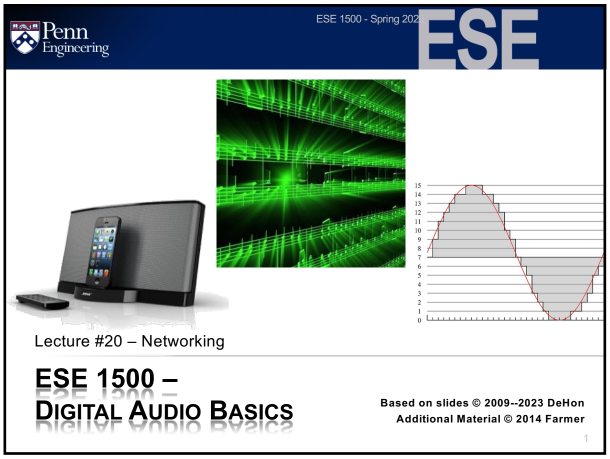

Lecture #20 – Networking

ESE 1500 – Digital Audio Basics

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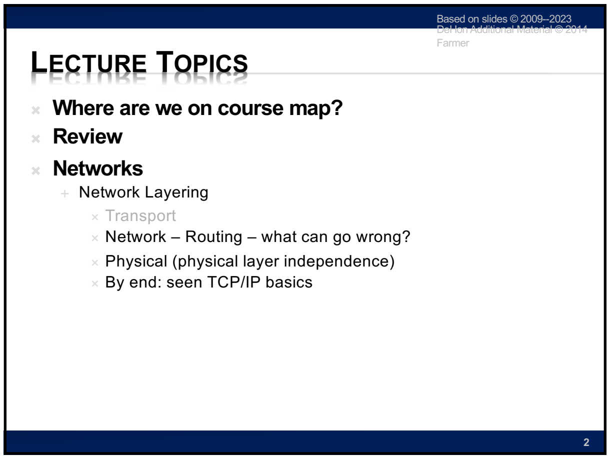

Lecture Topics

- Where are we on course map?
- Review
- Networks
  - Network Layering
    - Transport
    - Network – Routing – what can go wrong?
    - Physical (physical layer independence)
    - By end: seen TCP/IP basics

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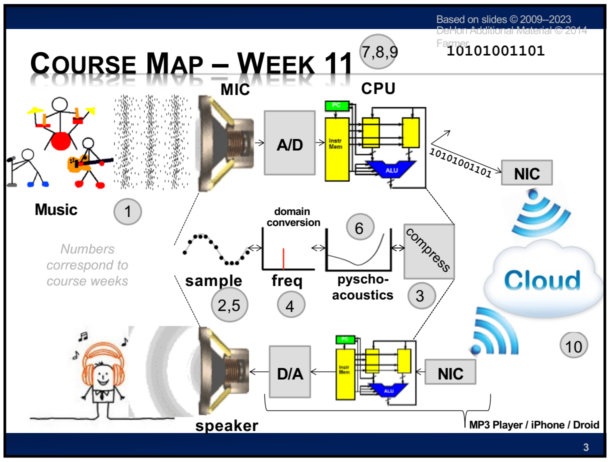
2



Course Map – Week 11

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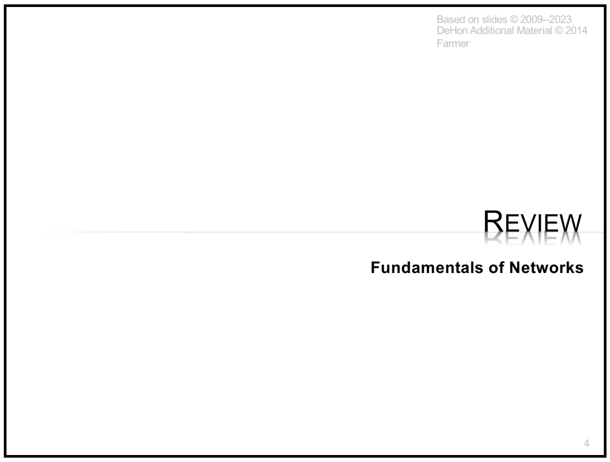

Review

Fundamentals of Networks

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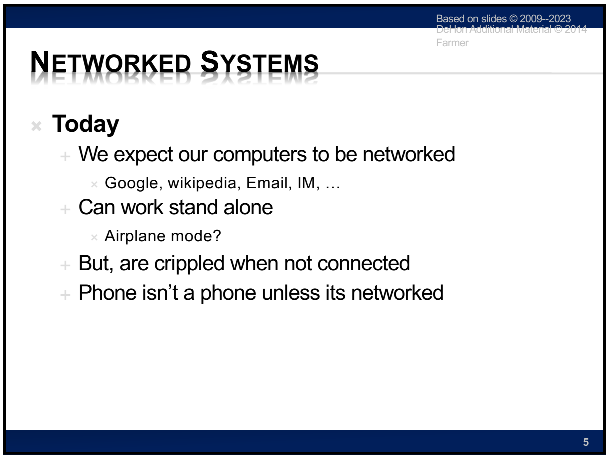
4



Networked Systems

- Today
  - We expect our computers to be networked
    - Google, wikipedia, Email, IM, …
  - Can work stand alone
    - Airplane mode?
  - But, are crippled when not connected
  - Phone isn't a phone unless its networked

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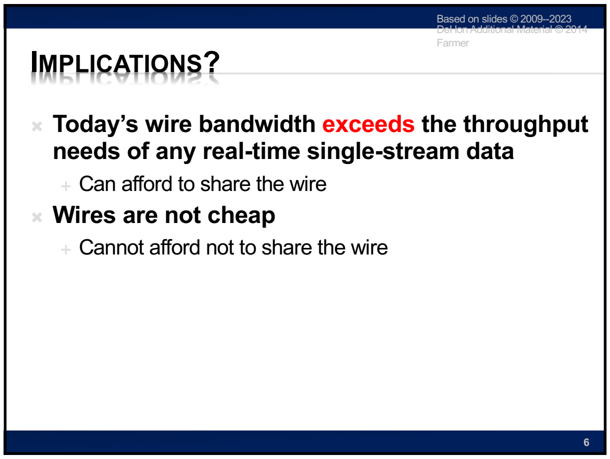
5



Implications?

