计算机网络
Computer Networks

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School of Computer
Beijing Institute of Technology

A bit about myself

- **Research interest in networking**
  - Computer Networks
  - Parallel and Distributed Systems
  - Big Data, Cloud Computing
- **Teaching**
  - **Graduates:**
    - Advanced Computer Networks
  - **Undergraduates:**
    - Computer Networks,
    - Computer Architectures

Office hours

- **Location**

  Room 920, Central Bldg.

- **Office Hours**

  9:00 to 16:00 .

- **Email**

  hongzheng@bit.edu.cn

Course Information

- Credits/Hours: 3/48
- Course Web site:

https://lexue.bit.edu.cn/course/view.php?id=12996
100071011 计算机网络（双语） (2020级本科生 计算机学院 2022-2023-2学期)

  - Login Name: your student ID
  - Login Pass: your pw
  - Download PPT/PDF
  - Upload your homework/papers/reports

Goals of this course

- Learn and get **familiar with** the basic concepts and aspects of computer networks;
  - ✓ Switching, Forwarding, Routing, Naming, ...
- **Thoroughly understand** network architectures, primary ideas of network engineering, as well as applications;
  - ✓ Layering, ...
- **Build up ground work** for further study and R&D in computer networks field.

What You Learn in This Course

- **Knowledge:** how the network (e.g. Internet) works
  - Network (Internet) architecture
  - TCP/IP Protocol suite
  - Applications (Web, e-mail, FTP, P2P, …)
- **Insight:** key concepts in networking
  - Protocols
  - Layering
- **Skill:** network engineering/network programming
  - Network design/configuration/troubleshooting
  - Socket programming
  - Designing and implementing protocols

Focuses on the Internet

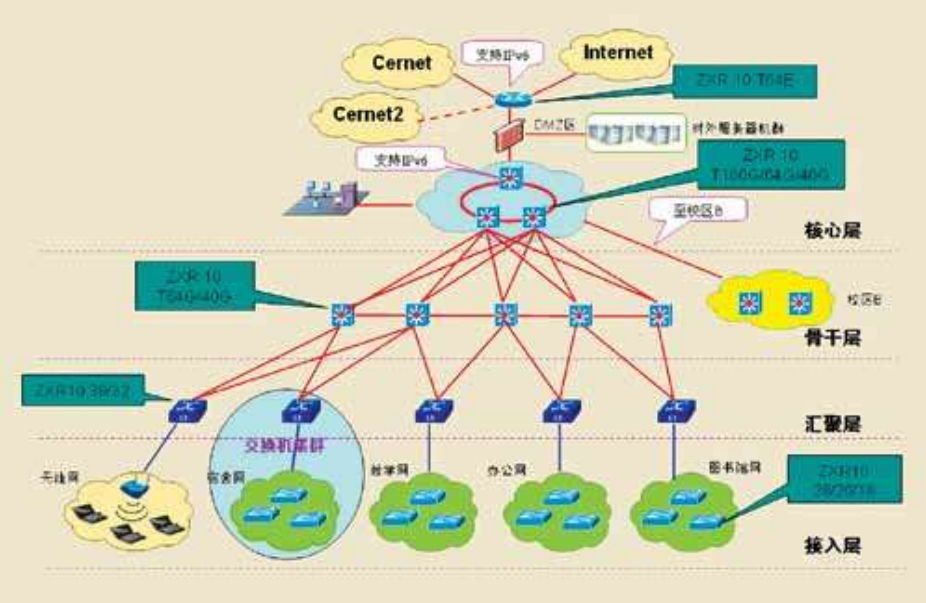
- **Internet only one that matters for computer science**
  - When computers use these other networks for IP-based communication, they are part of the Internet!
  - The Internet is not a network “technology”, it is the paradigm that ties networks together! (Internet)

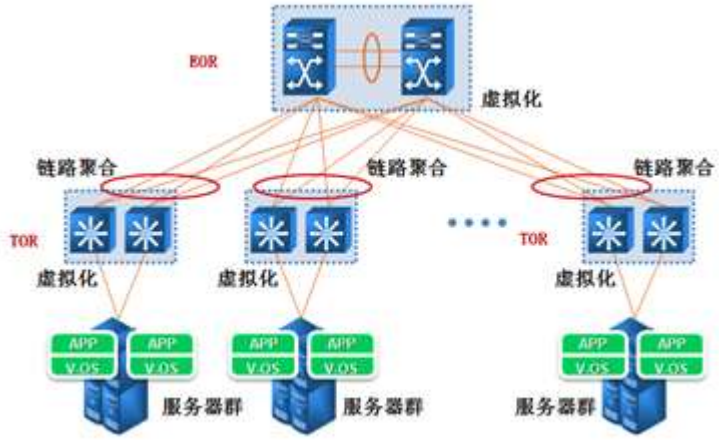
Focuses on the Internet

- Can you draw the picture of networks being joined (for example , BIT Campus network)?

