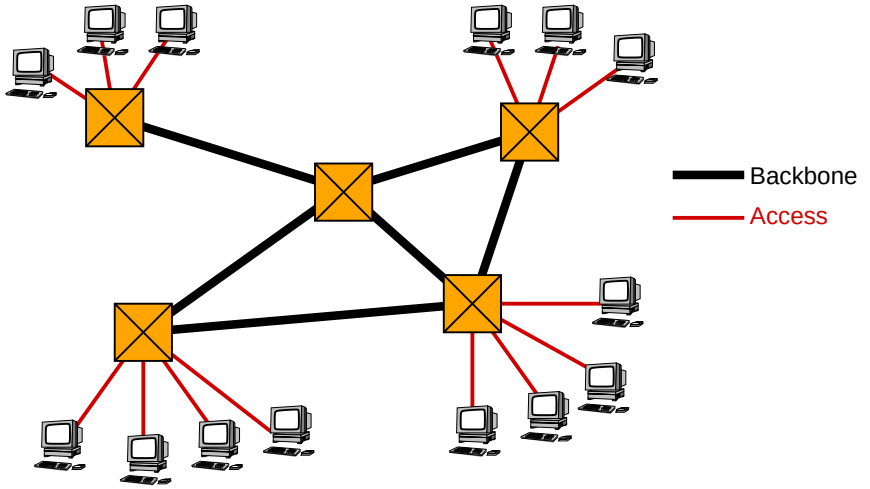
Roughly doubles every two years (45% per year)



Note that extra links are added every year

Access vs Backbone

Simplistic picture of access vs backbone



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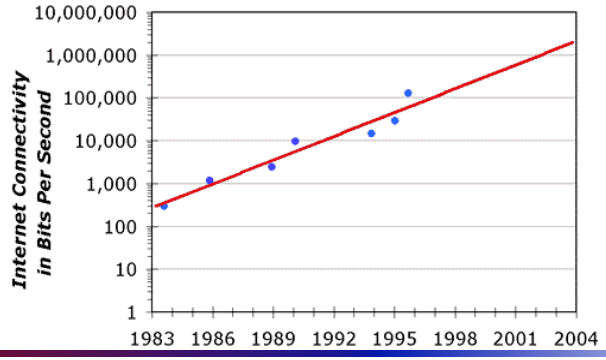
Early Internet Bandwidth Growth

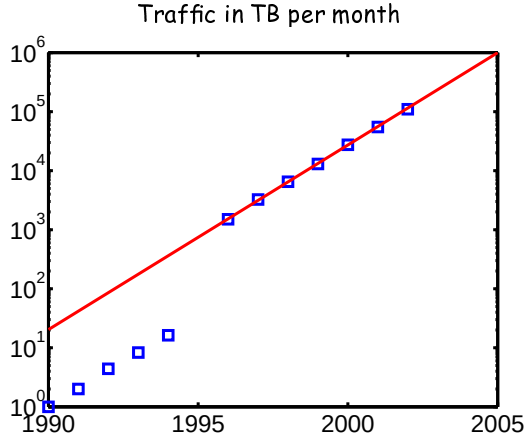
Access link speeds grow as well

- Nielsen's Law of Internet Bandwidth
  - a high-end user's connection speed grows by 50% per year
  - http://www.useit.com/alertbox/980405.html



Internet Traffic Growth

Traffic roughly doubles every year [7].



Combination of new users and higher bandwidth!

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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

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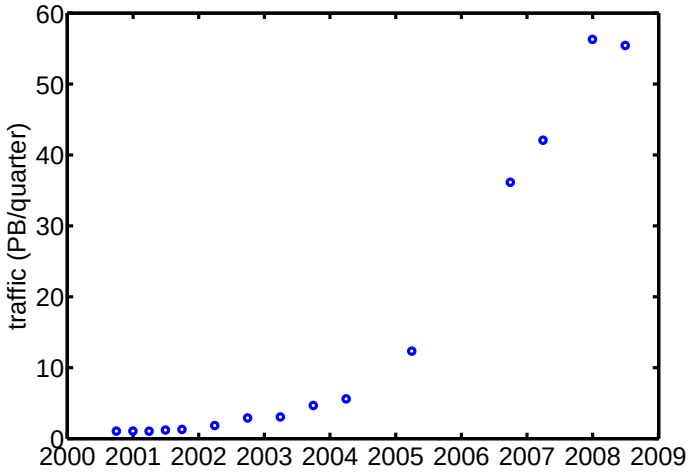
Australian Traffic Growth