- Today's wire bandwidth exceeds the throughput needs of any real-time single-stream data
  - Can afford to share the wire
- Wires are not cheap
  - Cannot afford not to share the wire

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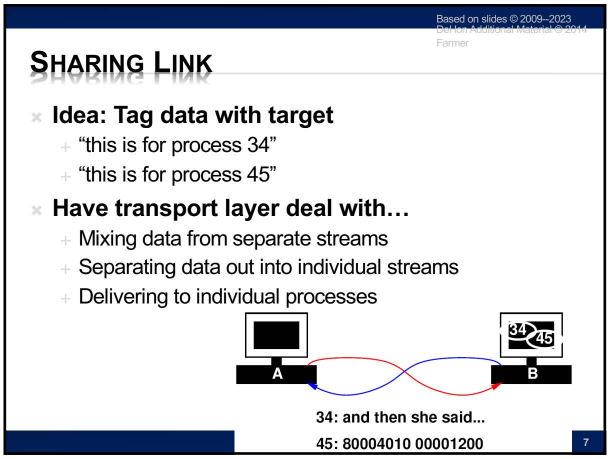

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Sharing Link

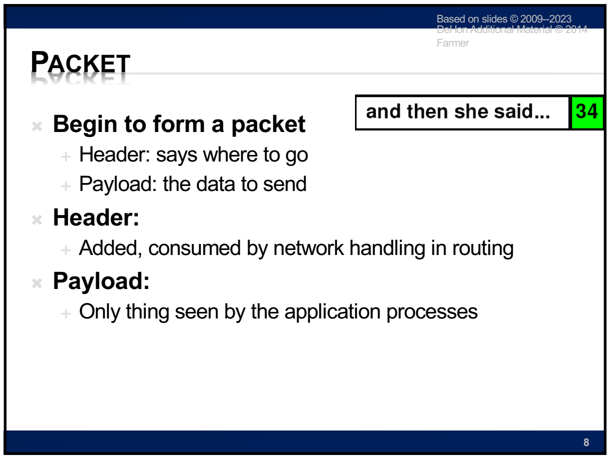
- **Idea: Tag data with target**
  - "this is for process 34"
  - "this is for process 45"
- **Have transport layer deal with…**
  - Mixing data from separate streams
  - Separating data out into individual streams
  - Delivering to individual processes

34: and then she said...

45: 80004010 00001200

7

7



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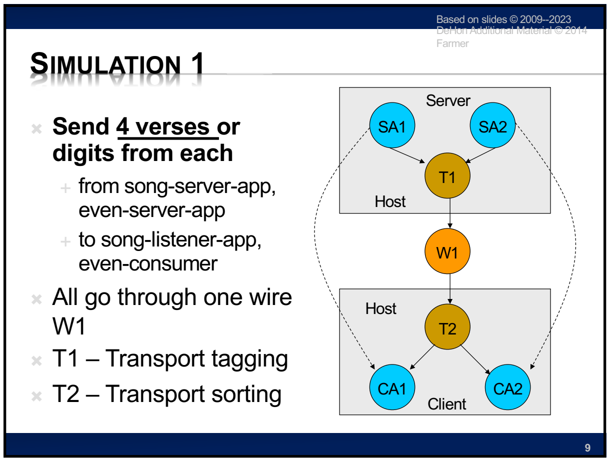
Packet

and then she said...	34

- **Begin to form a packet**
  - Header: says where to go
  - Payload: the data to send
- **Header:**
  - Added, consumed by network handling in routing
- **Payload:**
  - Only thing seen by the application processes

8

8



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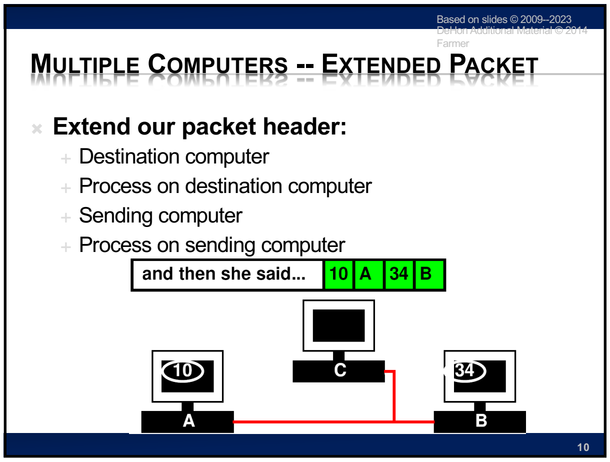
Simulation 1

- **Send 4 verses or digits from each**
  - from song-server-app, even-server-app
  - to song-listener-app, even-consumer
- All go through one wire W1
- T1 – Transport tagging
- T2 – Transport sorting

9

9



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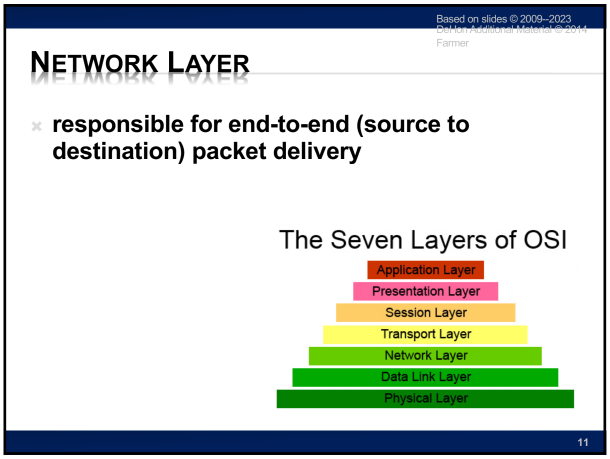
Multiple Computers -- Extended Packet

