Lecture 21: Network Security

COMP 332, Spring 2018

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Acknowledgements: materials adapted from Computer Networking: A Top Down Approach 7th edition: ©1996-2016, J.F Kurose and K.W. Ross, All Rights Reserved as well as from slides by Abraham Matta at Boston University, and some material from Computer Networks by Tannenbaum and Wetherall.

Today

1. Announcements
   - hw7 programming and hw8 due Wed.11:59p
2. A day in the life of a web request
3. Network Security
   - overview
   - principles of cryptography
4. Symmetric encryption
   - overview
   - block ciphers
   - Data Encryption Standard (DES)
   - Advanced Encryption Standard (AES)

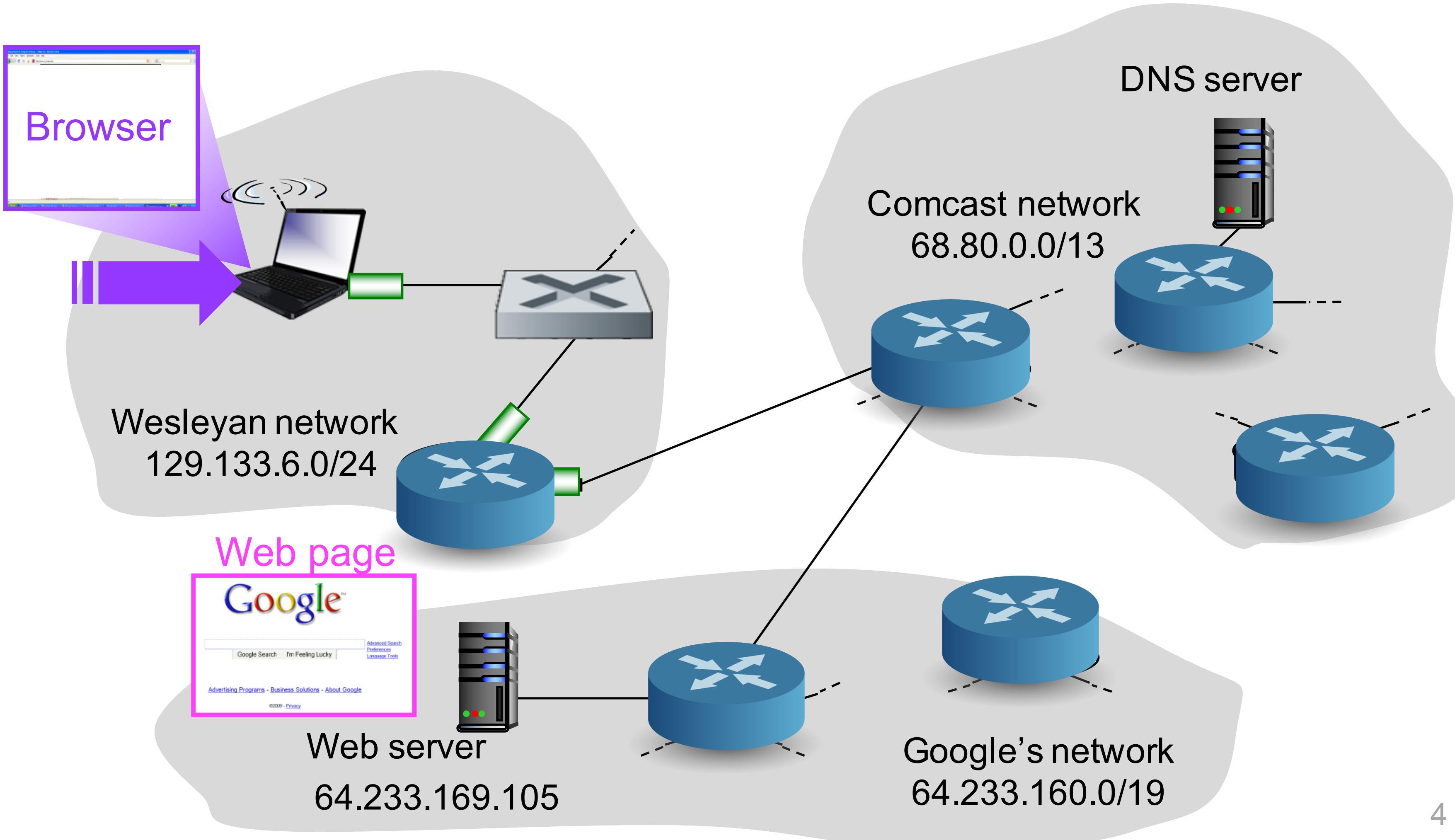
Summarizing Example

A DAY IN THE LIFE OF A WEB REQUEST

What really happens when you enter URL?

