School of Computing

Evolution of the Internet

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Approach for this presentation

The Internet has to be considered at two levels – with different ‘rules’ applying at each level:

- At the micro level the Internet consists of a set of components, each of which has been optimised to do a specific job using standard engineering principles. Users (people) and components interact in defined ways.
- At a macro level, the Internet is not designed - but evolves as a results of accumulating changes in the components.
  Users (people) and components may interact in complex and unpredictable ways.

A Hegelian view

Georg Wilhelm Friedrich Hegel,
Born 1770 in Stuttgart Germany - Died 1831 in Berlin.
Philosopher

“ … Hegelian dialectics considers things in their movements and changes, interrelations and interactions. Everything is in process of becoming and ceasing to be, in which nothing is permanent but everything changes and is eventually superseded.

All things contain contradictory sides or aspects, whose tension or conflict is the driving force of change and eventually transforms or dissolves them. …”

Encyclopaedia Britannica

Theory of Punctuated Equilibrium
in Evolution

- Controversial theory that biological evolution does not proceed continuously, but by jumps with intervening periods of stasis.
- Currently considered unproven for real biology.
- Recent work in simulated artificial evolution systems by Danny Hillis has shown how genetic mutations may accumulate continuously, but have little effect on the overall organism until a particular *combination* of mutations occurs, causing a jump in the organism's evolutionary fitness.

What is the Internet? - 1

- A large number of **people**, world-wide, who wish to communicate and share information spontaneously in a variety of ways.
- A large number of **computers,** with appropriate applications software, available to the above people
- A **communications infrastructure** which allows any pair of participating computers to communicate quickly, cheaply and effectively in an ad-hoc way enabling those computers to provide appropriate services to their users.

What is the Internet? - 2

Official resolution: ‘Internet’ refers to the global information system that - -

- is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
- is able to support communications using the Transmission Control Protocol/Internet protocol (TCP/IP) suite or its subsequent extensions/follow-ons and/or other IP-compatible protocols
- provides/uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein.

What is the Internet? - 3

- The Internet is not a computer network - It is a *network* of *networks*.
  - The constituent sub-networks are owned and administered by different organisations in different places and may use entirely different technologies.
  - The amount of standardisation within the Internet is the minimum necessary for effective inter-working.

Why use networks of networks?

- Politics: different organisations want to run *their own* networks.
- Geography: Different organisations are in different places.
- History: The networks were developed separately.
- Technology: e.g. limits on physical size & number of connections.
- Performance: Localisation of data traffic.
- Security: Controlling access to data & services
- Resilience against failure
- etc.

Evolution of Internet 1
Pre-1956 Data communications

- Communicating devices were not computers but hard-wired devices , e.g. telex machines or the control parts of telephone switches. So 'message formats' were very simple and inflexible.
- Much of the fundamental principles were worked out in the 1940s (e.g. by Shannon).
- Asynchronous transmission methods introduced with telex systems in the 1920s are still in use.

Evolution of Internet 2
Closed computer networks, 1956-1969

- Private, closed networks for specific tasks. Usually wide-area star configurations centred on mainframes
- Pioneering system: SAGE for for co-ordinating US air defences against bomber attacks (1956). Followed by civilian banking and airline reservation applications.
- Introduced communications protocols for reliable communication with a variety of devices.
- Engineered to do a specific job using very limited computing power - consequently very inflexible.

Communication protocols

- Communications protocols are primarily concerned with *choice*.
- In any situation where there is more than one possibility, the Tx uses a protocol to inform the Rx what choice has been made. E.g. :
  - Starting to send data/not starting to send data.
  - Continuing to send data/stopping sending data.
  - Send me the next data/repeat the last data.
  - I am sending you a file/you send me a file.

Evolution of Internet 3
Time-sharing networks, 1960-1969

- Also private, closed networks. Communications very simple and inexpensive - usually star configurations using asynchronous transmission over local twisted-pair, and telex-like terminals (e.g. Teletype 33)
- Introduced resource sharing of computer systems by time-slicing (i.e. time division multiplexing) and hence the interactive use of computers for personal activities
- Very little standardisation of services, software and communications and data formats

Evolution of Internet 4
ARPANET, 1969-mid 1970s

Pioneering network sponsored by the US DoD Advance Research Project agency:

- To evaluate the feasibility of packet switching technology.
- To provide the convenient sharing of specialised computing resources across different institutions.

Introduced :

- Packet switching using free-standing switching computers.
- A communications network intended to serve a *large community* of heterogeneous hosts and hence not dependent on specific hosts for its internal operation
- A clear separation of the data transport services from the applications using those services.

ARPANET applications

- ARPA only took responsibility for the development of the communications infrastructure.
  It left it to the user community to develop suitable applications.
- Most applications were pioneered by graduate students.The method of standardisation was the RFC (Request for Comments) - still in use!
- The most common applications were:
  - E-mail
  - Access to remote timesharing services (Telnet)
  - File Transfer

Evolution of Internet 5
Proliferation of PS networks, ~1974-~1982

- Numerous other packet-switched networks, both in US & other countries.
- Mainly for the same purpose as ARPANET - resource sharing of heterogeneous hosts in an academic/research environment.
- Little standardisation of either networking technologies or or applications.

Contradicting principles 1

- Standardisation is a good thing because it permits the flexible interconnection of components.
- Standardisation is a bad thing because it inhibits technological progress and because it may prevent solution of new classes of problem.

Contradicting principles 2

Time division multiplexing is an effective way of sharing digital communications links.

