# Introduction

Advanced Computer Networks

Summer Semester 2013

# Organizational Information

-

- Slides are available online
- Course is held in English

- 6 ECTS credits (old + new PO)
- M.Inf.1222.Mp, M.Inf.1223.Mp, M.Inf.221.3C1

- ITIS: 5 credits, Module number 3.17

# Organizational Information

○ Exam: 2013-07-11


○ Check the FlexNow registration deadlines

# Course Overview

o This course covers (currently):

    o P2P and Overlay Networks

    o CDN/CCN

    o Cloud Computing

    o Security

    o Social Network Analysis

o Please note that the slides are subject to change. Before the exam, please check again the wiki for updated slides and other info!

# Course Materials - Basics

- J. Kurose and K. Ross, "Computer Networking: A Top-Down Approach Featuring the Internet" (some slides are based on the book)

- A. S. Tanenbaum, "Computer Networks"

- C. Schindelhauer, Peer-to-Peer Netzwerke (german)

- Further materials are released on the wiki
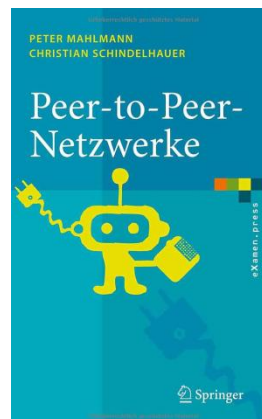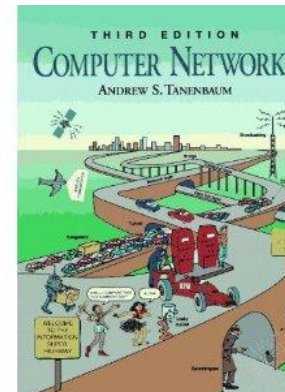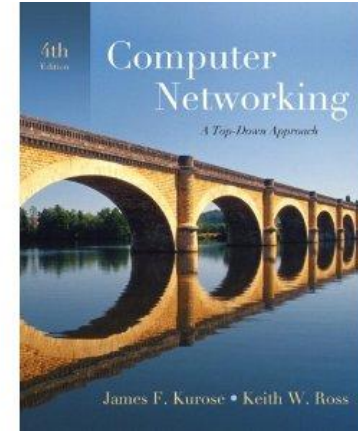
# Course Materials – Suggested Readings

o Books
  o David Easley and Jon Kleinberg, Networks, Crowds, and Markets: Reasoning About a Highly Connected World, Cambridge University Press, 2010.
  o John P Scott, Social Network Analysis: A Handbook, SAGE Publications Ltd; (2nd edition) March 2000.

o Papers
  o M. E. J. Newman, The structure and function of complex networks, SIAM Review, 2003.
  o Réka Albert and Albert-László Barabási, Statistical mechanics of complex networks, Review of Modern Physics, 2002.
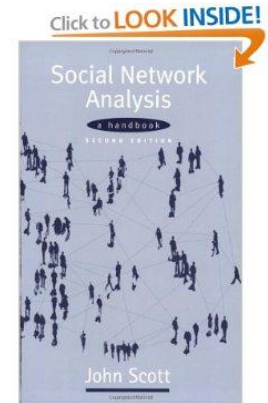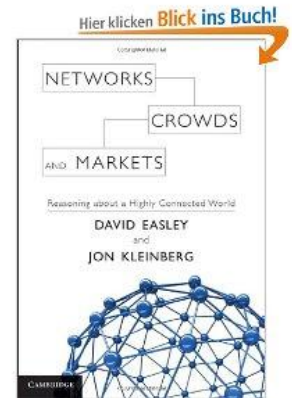
# Recap of Basics

o The following slides repeat fundamentals for advanced networks:

  - o Protocols / Layering

  - o The hierarchical structure of the Internet

  - o Addressing on the different layers

  - o Routing and IP subnet aggregation

  - o Layer 4 services such as reliable data transfer

o If something is new for you, please review the Computer Networks slides at: https://wiki.net.informatik.uni-goettingen.de/wiki/Computer_Networks_(Winter_2012/2013)

# What is the Internet?

What is the Internet?

o millions of connected computing devices: *hosts, end-systems*

  o PCs, workstations, servers

  o PDAs, phones, toasters

  o running *network apps*

o *communication links*

  o fiber, copper, coax, radio, satellite

  o transmission rate = *bandwidth*

o *routers:* forward packets (chunks of data)
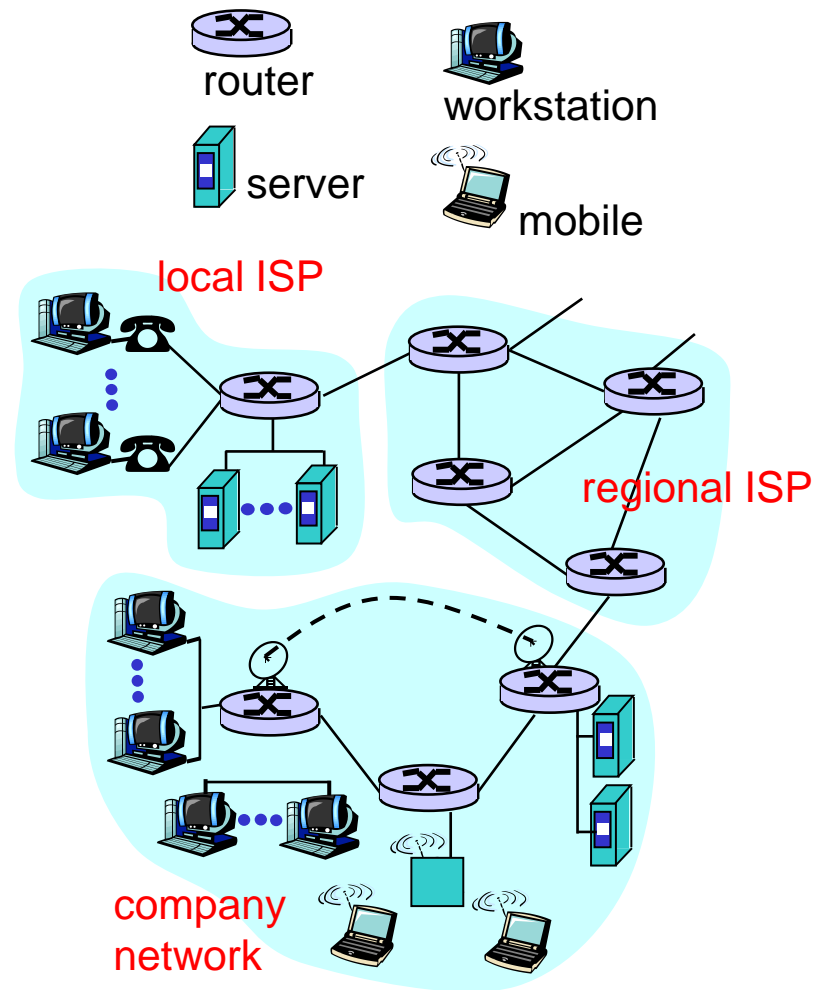
# What is the Internet?

