Technological Networks
The Internet

**Vertices** are computers or computer routers
**Edges** are cables or optical fiber lines linking computers
The Internet

Packet Switching in a Data Network

Many paths may be used for a single communication as individual packets are routed to a destination.

Prior to transmission, each communication is broken into packets which are addressed and numbered.

During peak periods, communication may be delayed, but not denied.

At the destination, packets may be reassembled into order according to their sequence number.

No fixed path is established. Packets are routed according to the best path available at the time.
The Internet Protocol (IP)

Accounting system used for packets of information on the internet. Include an IP address for each packet. This is a sequence of 4 numbers separated by periods. For example:

142.201.098.179

Error checking at target of message is done through a software protocol called Transport Control Protocol (TCP), which also can initiate resubmission of lost packets. All done automatically!
End users are the computers and other devices we all use.

Interior vertices are routers, which are special-purpose computers at the junctions between data lines.
Internet Network Structure

ISP = Internet Service Providers

Backbone routers are the core of the network, with high-performance routers linked with the fastest fiber optic connections available. Operated by Network Backbone Providers (NBPs) such as AT&T.
An Emergent Network

Who determines the structure of the internet? No one

Emergent system: a number of simple entities interact to produce complex behaviors

The structure constantly changes, but can be probed using traceroutes.

This takes advantage of a portion of the packet called the Time-To-Live (TTL), which is the number of hops that a packet can make going to its destination.
Constructing a Traceroute

source computer

TTL=1
Constructing a Traceroute

source computer

TTL=1

TTL=2
Take the Union of Multiple Traceroutes

Approximation of network
Internet as Connected Subnets

Subnet = group of IP addresses

142.201.098.xxx is a class C subnet: all elements typically owned by one organization

142.201.xxx.yyy is a class B subnet

142.xxx.yyy.zzz is a class A subnet

Internet can be described as a network of class C subnets, since each of these is usually owned by a single organization.

Each vertex is a class C subnet. Each edge is a router connection between two subnets.

This is an example of coarse graining.
Internet as Connected Domains

**Domain** = group of computers and routers typically controlled by one organization

fsu.edu is the **domain name** for FSU

Each **vertex** is a domain, each **edge** is a router connection between two domains

Since some domains contain more than one class C subnet, this network is smaller than the previous one. Even more extensive coarse graining is used
Over 1 Million Domain Registrations Per Year

Number of domain names registrations yearly

Domain name registry
Lines or circuits are established once a call is made, and the caller has continuous use of the circuit throughout the duration of the call.

Most phone lines are multiplexed, so that each line carries several phone calls.

Most cell phone calls are carried through the same land lines.
Telephone Networks

Vertices are telephones
Edges are phone lines

Often now digitized and packet switched

Newman text
Transportation Networks

London subway map

Vertices indicate subway stations
Edges subway lines
Delivery Networks

Gas pipelines in Western Europe

Vertices indicate storage facilities, refineries, etc. Edges indicate pipelines.
High-Voltage Power Grids

Example: Florida high-voltage power grid

Vertices: squares are power stations, ovals are switching stations

Edges: indicate power lines (thicker lines mean more power lines)

Per Rikvold group, FSU
The End