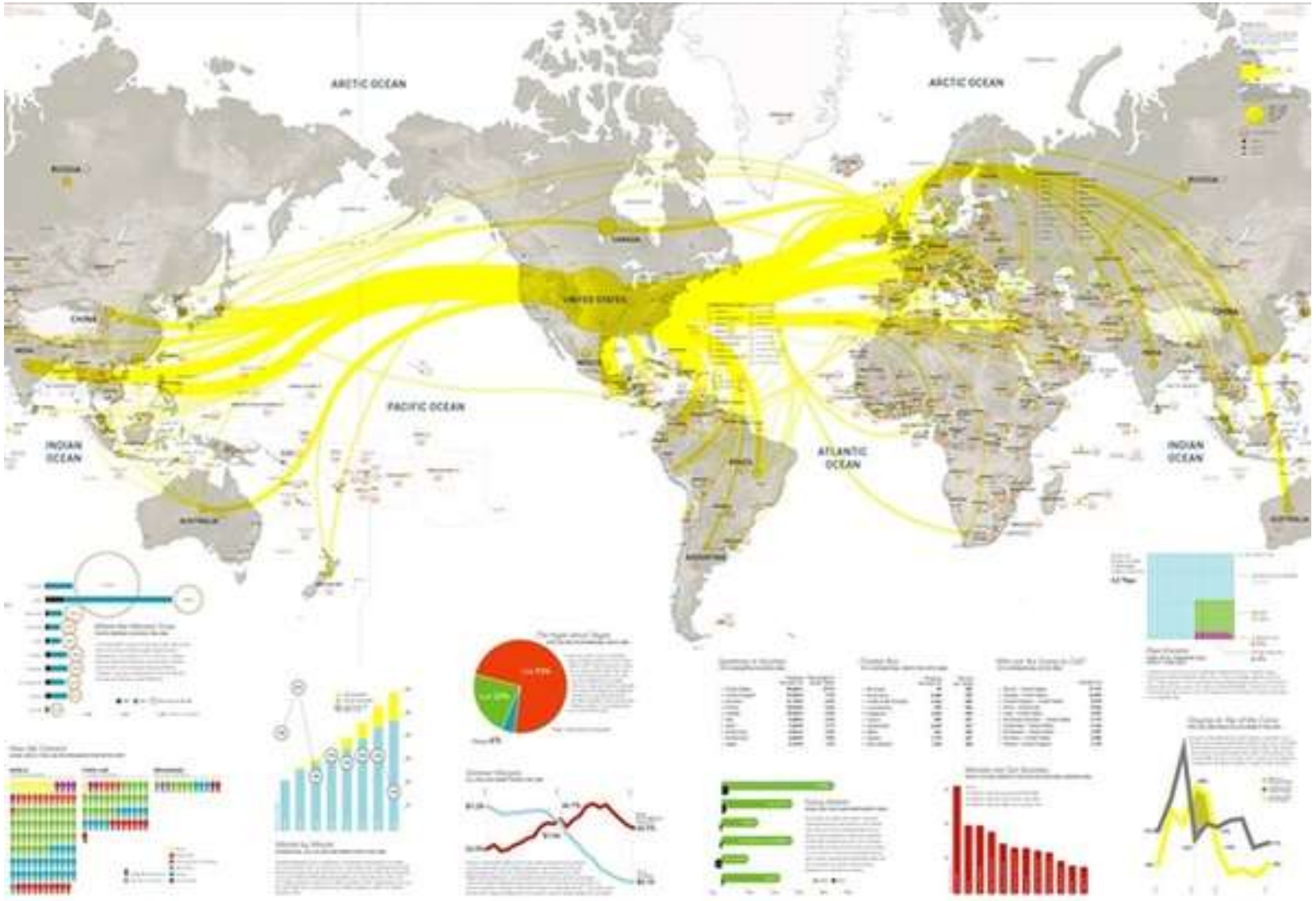
- Can you draw the picture of the Internet?