○ *protocols* define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

○ *Internet:* "network of networks"
  ○ loosely hierarchical
  ○ public Internet versus private intranet

○ *Internet standards*
  ○ RFC: Request for Comments
  ○ IETF: Internet Engineering Task Force



router
workstation
server
mobile
local ISP
regional ISP
company network
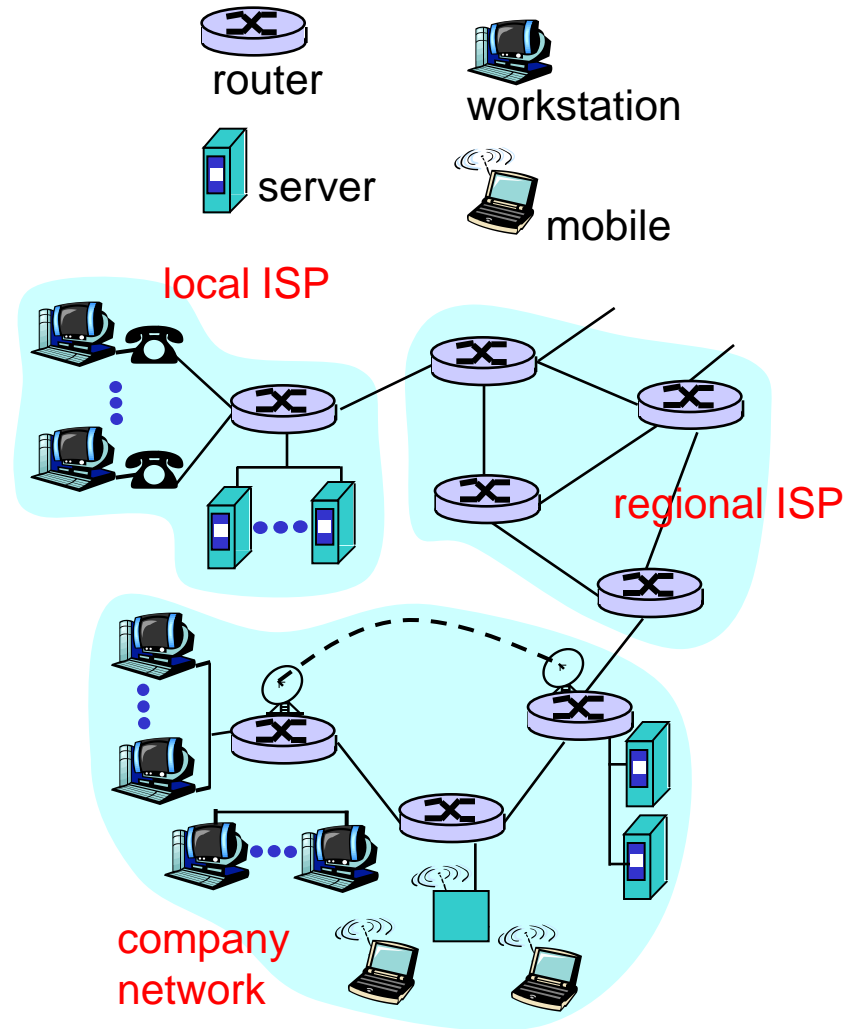
# What is the Internet?

o The network is typically divided into the network core and the network edge

    o Edge: end systems, access networks, links

    o Core: circuit switching, packet switching, network structure, routers etc.

o Users access the Internet from the edge: e-mail, http web access, applications, social networks

# At the edge

o client/server model

- o client host requests, receives service from always-on server

- o e.g. web browser/server; email client/server

- o **Is that optimal for large scale?**

peer-peer

o peer-peer model: client/server

- o minimal (or no) use of dedicated servers

- o e.g. Skype, BitTorrent
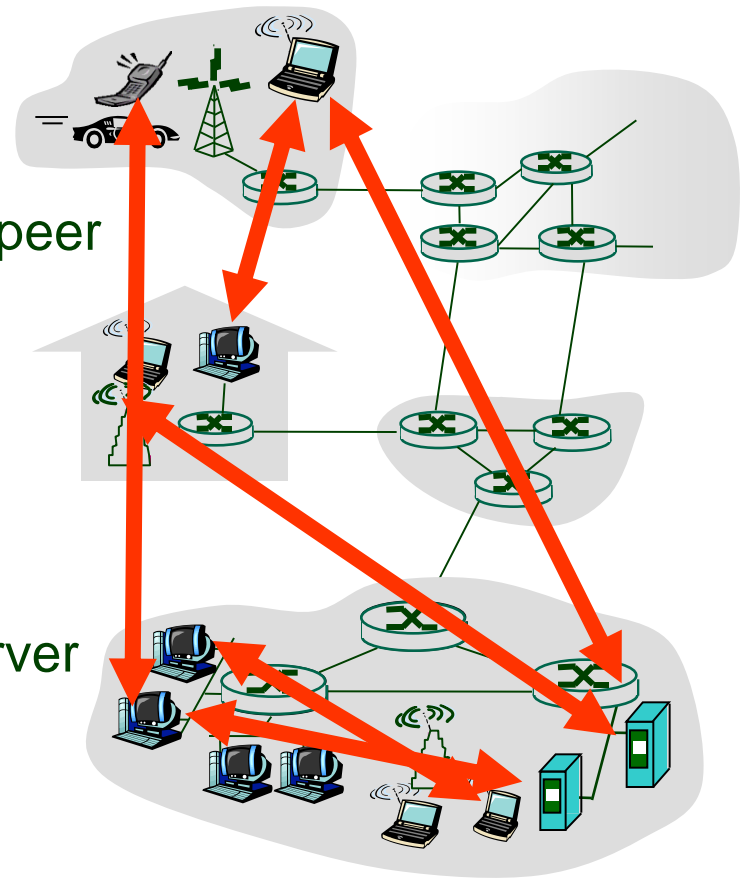
# Packet Switching Implications

o End data stream is divided into „packets"

o Multiple users share network resources

   o Sequence of packets does not have fixed pattern, this effect is called statistical multiplexing

   o Each packet uses full bandwidth

   o Resources are used as needed

o No dedicated resource allocation!