- **Extend our packet header:**
  - Destination computer
  - Process on destination computer
  - Sending computer
  - Process on sending computer

and then she said...	10	A	34	B

10

10



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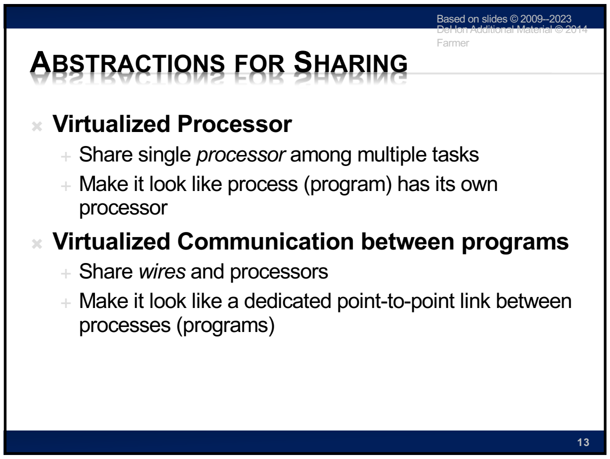
Network Layer

- **responsible for end-to-end (source to destination) packet delivery**

The Seven Layers of OSI

11

11



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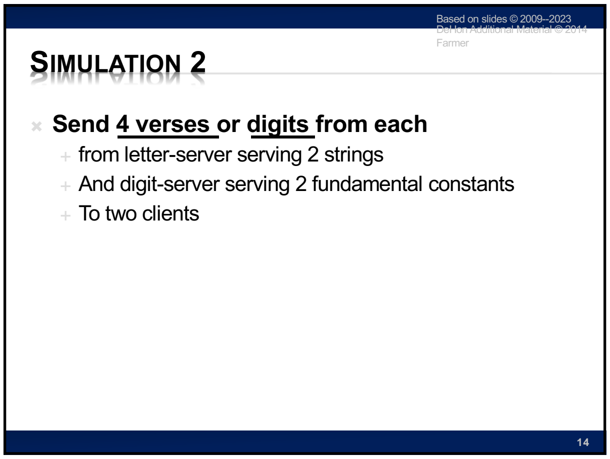
Abstractions for Sharing

- **Virtualized Processor**
  - Share single *processor* among multiple tasks
  - Make it look like process (program) has its own processor
- **Virtualized Communication between programs**
  - Share *wires* and processors
  - Make it look like a dedicated point-to-point link between processes (programs)

13

13



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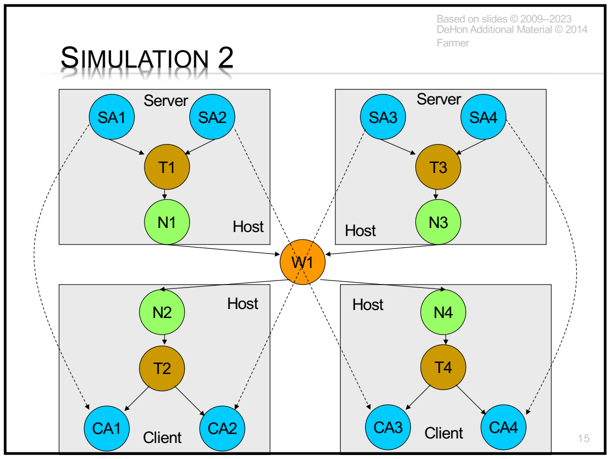
Simulation 2

- **Send 4 verses or digits from each**
  - from letter-server serving 2 strings
  - And digit-server serving 2 fundamental constants
  - To two clients

14

14



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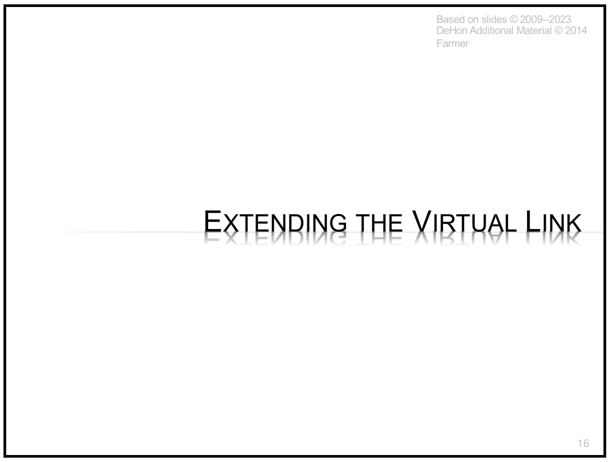
Simulation 2

15

15



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Extending the Virtual Link

16

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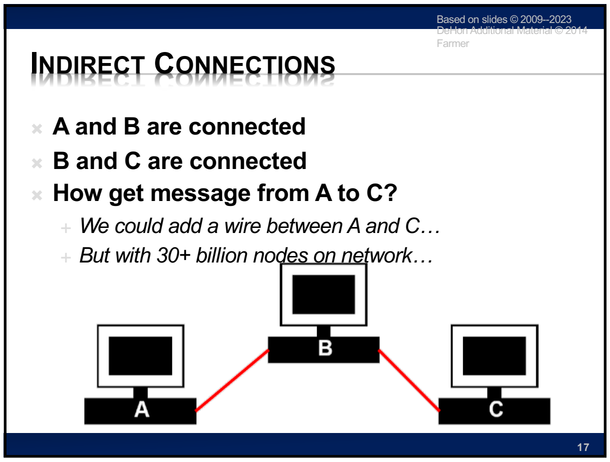

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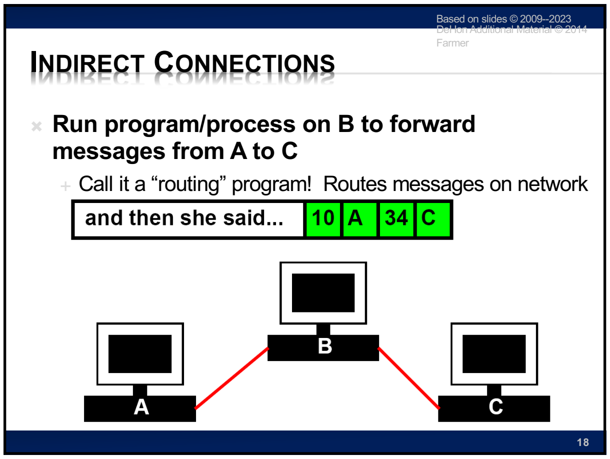
Indirect Connections