Focuses on the Internet





The picture of a campus network

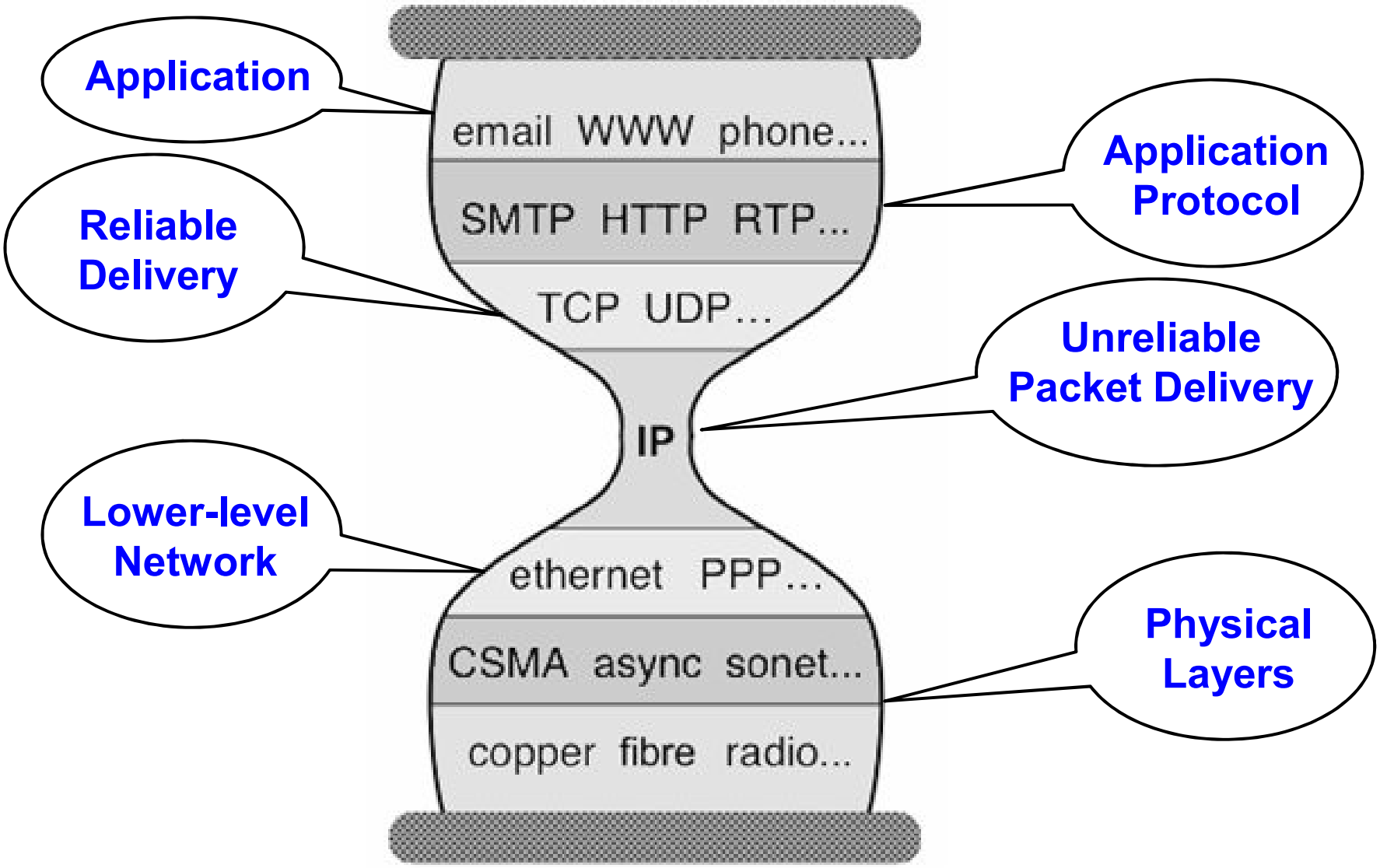


The picture of the part of the Internet

Various perspectives on Internet

- **Different levels of abstraction**
  - Basic concepts *vs.* actual protocols
- **Different geographic scales:**
  - LAN *vs.* Enterprise *vs.* WAN *vs.* Inter-domain
- **Different conceptual approaches:**
  - Architecture *vs.* Protocol *vs.* Algorithm
- **Different aspects of functionality:**
  - Different "layers" focus on different tasks

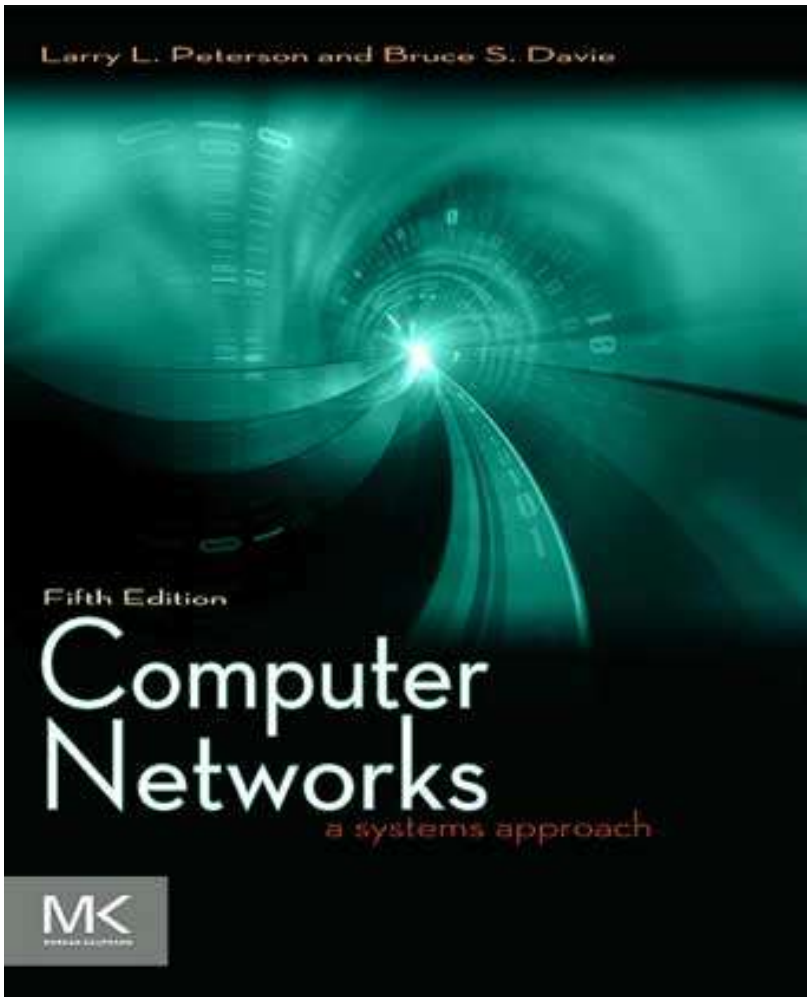
The Internet: an hourglass *with layers*