Scenario: student attaches laptop to campus network

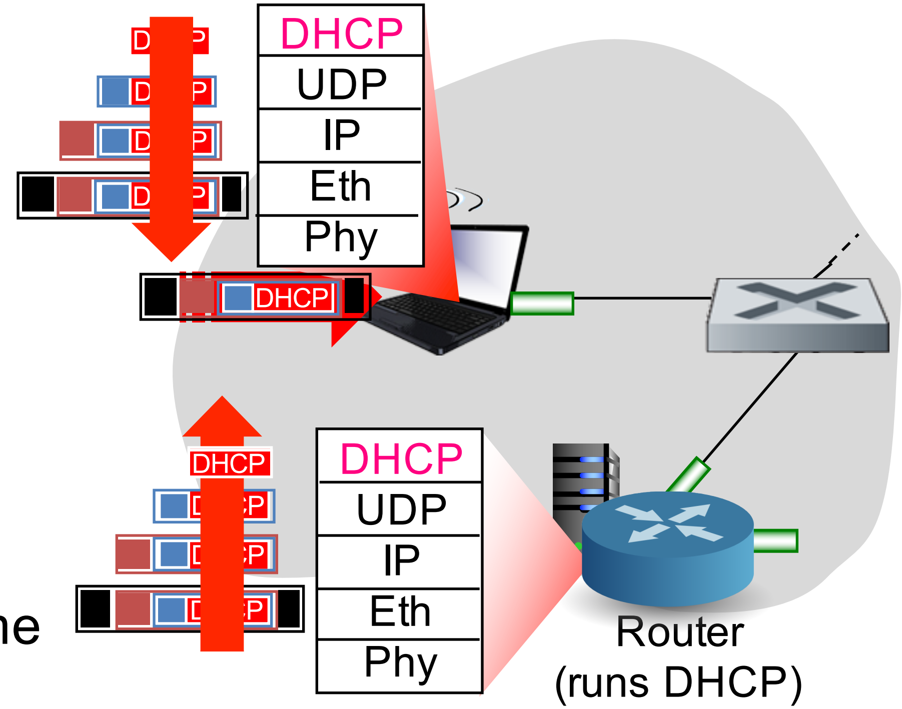
– requests/receives www.google.com



How does client connect to Internet?

Client needs

- its own IP addr on network
- IP addr of first-hop router
- IP addr of DNS server