- **A and B are connected**
- **B and C are connected**
- **How get message from A to C?**
  - *We could add a wire between A and C…*
  - *But with 30+ billion nodes on network…*

17

17



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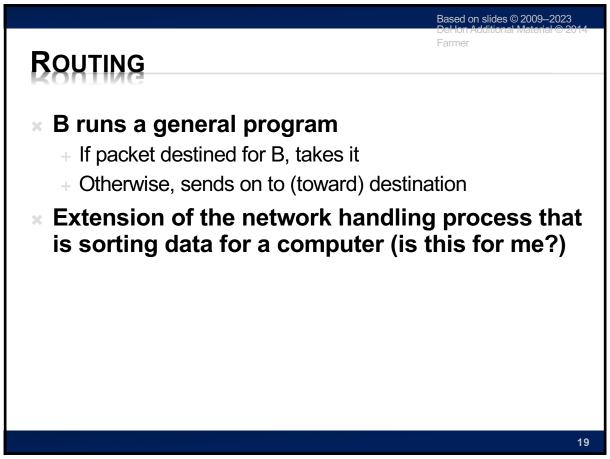
Indirect Connections

- **Run program/process on B to forward messages from A to C**
  - Call it a "routing" program! Routes messages on network

and then she said…	10	A	34	C

18

18



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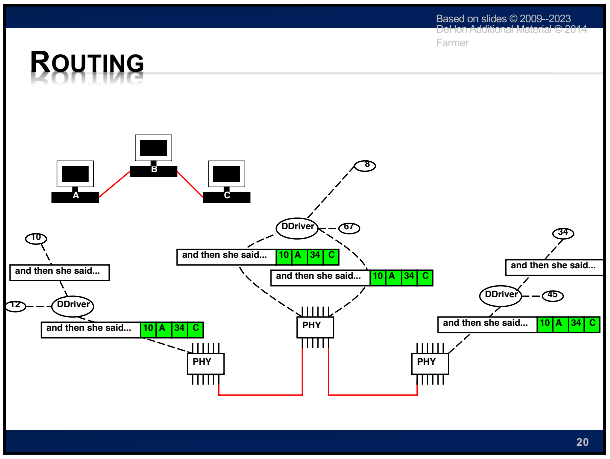
Routing

- **B runs a general program**
  - If packet destined for B, takes it
  - Otherwise, sends on to (toward) destination
- **Extension of the network handling process that is sorting data for a computer (is this for me?)**

19

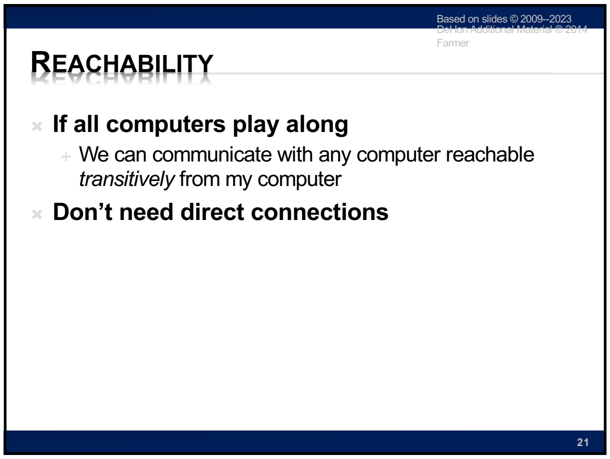
19



Routing

A
B
C
8
DDriver
67
10
and then she said...
12
DDriver
and then she said... 10 A 34 C
and then she said... 10 A 34 C
and then she said... 10 A 34 C
34
and then she said...
DDriver
45
and then she said... 10 A 34 C
PHY
PHY
PHY

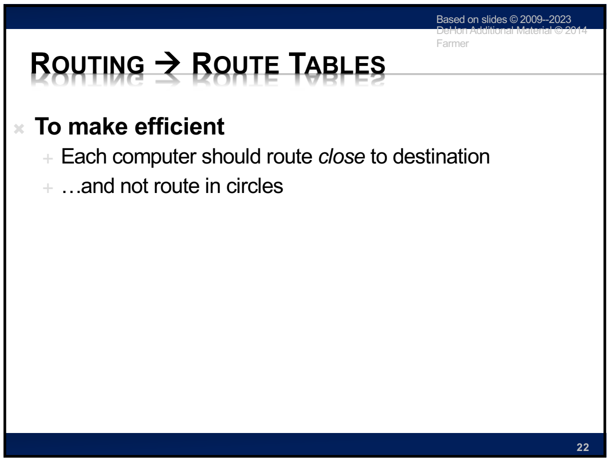
20



Reachability

- **If all computers play along**
  - We can communicate with any computer reachable *transitively* from my computer
- **Don't need direct connections**

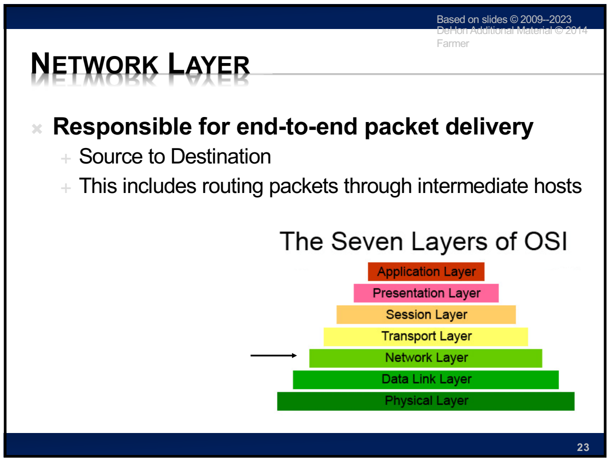
21



Routing → Route Tables

- **To make efficient**
  - Each computer should route *close* to destination
  - …and not route in circles