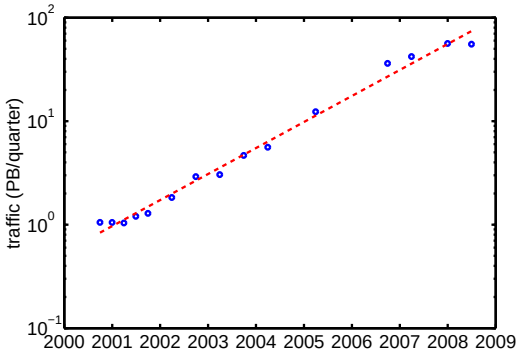


www.abs.gov.au

The Early Internet

- Focus of early commercial design was connectivity
  - not optimality
- Networks were almost designed on the back of an envelope
  - NFL cities (-Greenbay)
  - capacities chosen to make network sound hot
- exponential growth makes design simple
  - the network will be completely rebuilt every couple of years
- As they grew, they became more unwieldily
  - became partitioned and hierarchical
  - separate simpler networks

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



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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

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Economics lesson

Even without changes in growth patterns, much more care is needed in network design (for the Internet) now

- 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

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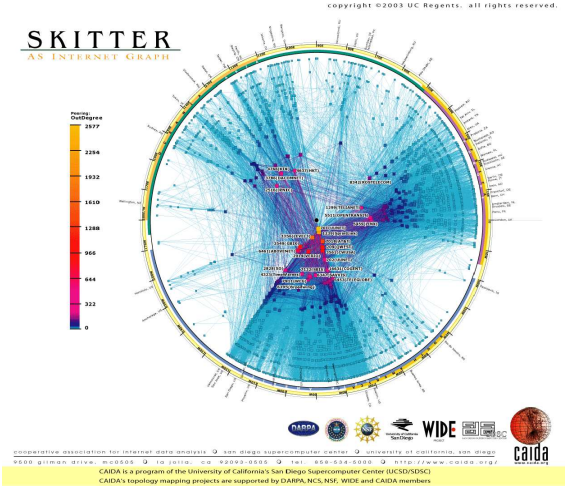
Maps of the Internet

Now the Internet is so complex, its hard to draw a map, so people try to visualise in other ways.



Other computer networks

The history of computer communications is not just about the Internet

- other technologies, e.g.
  - packet radio (Hawaii)
  - ATM/Framerelay
  - x.25
  - IBM's SNA
  - Appletalk
- other countries, e.g.
  - France
  - UK
- people: I haven't talked about them, but many individuals' contributions were critical [4, 6, 8].

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References

[1] G. E. Moore, "Cramming more components into integrated circuits," Electronics, vol. 38, April 1965.

[2] L.Kleinrock, "Information flow in large communication networks." RLE Quarterly Progress Report, July 1961.

[3] P. Baran, "On distributed communications: 1. introduction to distributed communications network." RAND Memorandum, August 1964.

[4] K. Hafner and M. Lyon, Where Wizards Stay Up Late: The Origins of the Internet. Touchstone, 1996.

[5] V. Cerf and B. Kahn, "Selected ARPANET maps," Computer Communications Review (CCR), vol. 20, pp. 81–110, 1990.

[6] J. Abbate, Inventing the Internet. MIT Press, 1999.

[7] A. M. Odlyzko, "Internet traffic growth: Sources and implications," in Optical Transmission Systems and Equipment for WDM Networking II, Proc. SPIE, vol. 5247, pp. 1–15, 2003.

[8] P. H. Salus, Casting the Net: From ARPANET to Internet and beyond... Addison-Wesley, 1995.