Fundamental conceptual questions

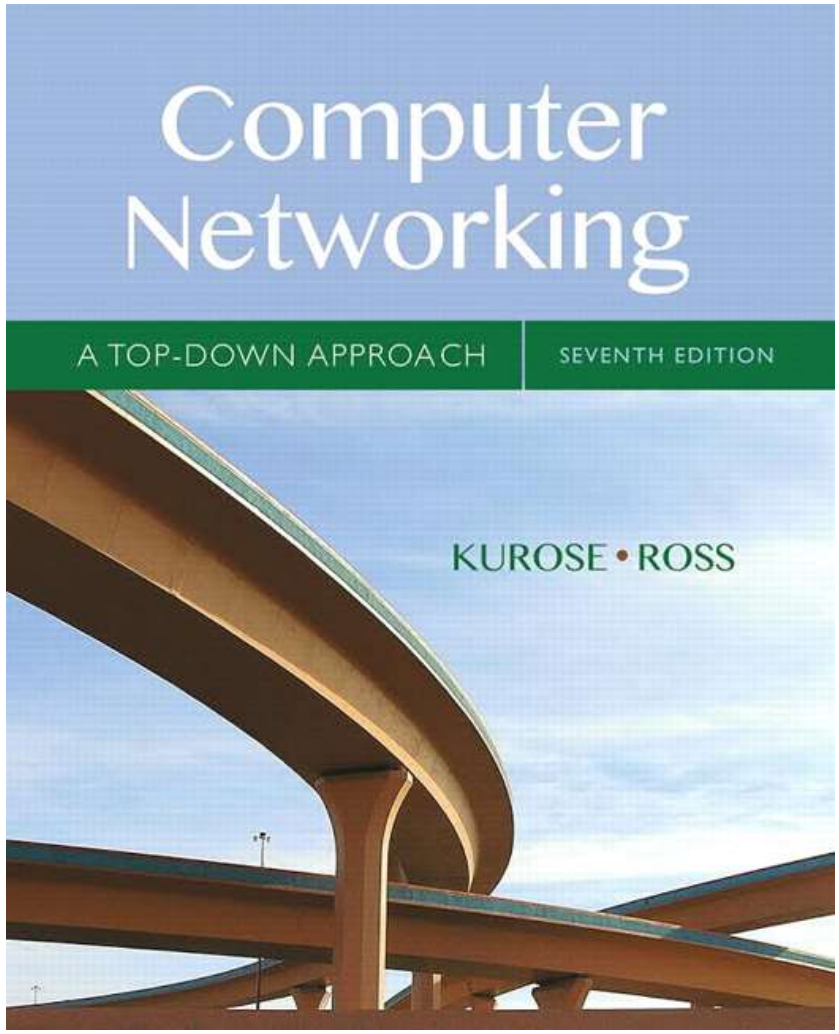
- How can you deliver packets from source to destination?
- How do you build reliable transport on top of an unreliable network?
- How can you build applications on top of a packet delivery interface?
- How do you manage such networks?
- How can you federate a set of competing ISPs?

Recommended Reference Textbooks



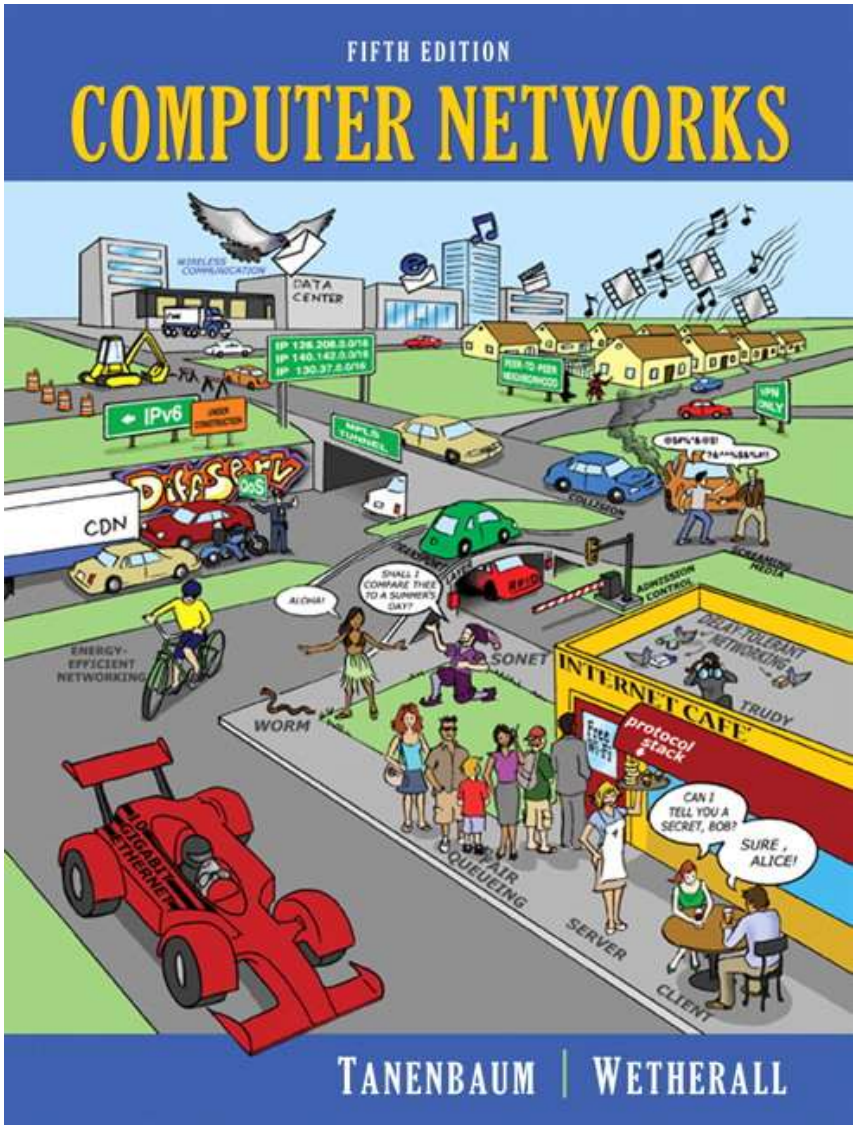
- Computer Networks: A Systems Approach (5th / 6th Edition), Larry L.Peterson, Bruce S.Davie.