22

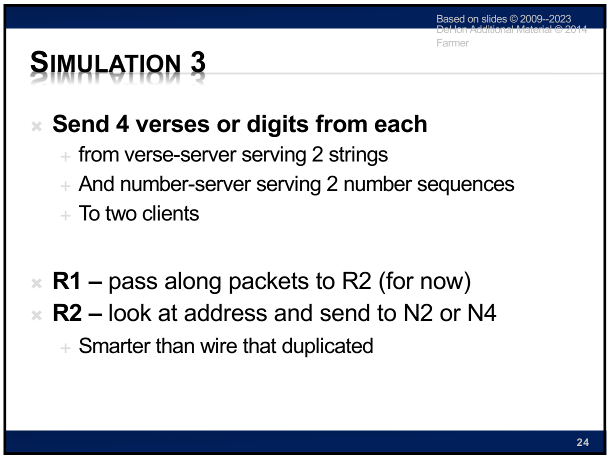


Network Layer

- **Responsible for end-to-end packet delivery**
  - Source to Destination
  - This includes routing packets through intermediate hosts

The Seven Layers of OSI

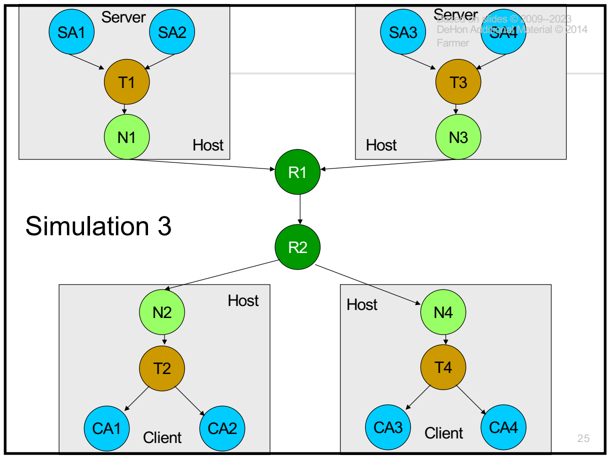
23



Simulation 3

- **Send 4 verses or digits from each**
  - from verse-server serving 2 strings
  - And number-server serving 2 number sequences
  - To two clients
- **R1** – pass along packets to R2 (for now)
- **R2** – look at address and send to N2 or N4
  - Smarter than wire that duplicated

24



Simulation 3

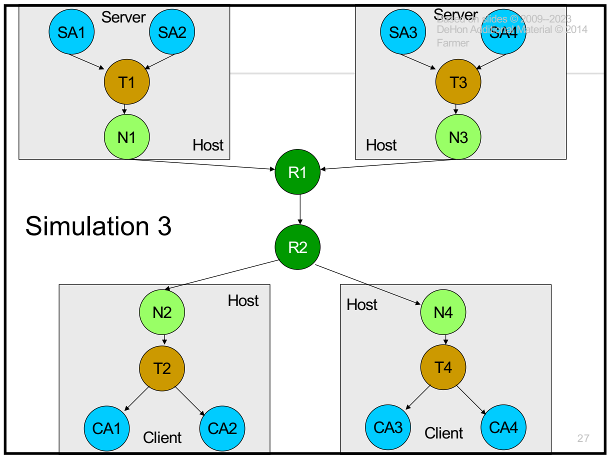
25

Simulation 3 Simplification (if necessary)

- T1/N1, T3/N3 same as before
- Start with packets into R1
- If necessary one person does N2/T2
  - (N2, N4 should only get packets for it)

26

26



Simulation 3

27

27

Where are we now?

- Can communicate
  - From one process on a computer
  - to any other process on any other computer
  - *if* the two are transitively connected
    - By a set of participating computers which route data
- Layers have provided "Abstraction"
  - Processes just see streams of data between the endpoints

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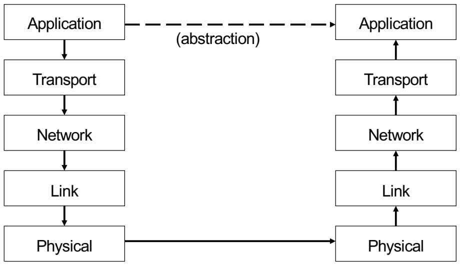
Layers



29

29

Protocols

- Protocol – common discipline used to interoperate smoothly
  - rules of the game
  - Include
    - How to format packets
    - How to handle data
- So far, we've discussed a protocol called IP:
  - IP = Internet Protocol
- Minimal transport with delivery to processes (rather than hosts): UDP
  - UDP = Unreliable Datagram Protocol

30

30

Simulation 5

- Send 4 verses or digits from each
  - from letter-server serving 2 strings
  - And number-server serving 2 number sequences
  - To two clients
- Deliberately delay data through R3
  - Model non-determinism in route timing

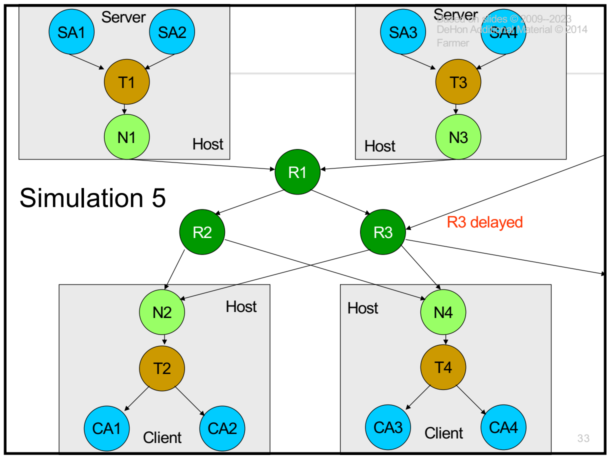
31

31

Simplify Simulation (as necessary)

- **Again, skip T1/N1, T3/N3**
- **Maybe merge N2/T2, N4/T4**

32



33

What can go wrong?