o Demand may exceed resources:

   o Congestion, delay, loss

# Hierachical Structure

o A packet traverses multiple networks from
source to destination!
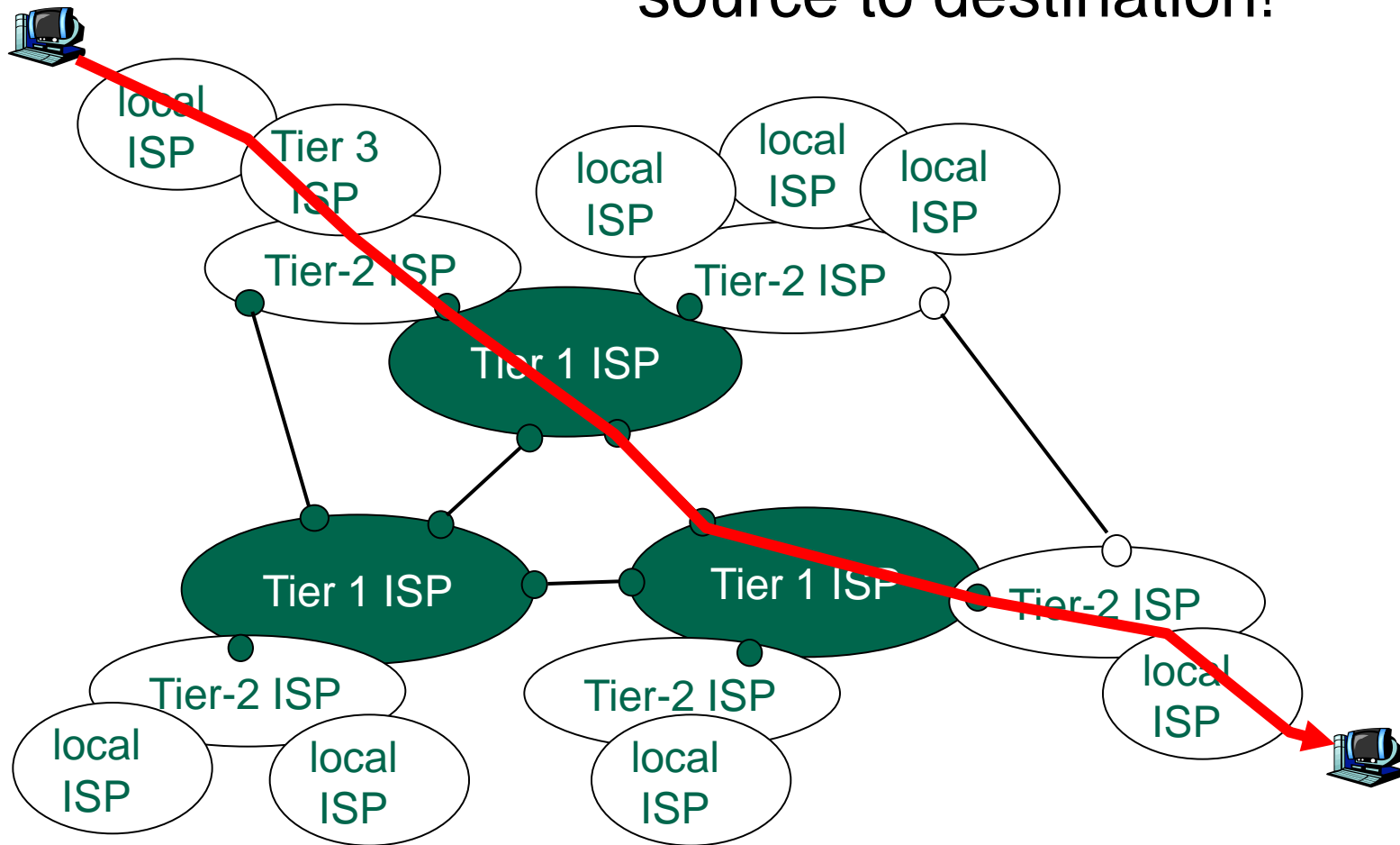
# Impact of Hierarchy

o Main goal accomplished:
  - o Efficient, works!
o But:
  - o Providers have to buy resources from higher tiers or exchange directly on low tier level (peering)
  - o Transferring data through external network is costly
  - o Many modern technologies make it relevant HOW a packet traverses through the net
    - • File sharing consumes large of resources, P2P is not business model of providers! Providers have an incentive to control P2P flows!
  - o Efficient content delivery of large amounts of data (IP-Television, Video etc…)

# Protocol Layering

o Networks are complex and consist of many pieces: hosts, routers, links, applications, protocols et cetera...

o Idea: Simplify by using layers to distinguish organizational parts of networking.

o Inspired by other, real-world „layered" processes

# Internet Protocol Stack

o Application: network apps
  o FTP, SMTP, HTTP
o Transport: process-to-process data transfer
  o TCP, UDP
o Network: routing of datagrams from source to destination
  o IP, other routing protocols
o Link: data transfer between neighboring network elements
  o PPP, Ethernet
o Physical: bits „on the wire"

| application |
| --- |
| transport |
| network |
| link |
| physical |
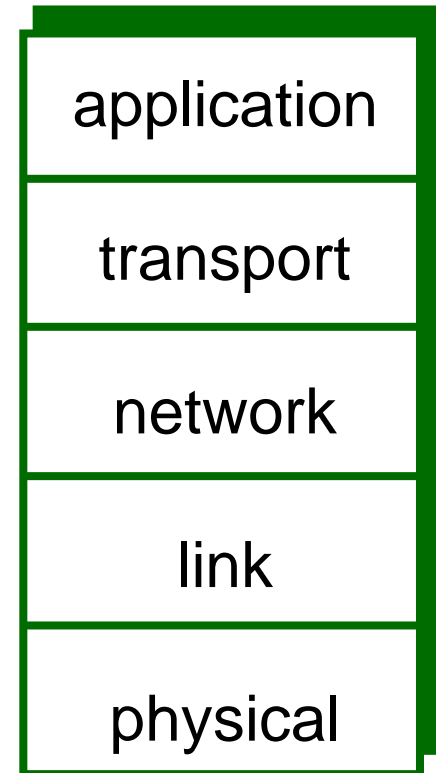
# ISO/OSI Reference Model

o Presentation: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions

o Session: synchronization, checkpointing, recovery of data exchange

o Internet stack "missing" these layers!