- However **continuous** data flows (e.g. digitised voice) are most efficient with **synchronous** TDM.
- **Intermittent** data flows (e.g. interactive computer traffic) are most efficient with **asynchronous** TDM.

Contradicting principles 3

Satisfactory communications requires that data errors are detected and correctly automatically, and that the flow of data can be controlled to prevent overload of both the network and the end systems.

- Such mechanisms can be implemented solely in the end systems.
- Such mechanisms can also be implemented *within* a network and operate hop-by-hop through the subnetworks.

Contradicting principles 4

Closely related to the previous point:

- A communications service may be *connectionless* - each data item in sent independently through the service. Data may be lost, duplicated or re-ordered (but not often).
- A communications service may be *connection-oriented*.
  Before data is sent, a logical connection must be opened and then closed after use.
  Transmitted data will maintain its original order.

Evolution of Internet 6

Unification through TCP/IP, 1978-1985

- Introduction of TCP/IP as a set of protocols for *inter-networking* - i.e. interoperation of heterogeneous networks.
- Progressive adoption of TCP/IP by new and existing networks, world wide, to create the nucleus of the Internet.
- Progressive development and adoption of standards for common internet applications - e.g. e-mail, file transfer, etc.
- Development of the Domain Naming Service.

Internet protocol layers

- ISO Physical Layer (1). Concerned with the physical connection with the network.
  Not standardised for the Internet - up to the sub-network operator.
- ISO Data link Layer (2). Concerned with the process of transmission over a a sub-network.
  Not standardised for the Internet - up to the sub-network operator.
- ISO Network Layer (3). Concerned with process of communicating end-system to end-system across the Internet
  For the Internet - must be the Internet Protocol (IP)
- ISO Transport Layer (4). Concerned with application to application communication with an appropriate quality of service.
  For the Internet, *must be TCP or UDP*.
- ISO Application Layer (7). Concerned with the meaning of the message sent. *Numerous Internet standards exist.*

Evolution of Internet 7
Commercialisation of the Internet, 1985-1990

- The adoption of TCP/IP standards by hardware and software vendors - allowing organisations to create Internet-compatible private networks - e.g. for interconnecting heterogeneous systems.
- Relaxation of rules restricting the carriage of commercial traffic on government-funded networks - permitting the connection of existing commercial network/information services to the Internet.

Evolution of Internet 8
World wide adoption, 1990-now

- Mass-market sales of Internet-capable personal computers.
- World-wide growth in the numbers of commercial Internet Service Providers, enabling dial-in access to the Internet to the public.
- Acceptance of Internet applications - particularly e-mail and the World Wide Web - by the general public.
- The introduction of e-business.
- Appropriate growth in the network infrastructure.

Future influences 1
Network Infrastructure

- Current challenges are:
  - To provide huge expansions in capacity to meet the expected growth of Internet traffic - whilst reducing costs.
  - To enable carriers to provide different grades of service and to enter into Quality of Service agreements with customers.
  - To achieve appropriate integration with the current range of services (e.g. voice).
- There seem to be no impending developments which may *of themselves* trigger step-changes in the Internet, but there are sufficient not to inhibit other factors triggering such changes.

Future influences 2
General Information Technology

- Business & organisational use of networking will increase in scale. Increasing use will be made of Internet technology even for closed, private networks.
- The main areas under pressure are largely associated with applications servers - i.e. performance, reliability, security, application development & support costs. Improvements here will not cause step-changes to the Internet itself.
- One are with potential for radical developments is concerned with providing the full range of organisational services to remote or mobile workers.

Future influences 3
E-business

- E-business (both B-to-B and B-to-C) will grow and have a large effect on the Internet.
- For the network infrastructure, E-business will be largely a matter of ‘a lot more of what we do already’ - but with tighter Quality of Service constraints.
- E-business may have an important role in funding the expansion of the infrastructure.
- The main technological demands of e-business will be on the applications servers - e.g. performance, reliability, security & rapid development of new applications.

Future influences 4
Broadband to the home

- Broadband services to the home will come - but the form of its initial deployment is still unclear.
  The various technologies are coming together, but are not yet sufficient to drive the next step-change in the Internet. E.g.:
  - What connection technology(ies) will be used? (xDL SL? HFC?).
  - *Who* will provide the connections? (PTTs? CTVs?).
  - What applications will generate the cash flow to fund the deployment (Video-on-demand? TV broadcast? Internet?).
  - What user equipment is required to use the connection? (PC? TV set-top box? Games machine? etc).

Future influences 5
Home networking

- As with broadband to the home - this will come, but the exact form of its initial deployment is not clear:
  - What interconnection technology(ies) will be used within the home? (Structured wiring? Wireless e.g. Bluetooth?)
  - *What* sort of ‘always-on’ connection can be provided economically to the outside world?
  - What applications will generate the cash flow to fund the deployment (Security? Utility meter reading?)

Future influences 6
In-vehicle telematic Internet services

- For commercial vehicles, applications are already under development, e.g.
  - Command & control of truck fleets
  - Monitoring of vehicle operational & maintenance state
- For private vehicles, viable applications are more speculative, e.g.
  - Traffic condition and navigation information.
  - In-vehicle entertainment

Future influences 7
Ubiquitous/pervasive computing

- On a longer time scale, we can expect vast numbers of inexpensive computers to become embedded through our entire environment, in buildings, in clothes, in vehicles, etc.
- Such devices will also be networked - both to communicate with one another and with the outside world.
- Such systems must be able to operate in the presence of failure both of the computers themselves and interconnection mechanisms