- **Packets arrive out of order**
- **Solution?**
  - Add a sequence number

I was born,	2	10	A	34	C

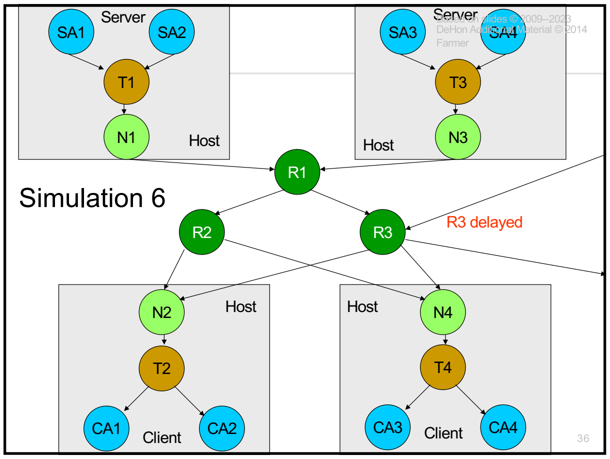
In the town where	1	10	A	34	C

34

Simulation 6

- **Send 4 verses or digits from each**
  - from song-server serving 2 songs
  - And number-server serving 2 number sequences
  - To two clients
- **T1/T3 –** add sequence number to packet
- **T2/T4 –** hold packets, reorder, and deliver in order of sequence number
- **R3** – still delaying packets

35



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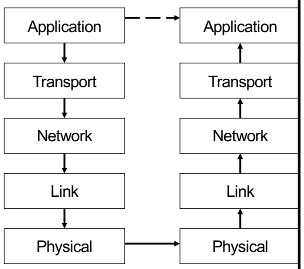
Abstracting Physical Layer

- **Application, transport, network**
  - Don't really care how the bits are moved from machine-to-machine
- **What are other ways we send bits?**
  - Beyond wires
  - Optically
  - RF/wireless
  - Pneumatic tubes, passing paper notes, SMS Text messages…



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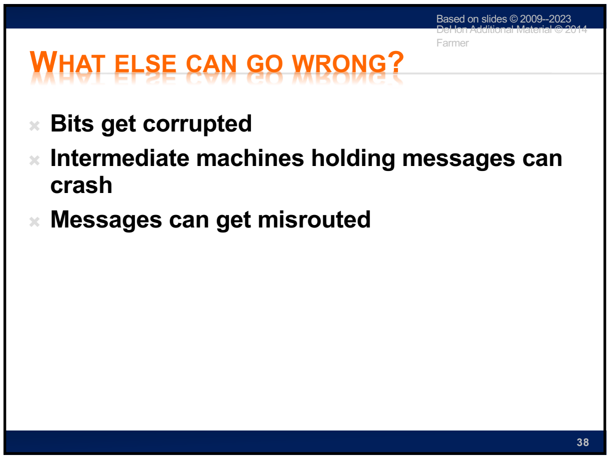

What else can go wrong?

- Bits get corrupted
- Intermediate machines holding messages can crash
- Messages can get misrouted

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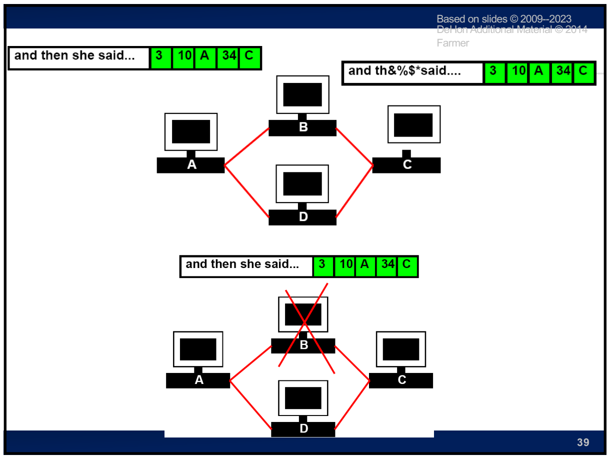
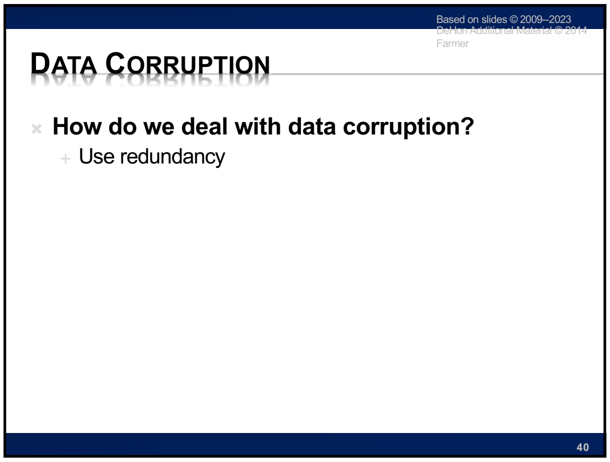


and then she said... | 3 | 10 | A | 34 | C
and th&%$*said.... | 3 | 10 | A | 34 | C
A
B
C
D
and then she said... | 3 | 10 | A | 34 | C
A
B
C
D

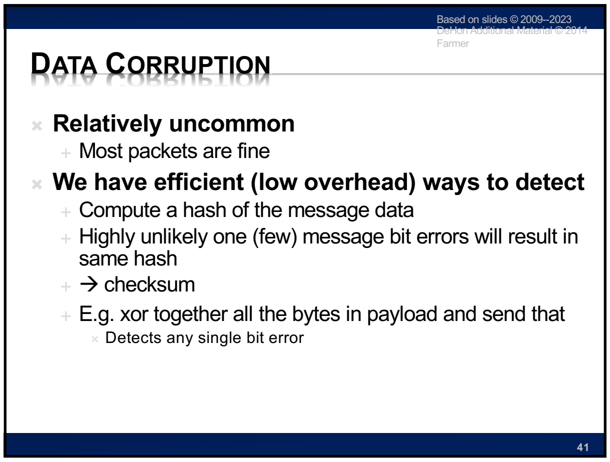
39



Data Corruption

- How do we deal with data corruption?
  - Use redundancy

40



Data Corruption

- Relatively uncommon
  - Most packets are fine
- We have efficient (low overhead) ways to detect
  - Compute a hash of the message data
  - Highly unlikely one (few) message bit errors will result in same hash
  - → checksum
  - E.g. xor together all the bytes in payload and send that
    - Detects any single bit error