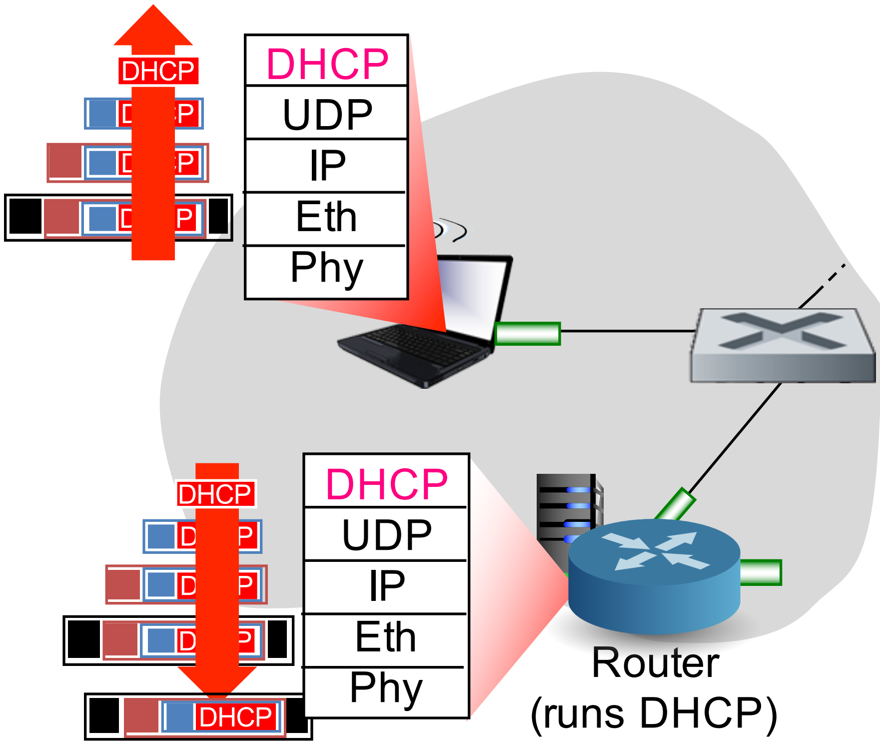
How? DHCP request

- encapsulated in UDP
- encapsulated in IP
- encapsulated in Ethernet frame
- broadcast on LAN
  - dst: FF-FF-FF-FF-FF-FF

Router running DHCP server receives DHCP request

- Ethernet demuxed to IP demuxed to UDP demuxed to DHCP

How does client connect to Internet?



DHCP server sends DHCP ACK

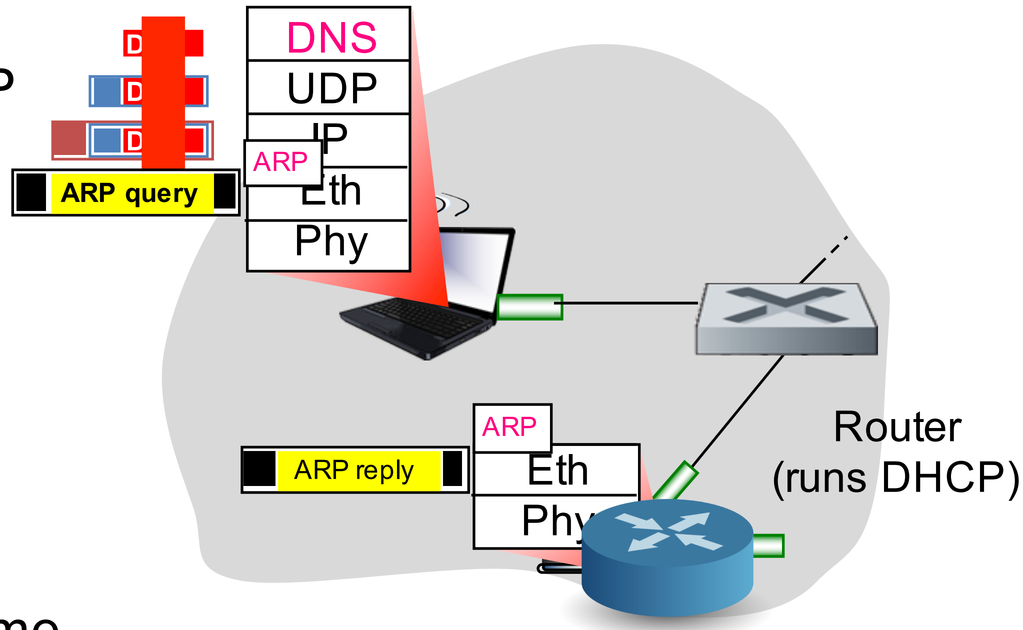
- contains
  - IP addr assigned to client
  - IP addr of 1st-hop router
  - name & IP addr of DNS server
- encapsulate
  - in UDP, then IP, then Ethernet frame
- forward to client
  - through LAN via switch

Client receives DHCP ACK, now has its **own IP addr**, knows name & IP addr of **DNS server**, IP addr of its **1st-hop router**