Recommended Reference Textbooks



- Computer Networking: A Top-Down Approach (6th / 7th / 8th Edition), James F. Kurose, Keith W. Ross.

Recommended Reference Textbooks



- Computer Networks, 5th / 6th edition
  - Andrew Tanenbaum

Grading Policy

Final Grade	
Attendance / Written Assignments / Quiz	10%
Configuration and Analysis Experiments	10%
Programming Projects	10%
Course paper	10%
Final exam	60%

Assignments

- All assignments (homework, Networking Experiments, Programming Projects, Course paper, etc.) are individual;
- Start early;
- Ask questions early;
- Submit on time.

Academic Integrity

- Means
  - No copying from anywhere
  - Don't solve assignments for others
  - Don't ask/give solutions.
  - Protect your code
- Dishonesty → Not fair to others.
  - You may get a grade of F.

3 Questions

1. Why is it important to study networking?
2. Why is this an exciting time for networking?
3. Why is networking so hard?

1: Why important to study networking?

- Huge impact
- New paradigm
- Unresolved challenges

Internet has had tremendous impact

- **Internet changed the way we gather information**
  - Web, search engines
- **Internet changed the way we relate to each other**
  - Email, facebook, twitter
- **Which would you choose?**
  - Computers without the Internet (standalone PCs)
  - Internet without modern computers

The Internet introduced new paradigm

- Completely different from the phone network
- Inventors had to overcome strong technical and commercial resistance to realize their dreams
- A true success story of "thinking differently"
  - Their strong vision kept the design on track
  - Brilliant in conception, sometimes weak in execution
- *While mired in details, leave room for awe*

Many challenges remain unsolved

- **Security**
  - Security of infrastructure
  - Security of users
- **Availability**
  - Internet is very resilient
  - But availability is not sufficient for critical infrastructures
- **Evolution**
  - It is too hard to change the Internet architecture

2: Why an exciting time in networking?

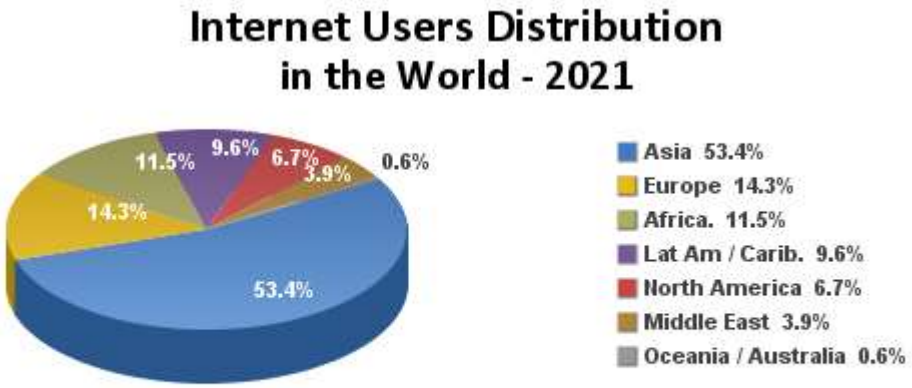
- **The "architecture" won't change**
  - But how we build and manage networks will
- **Industry has been closed, stagnant, and feudal**
- **But we are on the verge of a revolution!**
  - Commodity hardware making in roads
  - Developing intellectual (and practical) framework of applying systems principles of abstraction and modularity

3: Why is Networking Hard?

- Many challenges:
  - Scale
  - Dynamic Range
  - Diversity of
    - end systems
    - application requirements
  - Many components: protocols, NIC, routers
  - Security:
    - Greed, Malice
    - Virus
    - System vulnerabilities

Scale

WORLD INTERNET USAGE AND POPULATION STATISTICS 2021 Year-Q1 Estimates						
World Regions	Population (2021 Est.)	Population % of World	Internet Users 31 Mar 2021	Penetration Rate (% Pop.)	Growth 2000-2021	Internet World %
Asia	4,327,333,821	54.9 %	2,762,187,516	63.8 %	2,316.5 %	53.4 %
Europe	835,817,920	10.6 %	736,995,638	88.2 %	601.3 %	14.3 %
Africa	1,373,486,514	17.4 %	594,008,009	43.2 %	13,058 %	11.5 %
Latin America / Carib.	659,743,522	8.4 %	498,437,116	75.6 %	2,658.5 %	9.6 %
North America	370,322,393	4.7 %	347,916,627	93.9 %	221.9 %	6.7 %
Middle East	265,587,661	3.4 %	198,850,130	74.9 %	5,953.6 %	3.9 %
Oceania / Australia	43,473,756	0.6 %	30,385,571	69.9 %	298.7 %	0.6 %
WORLD TOTAL	7,875,765,587	100.0 %	5,168,780,607	65.6 %	1,331.9 %	100.0 %