    o these services, *if needed,* must be implemented in application

| application |
| --- |
| presentation |
| session |
| transport |
| network |
| link |
| physical |
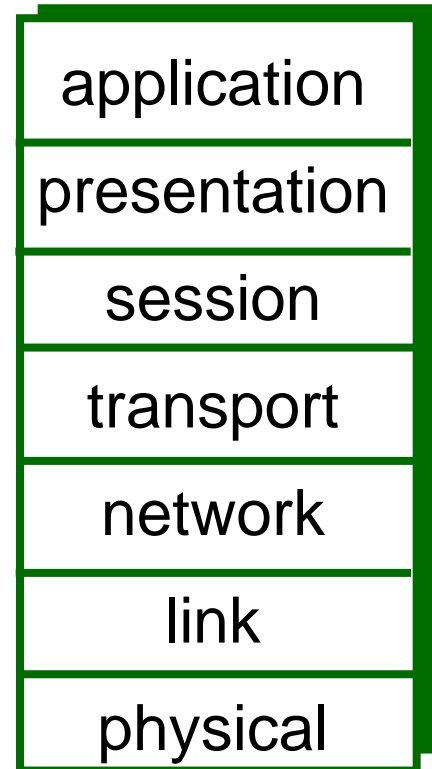
# Layering Challenges

o Many modern networks are application level networks

  o Social Networks such as Facebook, Twitter etc.

o P2P networks are a mixture of different layers

  o Sometimes implementing application level data lookup, packet (chunk) forwarding etc.

o Large scale applications demand optimizations on various levels:

  o Content delivery of large data streams!

# Layer 2 - Principles

o Switch processes up to layer 2

o Principles:

    o Reliable transmission of data over a link

    o Error detection, correction

    o Sharing a broadcast channel: multiple access

    o Link layer addressing

o Layer 2 packet is referred to as frame

> **data-link layer** has responsibility of transferring datagram from one node to adjacent node over a link

# Layer 2 – Error Detection

o Implemented in layer 2 adaptors (network interface cards etc.)

o Idea: Combine data payload with a Checksum to detect transmission errors

o Implemented using Cyclic Redundancy Checksum

o Typically frame is dropped if error occured. Re-transmit (reliability) has to be implemented at other layer

# Layer 2 – Multiple Access Prot.

o In general two types of „links":

   o Point-to-Point (e.g., PPP for dial-up, link between Ethernet switch and host)

   o Broadcast medium

      • Shared wire in old Ethernet

      • 802.11 wireless LAN
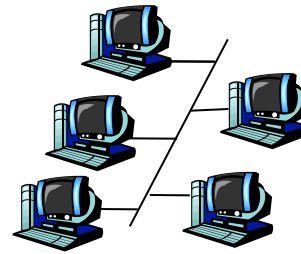
   shared wire (e.g., cabled Ethernet)

o In broadcast:

   o Distributed algorithms determine how nodes share channel and transmit

   o No „out-of-band" channel for coordination

# Layer 2 – Addressing
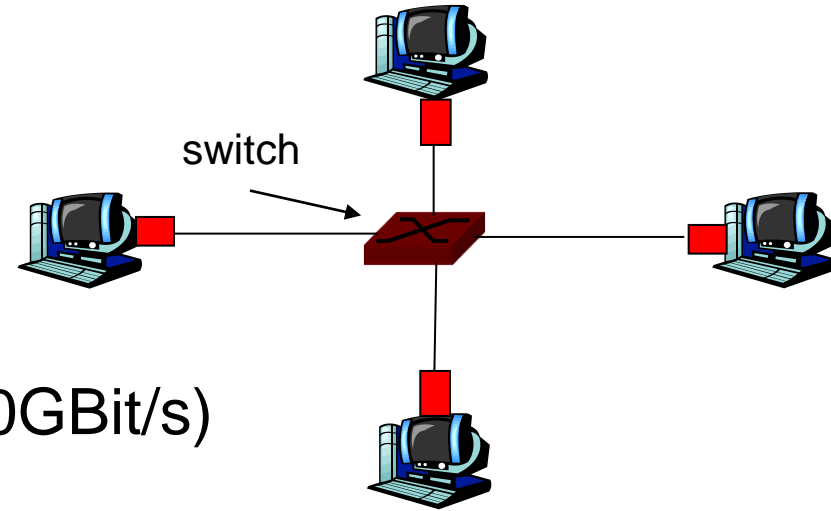
o 48 BIT MAC address

  o Burned in NIC Rom (sometimes software settable)

  o Should be unique (vendors have MAC-ranges)

  o No hierachical or aggregatable information! Also called flat address.

o IP to MAC address resolved using the Address Resolution Protocol (ARP)

  o Idea: Broadcast query: „Who has IP ...?". Host with queried IP replies unicast „IP ... is at MAC ...".

# Layer 2 – Forwarding

o Solved by switches
  o Learns in a plug and play mode, no configuration necessary!
  o Question: On what switch-port to forward incoming dataframe
    • If destination MAC is known (in forwarding table) and associated to a port, use that port
    • If destination MAC is unknown, broadcast the dataframe on all ports
    • If a packet with an unknown source MAC is observed, create an entry in the forwarding table that binds port to MAC

o Only works in the broadcast domain! No routing!

# Layer 2 – Ethernet

o Very common, very cheap

o Scales well (from 10MBit/s – 10GBit/s)

o Star topology used (no collisions!)

o Frame:

| Preamble | Dest. Address | Source Address | | Data | CRC |
|----------|---------------|----------------|--|------|-----|