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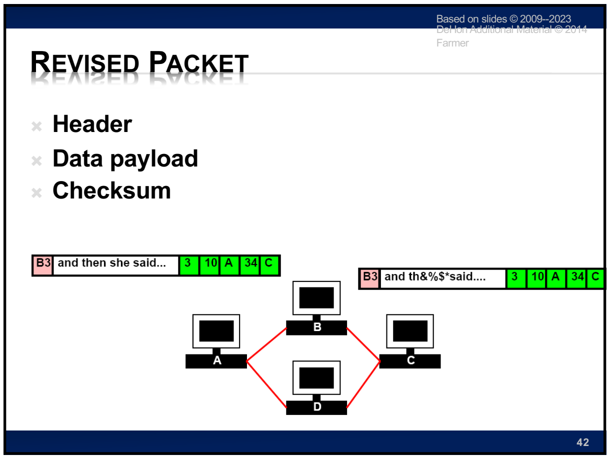
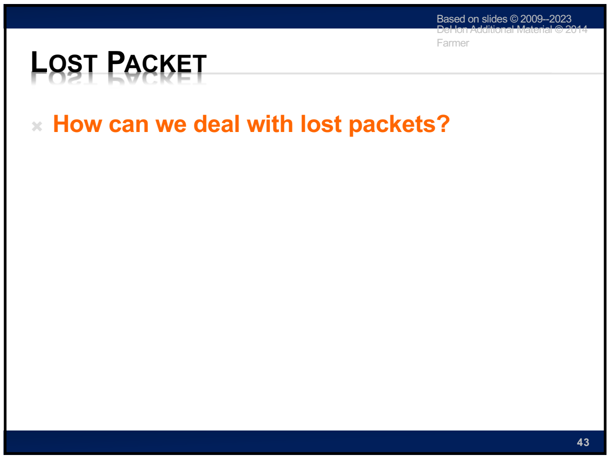


Revised Packet

- Header
- Data payload
- Checksum

B3 | and then she said... | 3 | 10 | A | 34 | C
B3 | and th&%$*said.... | 3 | 10 | A | 34 | C
A
B
C
D

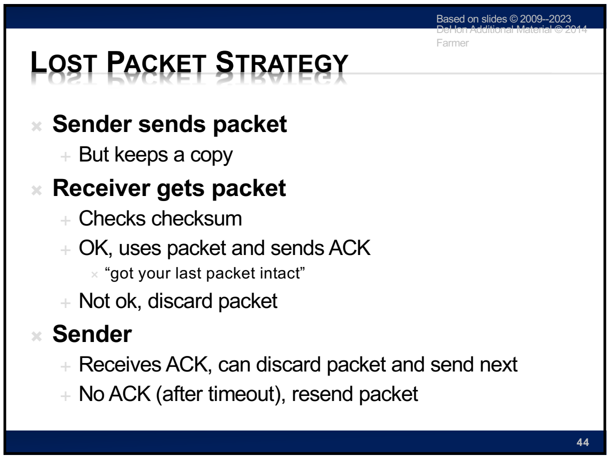
42



Lost Packet

- How can we deal with lost packets?

43



Lost Packet Strategy

- Sender sends packet
  - But keeps a copy
- Receiver gets packet
  - Checks checksum
  - OK, uses packet and sends ACK
    - "got your last packet intact"
  - Not ok, discard packet
- Sender
  - Receives ACK, can discard packet and send next
  - No ACK (after timeout), resend packet

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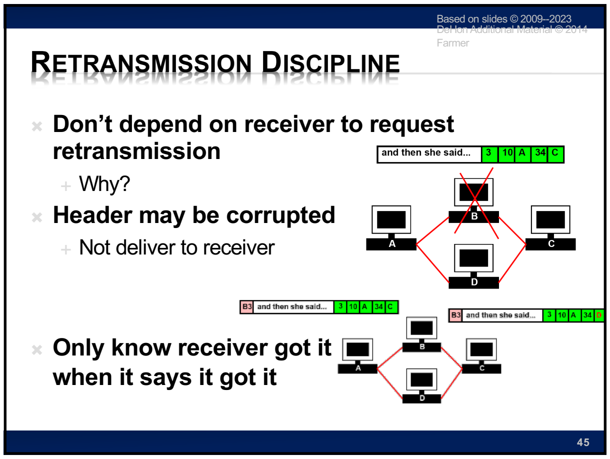


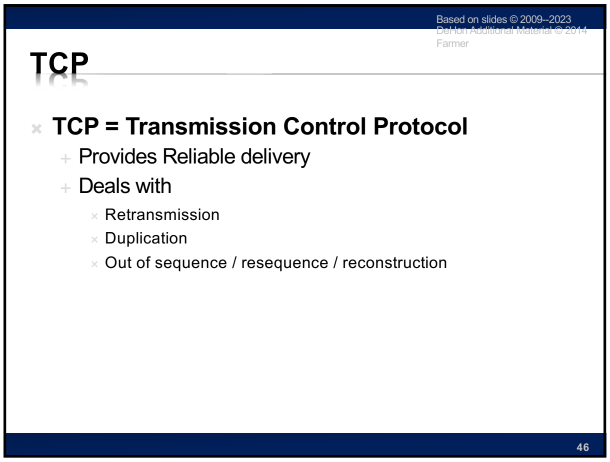
Retransmission Discipline

- Don't depend on receiver to request retransmission
  - Why?
- Header may be corrupted
  - Not deliver to receiver
- Only know receiver got it when it says it got it

and then she said... 3 10 A 34 C
A
B
C
D
B3 and then she said... 3 10 A 34 C
B3 and then she said... 3 10 A 34 D
A
B
C
D

45

45



TCP

- TCP = Transmission Control Protocol
  - Provides Reliable delivery
  - Deals with
    - Retransmission
    - Duplication
    - Out of sequence / resequence / reconstruction

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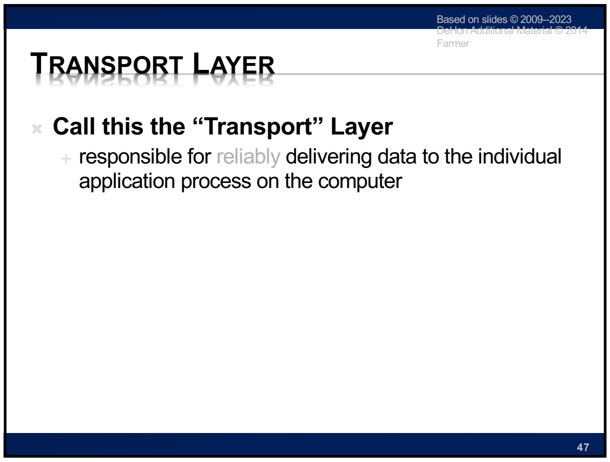