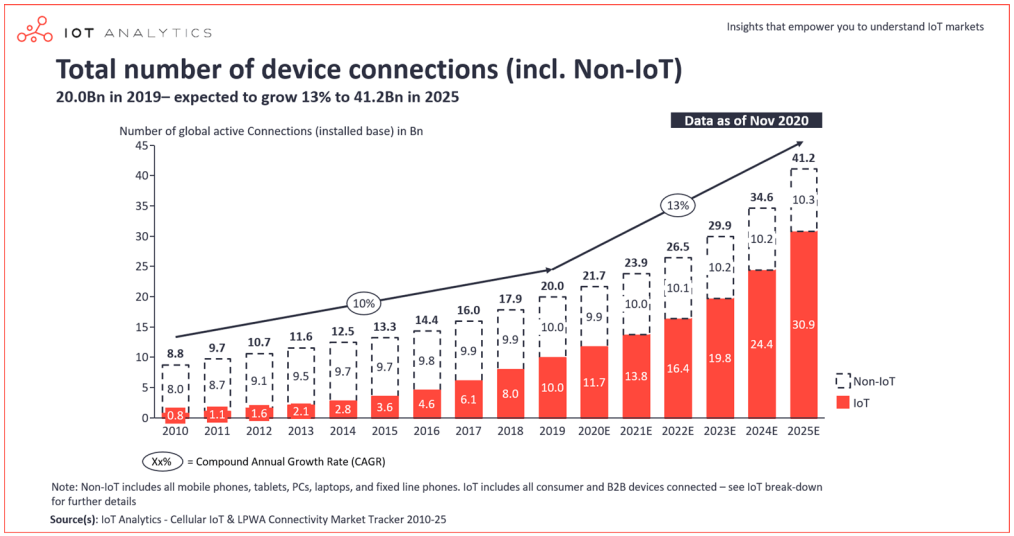
Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 5,168,780,607 Internet users in March 31, 2021

Dynamic Range

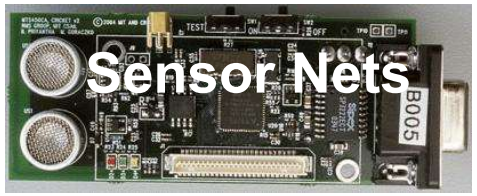
- **Round-trip times (latency) from 10μsecs to secs :** 5 orders of magnitude
- **Data rates (bandwidth) from kbps to 100 Gbps :** 8 orders of magnitude
- **Queuing delays in the network vary from 0 to secs**
- **Packet loss varies from 0 to 90+%**
- **……**

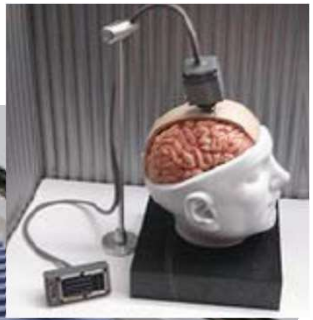
Diversity of end systems

- *Cell phones*
- *Supercomputer clusters*
- *Tablets*
- *Televisions*
- *Gaming consoles*
- *Web cams*
- *Automobiles*
- *Sensing devices*
- *Picture frames*
- *Security systems*
- *Power grid*
- *……*



Diversity of end systems





Diversity of application requirements

表 4　2020.12-2021.6 各类互联网应用用户规模和网民使用率

	2020.12		2021.6		
应用	用户规模（万）	网民使用率	用户规模（万）	网民使用率	增长率
即时通信	98111	99.2%	98330	97.3%	0.2%
网络视频（含短视频）	92677	93.7%	94384	93.4%	1.8%
短视频	87335	88.3%	88775	87.8%	1.6%
网络支付	85434	86.4%	87221	86.3%	2.1%
网络购物	78241	79.1%	81206	80.3%	3.8%
搜索引擎	76977	77.8%	79544	78.7%	3.3%
网络新闻	74274	75.1%	75987	75.2%	2.3%
网络音乐	65825	66.6%	68098	67.4%	3.5%
网络直播	61685	62.4%	63769	63.1%	3.4%
网络游戏	51793	52.4%	50925	50.4%	-1.7%
网上外卖	41883	42.3%	46859	46.4%	11.9%
网络文学	46013	46.5%	46127	45.6%	0.2%

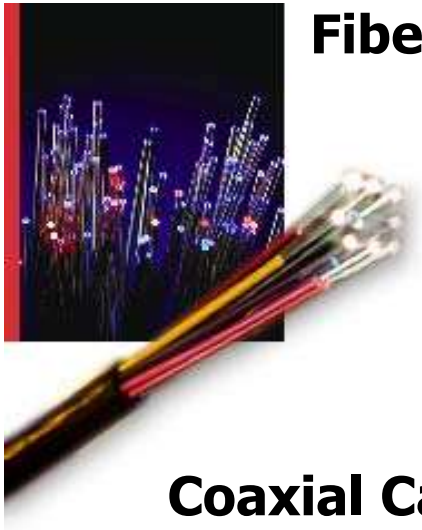
	2020.12		2021.6		
应用	用户规模（万）	网民使用率	用户规模（万）	网民使用率	增长率
网约车	36528	36.9%	39651	39.2%	8.5%
在线办公	34560	34.9%	38065	37.7%	10.1%
在线旅行预订	34244	34.6%	36655	36.3%	7.0%
在线教育	34171	34.6%	32493	32.1%	-4.9%
在线医疗	21480	21.7%	23933	23.7%	11.4%
互联网理财	16988	17.2%	16623	16.4%	-2.1%

Diversity of application requirements

- Size of transfers
- Bidirectionality (or not)
- Latency sensitive (or not)
- Tolerance of jitter (or not)
- Tolerance of packet drop (or not)
- Need for reliability (or not)
- Multipoint (or not)
- ……

Networks contain many components

Links



Fibers

Coaxial Cable

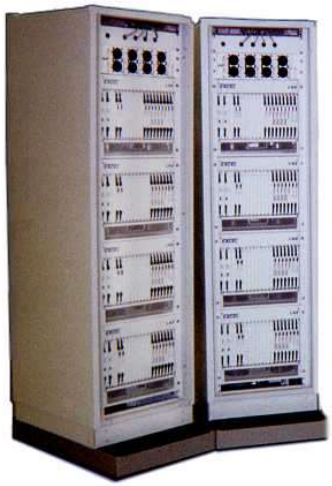
Interfaces

Ethernet card

Wireless card

Switches/routers

Large router



Telephone switch

They can all fail….