Type
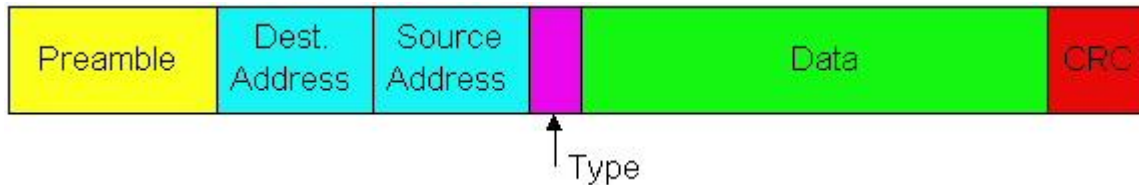
o Connectionless, unreliable

o Access protocol: CSMA/CD

switch

# Layer 3 – Principles

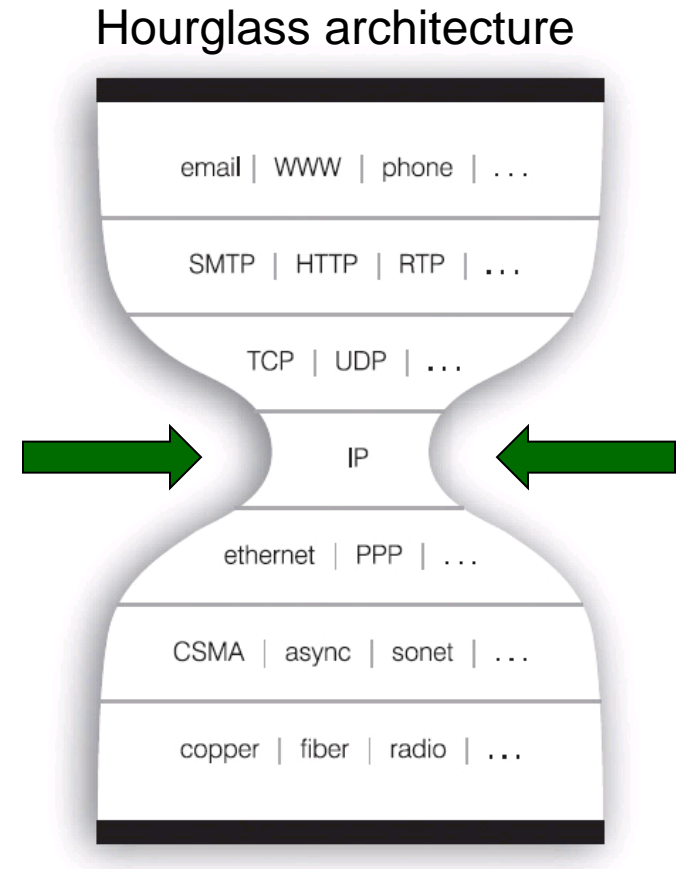o **Internet Protocol dominant networking technology**

o **Network layer transports datagrams from sending to receiving host**

o **Protocol runs in every host and router (not in switches!)**

Hourglass architecture



© Jonathan L. Zittrain (http://yupnet.org/zittrain/archives/13)

# Layer 3 – Routing

o Routing: determine the route taken by packts from source to destination

   o Analogy: planning a road trip from one city to another

o Functions of a router:

   o Forward datagram from incoming to outgoing link
   o Select outgoing link by running a routing algorithm
      • Examples: RIP, OSPF, BGP

o Routers buffer packets (buffer size rule of thumb: Round-Trip-Time times link capacity

   o Buffering source of delay, overflowing buffer causes loss

# Layer 3 – Addressing

o IP address: 32 bit identifier for host, router interface

o Interface: connection between host/router and physical link

  o Routers typically have multiple interfaces

  o Hosts typically have one interface

  o IP address associated with each interface



223.1.1.1

223.1.1.2

223.1.1.4   223.1.2.9

223.1.2.1

223.1.1.3   223.1.3.27

223.1.2.2

223.1.3.1   223.1.3.2
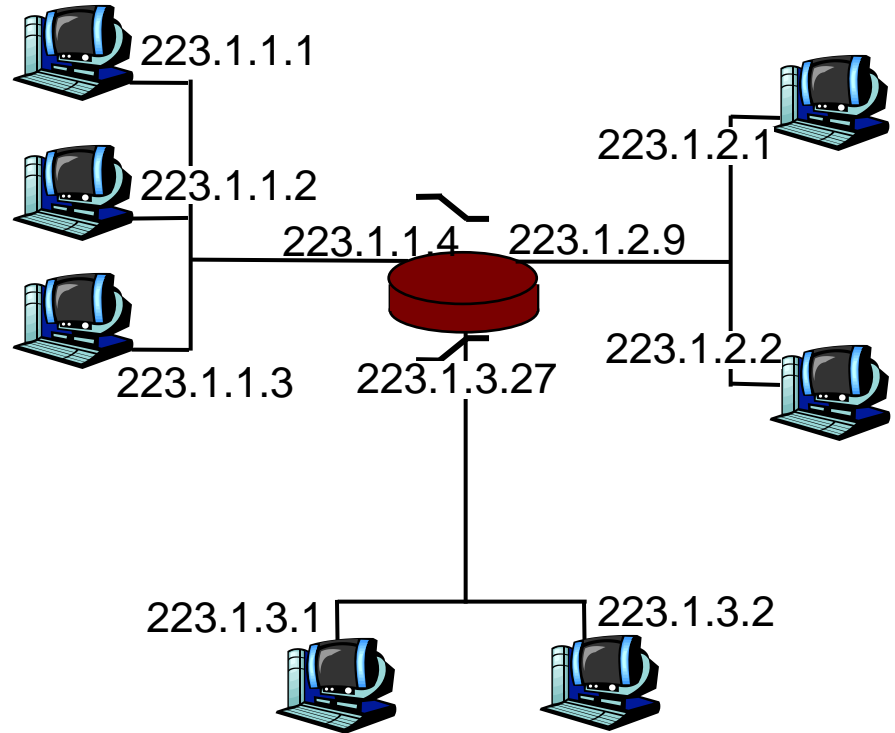
223.1.1.1 = 11011111 00000001 00000001 00000001

223         1         1         1

# Layer 3 – Subnets

- IP address not flat
- Hierachical structure of „subnets"
- Inside a subnet:
  - All device interfaces share part of IP address
  - Devices can reach each other without intervening a router