Transport Layer

- Call this the "Transport" Layer
  - responsible for reliably delivering data to the individual application process on the computer

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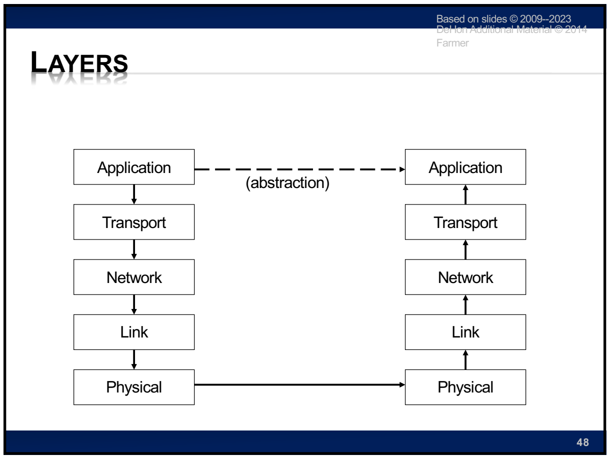

Layers

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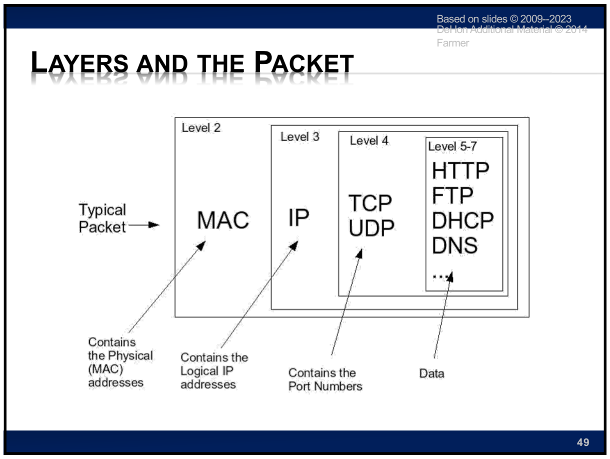
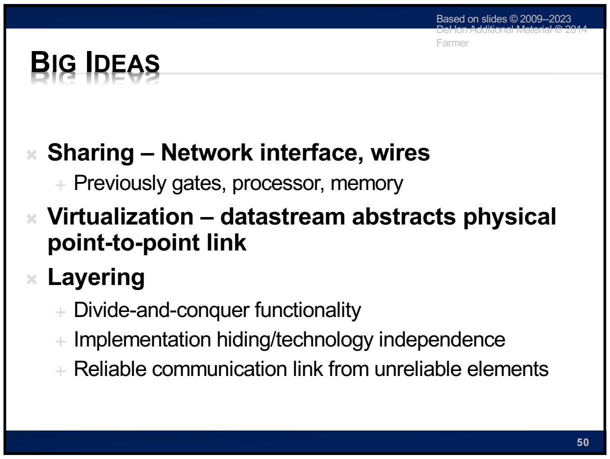


Layers and the Packet

Level 2
Level 3
Level 4
Level 5-7
Typical Packet
MAC
IP
TCP
UDP
HTTP
FTP
DHCP
DNS
…
Contains the Physical (MAC) addresses
Contains the Logical IP addresses
Contains the Port Numbers
Data

49

49



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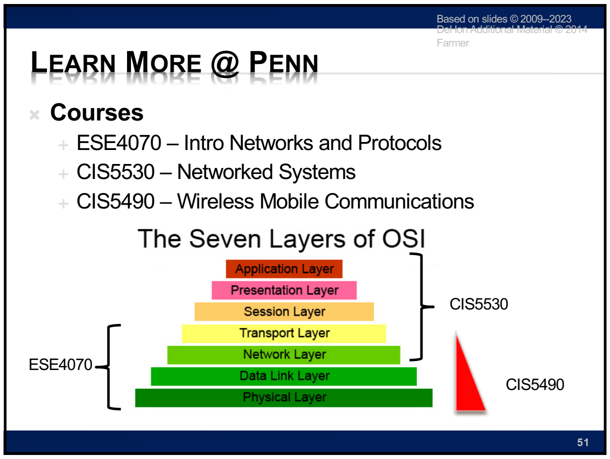
Big Ideas

- **Sharing – Network interface, wires**
  - Previously gates, processor, memory
- **Virtualization – datastream abstracts physical point-to-point link**
- **Layering**
  - Divide-and-conquer functionality
  - Implementation hiding/technology independence
  - Reliable communication link from unreliable elements

50

50



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Learn More @ Penn

- **Courses**
  - ESE4070 – Intro Networks and Protocols
  - CIS5530 – Networked Systems
  - CIS5490 – Wireless Mobile Communications

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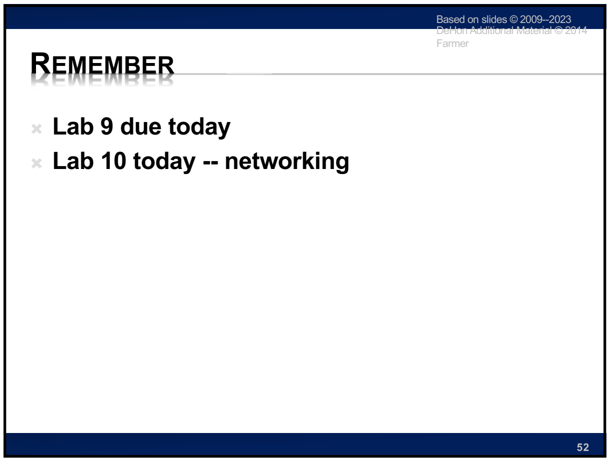

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Remember

- **Lab 9 due today**
- **Lab 10 today -- networking**

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