- **Consider communication that uses 50 components**
  - Assume each work correctly 99% of the time
  - What is likelihood communication fails?
- **Answer: success requires that they all function, so failure probability = 1 - $(.99)^{50} \approx 39.5\%$**
- **Even if nodes are 99.9% reliable, failure probability is still close to 5%**
- **Must design the system to expect failure!**

Greed

- **There are greedy people out there who want to:**
  - Steal your financial information (bank, credit card, etc.)
  - Use your computer for attacks
- **There is a thriving underground economy for compromised computers and financial information**

Malice

- **There are malicious people out there who want to:**
  - Bring your system down and/or steal confidential data
- **When attacker is a nation-state, attacks are far harder to stop**
  - Many defensive techniques involve stopping attacks that have been seen before
  - But nation-states can use *new* attack vectors

Speed of Light

- **Question:** how long does it take light to travel from Beijing to shanghai?
- **Answer:**
  - Distance Beijing → Shanghai: 1,088 km
  - Traveling 300,000 km/s, 3.63 msec

Networking Latencies

- **Answer:**
  - For sure ≥ 3.63 msec
  - Depends on:
    - The *route* the packet takes (could be circuitous!)
    - The propagation speed of the *links* the packet traverses
      - E.g., in optical fiber light propagates at about 2/3 *C*
    - The transmission rate (*bandwidth*) of the links (bits/sec)
      - and thus the size of the packet
    - Number of *hops* traversed (*store-and-forward* delay)
    - The "competition" for bandwidth the packet encounters (*congestion*). It may have to sit & wait in router queues.
  - In practice this boils down to: ≥ 10 msec

Implications for Networking

- **Question: how many cycles does your PC execute before it can possibly get a reply to a message it sent to a Shanghai web server?**

- **Answer:**
  - **Round trip** takes ≥ 20 msec
  - PC runs at (say) 3 GHz
  - 3,000,000,000 cycles/sec*0.02 sec = **150,000,000,000 cycles**
  - Communication feedback is always ***dated***
  - Communication fundamentally ***asynchronous***

Even a Problem for LANs

- **Question:** what about between machines directly connected (via a *local area network* or LAN)?
- **Answer:**

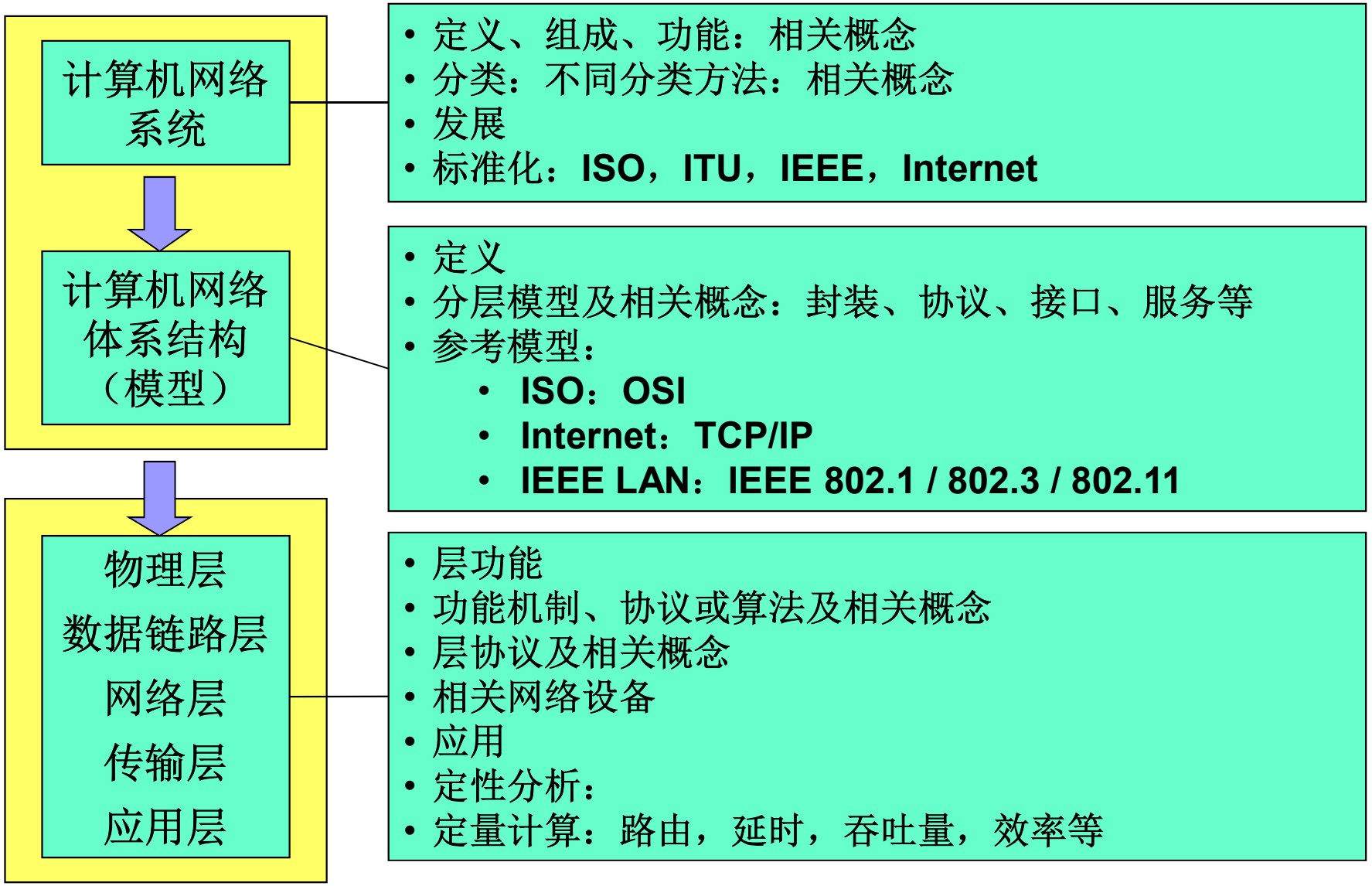
```
% ping www.icir.org
PING www.icir.org (192.150.187.11): 56 data bytes
64 bytes from 192.150.187.11: icmp_seq=0 ttl=64 time=0.214 ms
64 bytes from 192.150.187.11: icmp_seq=1 ttl=64 time=0.226 ms
64 bytes from 192.150.187.11: icmp_seq=2 ttl=64 time=0.209 ms
64 bytes from 192.150.187.11: icmp_seq=3 ttl=64 time=0.212 ms
64 bytes from 192.150.187.11: icmp_seq=4 ttl=64 time=0.214 ms
```