223.1.1.1
223.1.1.2
223.1.1.3
223.1.1.4
223.1.2.1
223.1.2.9
223.1.2.2
223.1.3.27
subnet
223.1.3.1
223.1.3.2
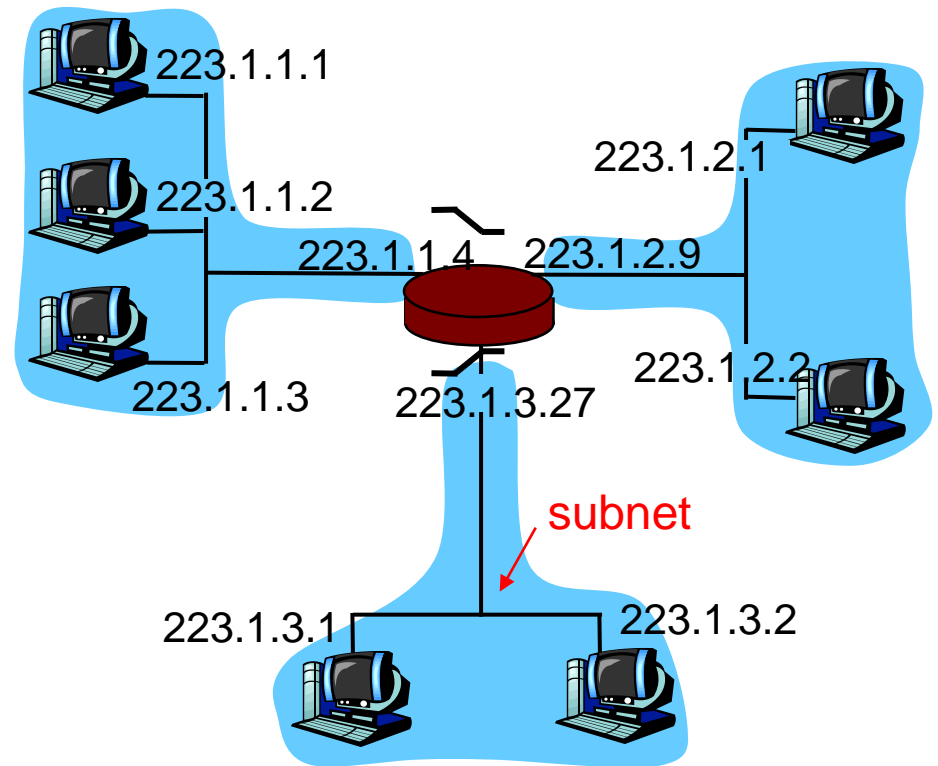
network consisting of 3 subnets

# Layer 3 – How to get an IP?

o MAC address was set by vendor

o IP needs to be obtained from ISP
  - o Either in a fixed configuration
  - o Or using the Dynamic Host Configuration Protocol (DHCP) (server offers service and hosts request IPs)

o How does the ISP get address space?
  - o Allocated by higher Tier! (remember the hierachy)
  - o Highest assignment done by Internet Assigned Numbers Authority (IANA) via ICANN in the US

# Layer 3 – Aggregation

o Hierachical addresses allow to aggregate
   some prefixes:

Organization 0
   200.23.16.0/23

Organization 1
   200.23.18.0/23

Organization 2
   200.23.20.0/23

Organization 7
   200.23.30.0/23

Fly-By-Night-ISP

"Send me anything
with addresses
beginning
200.23.16.0/20"

Internet

ISPs-R-Us

"Send me anything
with addresses
beginning
199.31.0.0/16"
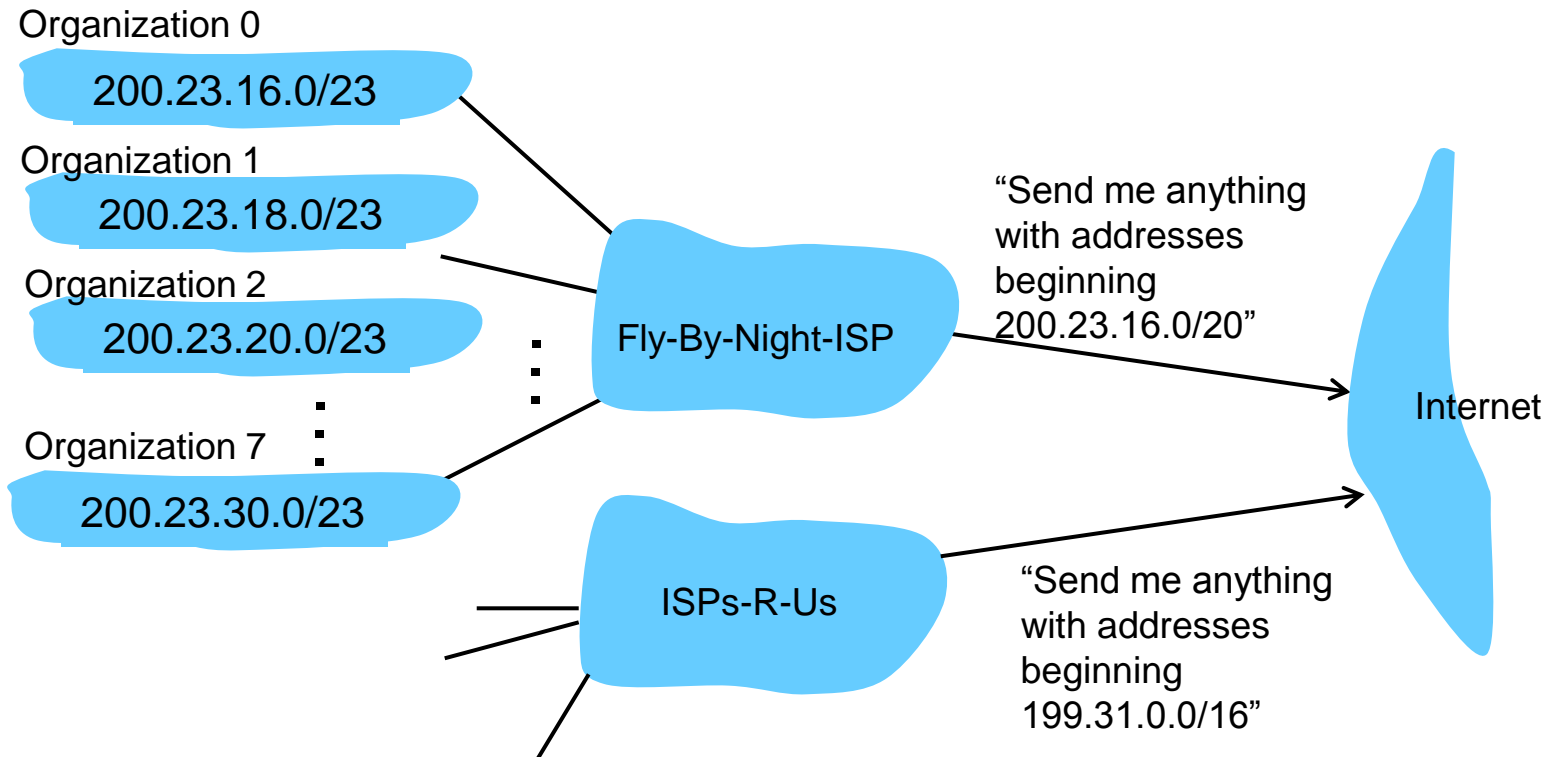
# Layer 3 – NAT

o Network address translation (NAT) allows local network to have more users than assigned IP addresses!

   o Use one IP address for all devices

   o Addresses inside the network can change without need to notify the outside world

   o The ISP may change without changes necessary inside the network

   o Devices inside the local network are not explicitly addressable by the outside world!