- 200 μsec = 600,000 cycles
  - Still a loooong time …
  - … and asynchronous

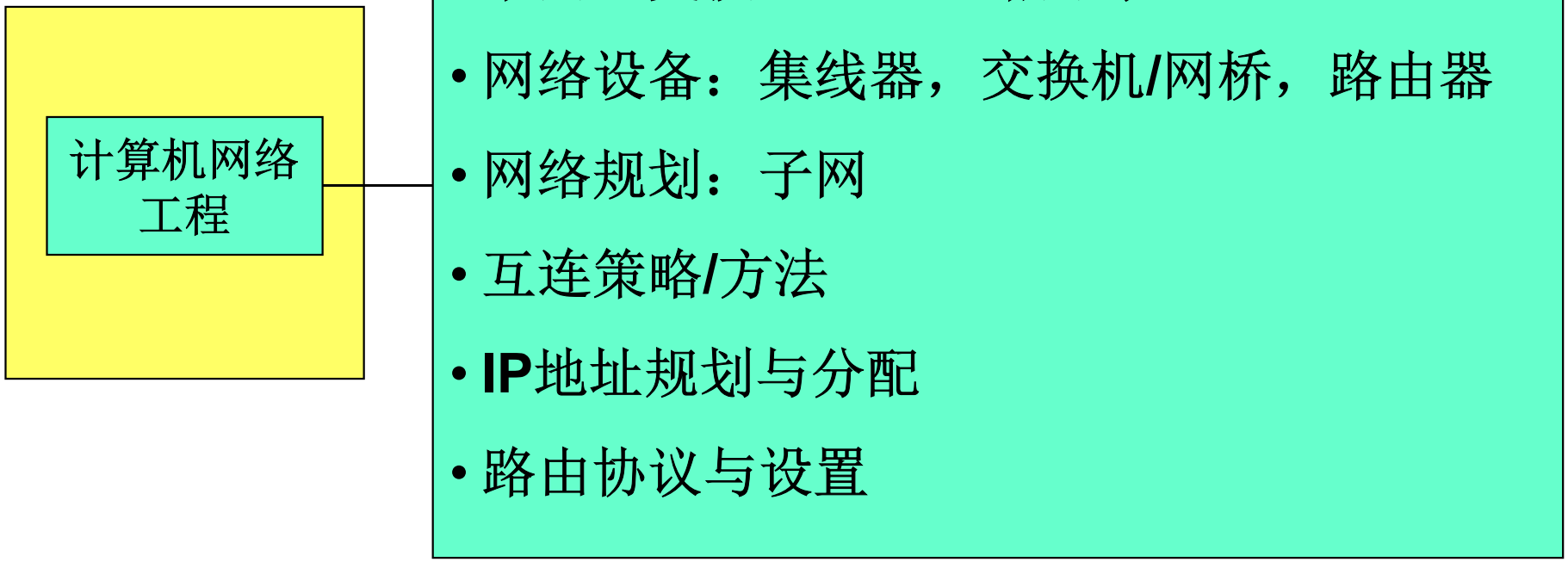
Summary

- **The Internet is a large complicated system that must meet an unprecedented variety of challenges**
  - Scale, dynamic range, diversity, ad hoc, failures, asynchrony, malice, and greed
- **An amazing feat of engineering**
  - Went against the conventional wisdom
  - Created a new networking paradigm
- **In hindsight, some aspects of design are terrible**

学习思路1


计算机网络系统
计算机网络体系结构（模型）
物理层
数据链路层
网络层
传输层
应用层
• 定义、组成、功能：相关概念
• 分类：不同分类方法：相关概念
• 发展
• 标准化：ISO，ITU，IEEE，Internet
• 定义
• 分层模型及相关概念：封装、协议、接口、服务等
• 参考模型：
• ISO：OSI
• Internet：TCP/IP
• IEEE LAN：IEEE 802.1 / 802.3 / 802.11
• 层功能
• 功能机制、协议或算法及相关概念
• 层协议及相关概念
• 相关网络设备
• 应用
• 定性分析：
• 定量计算：路由，延时，吞吐量，效率等

学习思路2


计算机网络工程
• 相关概念：网络体系结构，资源子网，通信子网，交换，互连，路由等
• 网络设备：集线器，交换机/网桥，路由器
• 网络规划：子网
• 互连策略/方法
• IP地址规划与分配
• 路由协议与设置