      • Security plus but makes connections more difficult!

# Layer 3 – NAT



rest of Internet ← → local network (e.g., home network) 10.0.0/24

10.0.0.4

138.76.29.7

10.0.0.1

10.0.0.2

10.0.0.3
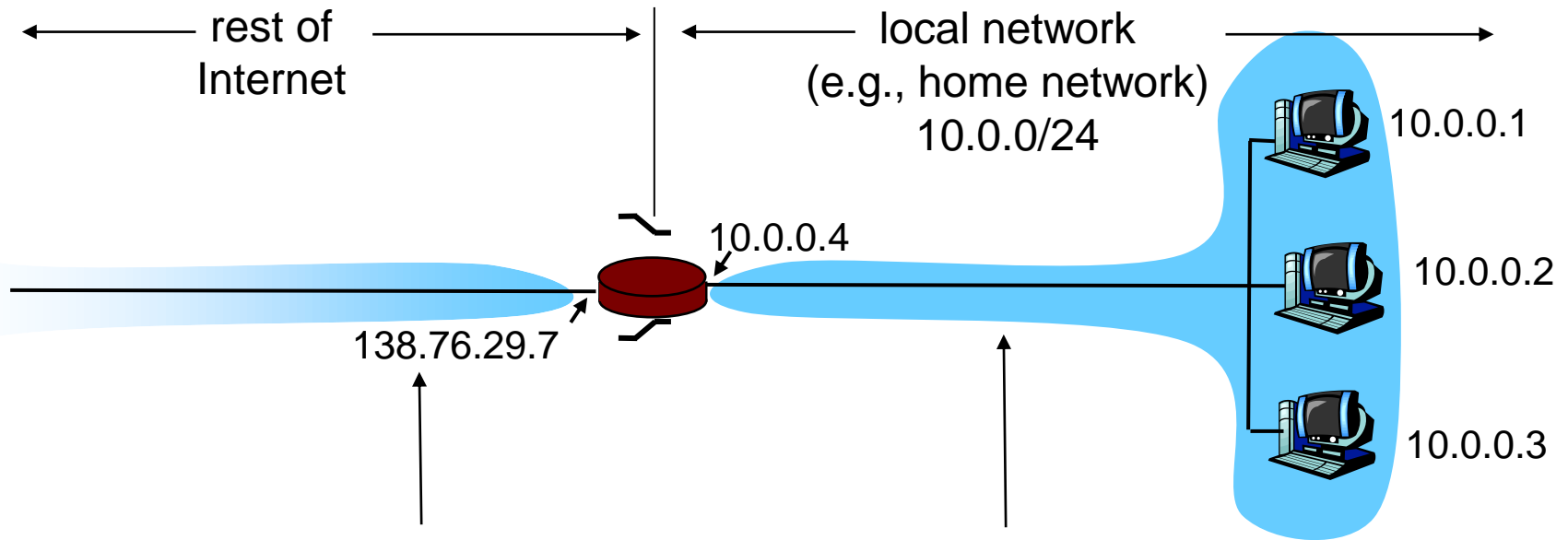
*All* datagrams *leaving* local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

# Layer 3 – NAT Challenges

○ NAT violates end-to-end argument

○ NAT traversal hard to solve for certain applications, for example P2P

○ Address shortage should instead be solved by IPv6


○ P2P Networks require to directly connect the destination host! How can this be solved?

# Layer 4 – Principles

o Provide logical communication between app processes running on different hosts

o Relies on and enhances network layer services

o Analogy: Network = postal service, Transport = secretaries at sender and receiver
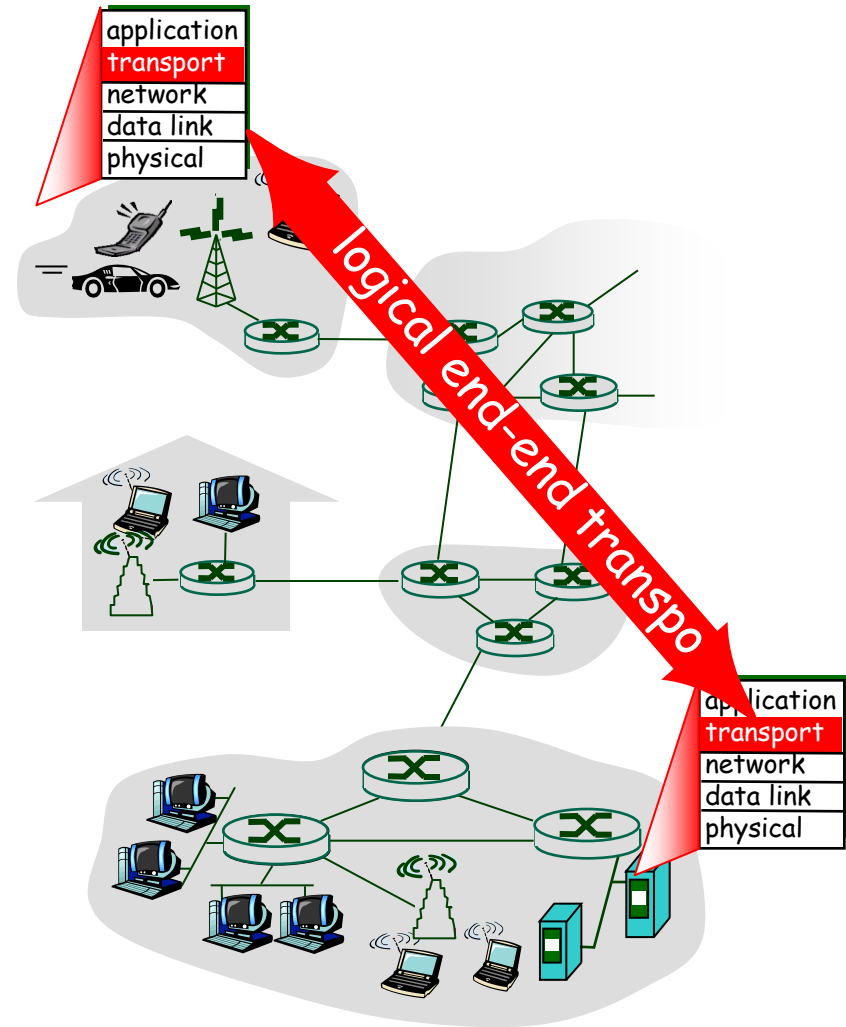
# Layer 4 – UDP and TCP

o UDP provides unreliable, unordered delivery
   o Conceptually minimal transport layer protocol with „best-effort" IP

o TCP provides
   o Reliable data transfer
   o In-order delivery
   o Congestion control
   o Flow control
   o Connection setup


o Both protocols do not guarantee certain delays or bandwidths

# Layer 4 – UDP and TCP

- UDP is minimalistic, therefore
  - Used in time-critical applications (Voice over IP)
  - Used when loss or out-of-order delivery is not critical
  - When the concept of connection is not of high relevance
- TCP ensures reliable data transfer:
  - Used when correctness is important
  - Typically used in all long-term non voice/video connections such as file transfers

# Layer 4 – Addressing

o TCP socket is identified by 4-tuple:

  o Source IP address

  o Source port number

  o Destination IP address

  o Destination port number

o This allows multiple apps to communicate simulataniously with same source and destination host but, for example, different source port

# Layer 4 – Data Transfer

o Reliable data transfer (TCP only) is ensured by

  o Maintaining state for each packet or group of packets (timeout timers)

  o Resend upon loss

    • Loss is inferred by missing Acknowledgments

  o Only send new packets if previous ones got acked

o Speeding things up: Pipelining

  o Idea: Maintain a large group of packets „on the fly" using a window. Examples: Go-back-N, Selective Repeat

# Layer 4 – TCP Properties

o Point-to-Point - one sender, one receiver

o Reliable, in-order delivery

o Pipelined – TCP congestion and flow control sets window sizes

o Send & receive buffers

o Full-duplex data transfer

o Connection oriented

o Flow-Control – Sender prevents to overwhelm receiver

# Application Layer

- Applications and application layer protocols:
  - HTTP/HTTPs for Web-Access
  - SMTP for e-mail
  - FTP/SFTP for data transfer
  - Many more…

- Challenge:
  - Utilize social information, peer-to-peer services, intelligent data storage and services (cloud) etc. to optimize content delivery!

# Different kinds of networks

o Content Distribution/Delivery Networks

    o Traditional client/server architecture

    o Centralized using multiple data centers

    o Utilizing server replication to enhance reliability

    o Big issues: load balancing, bandwidth allocation


o Idea: use P2P to decentralize network traffic

# Peer-to-Peer Networks

o Totally decentralized

o Self organized

o Every peer acts as a server and client

o Distributed algorithms


o How to find and retrieve data in the P2P network?

    o Distributed Hash Tables!

o How to ensure high service quality?

    o Security

# Cloud Computing

o Many networks composed of computationally weak clients

    o Smartphones, low energy devices

o Idea: Outsource all heavy computation to a centralized, powerful resource

    o Cloud computing

    o Again centralized infrastructure!

o Different from CDN as it provides not only delivery of content:

    o Also can provide computational services

    o Infrastructure services

    o Platform services

    o Software as a service

# Networks in General

o Motivation: What can we learn from IP networking that can be used in different fields for good?

o Many classical networks known:
  o Street network
  o Railroad network
  o Power grid

o But also networks that only recently found their technical representation:
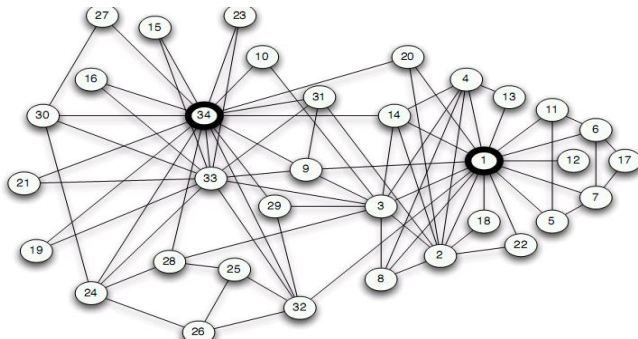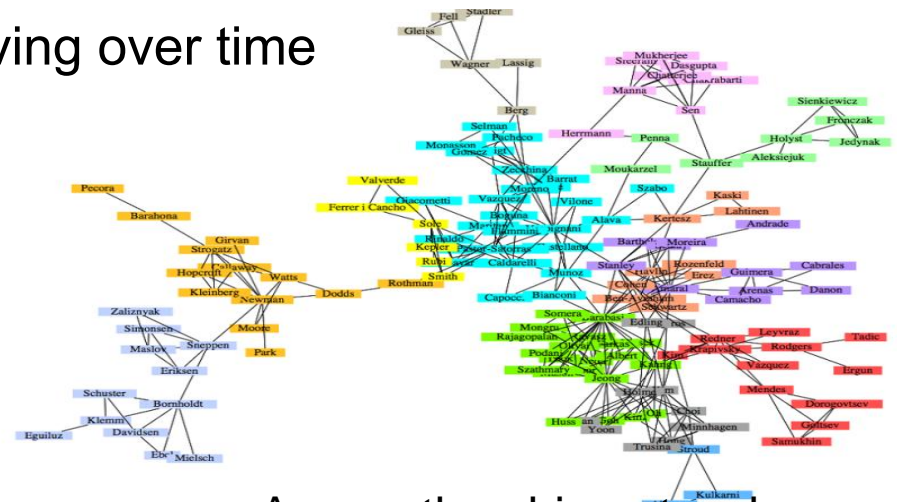  o Social networks

# Social Networks Preview

o Social Network
  o A network made up by a set of individuals interconnecting with each other basing on social relationships (such as friendships, partnerships, etc.)

o Characteristics
  o Virtual: it is not physically exists
  o Complex: it consists of a large scale number of nodes
  o Grouping: it forms communities due to different interests
  o Dynamic: it's structure is evolving over time



A friendship network in a karate club

A co-authorship network

# Social Networks Preview

- Structure: concepts and principles
- Properties of social networks
  - Strength of social ties
  - Power-law distribution in node degree
  - Small-World phenomenon
- Social network models
  - Random graphs
  - Preferential attachment model
- Applications issues
  - Epidemics and information cascade
  - Community detection
  - Security and Privacy

# Outlook

o In the next lectures:

    o Peer to Peer – From Napster to BitTorrent

    o Efficient lookup and data localization with distributed hash tables

    o Efficient content delivery with content centric networking…