Client now needs IP addr of www.google.com

DNS query created

- encapsulated in UDP
- encapsulated in IP
- encapsulated in Ethernet



Client needs MAC addr of router

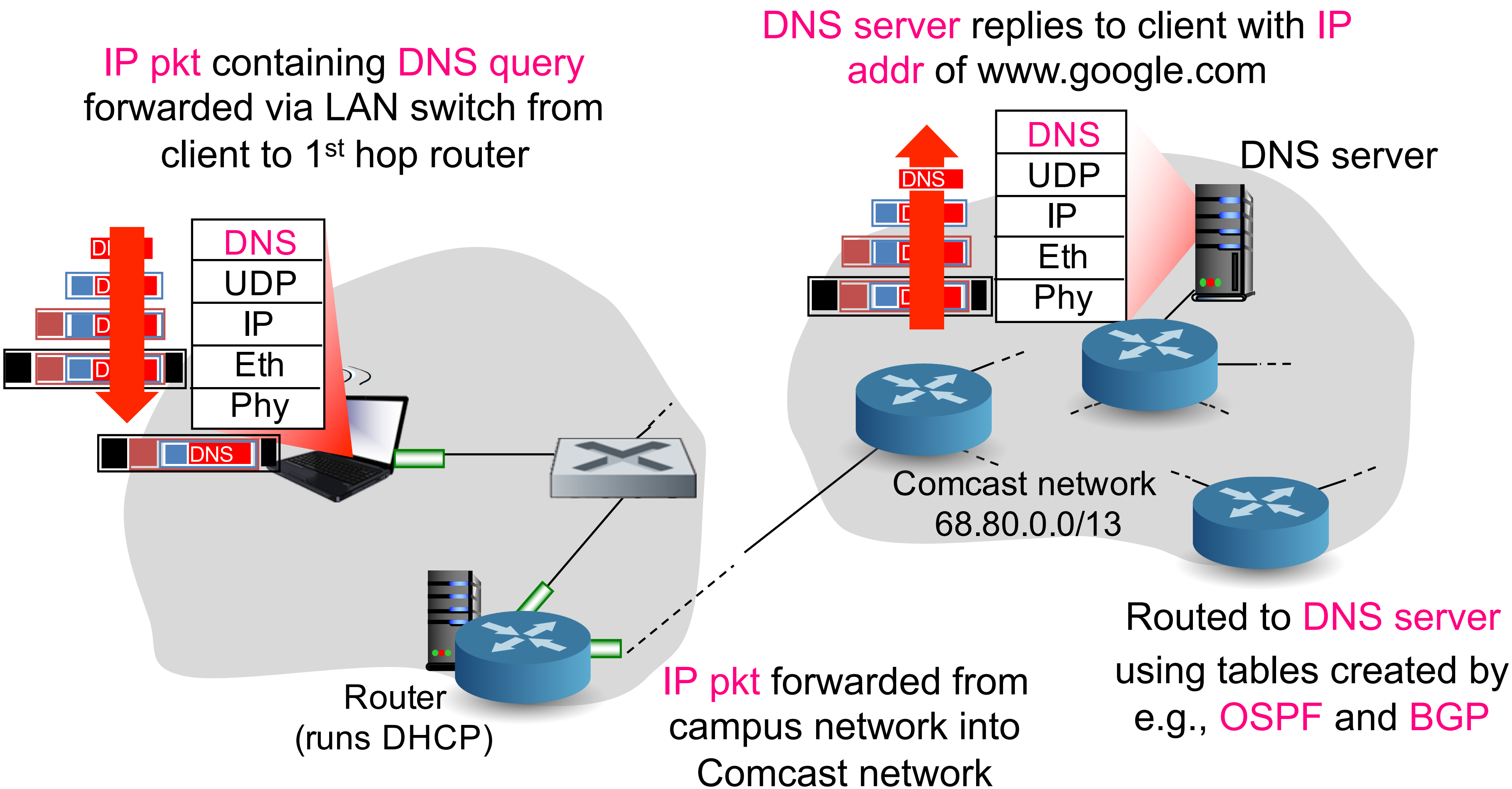
- to send Ethernet frame
- broadcasts ARP query

Router receives ARP query

- sends ARP reply with MAC addr of router interface

Client now has its **MAC addr of 1st-hop router**, can now send frame containing DNS query

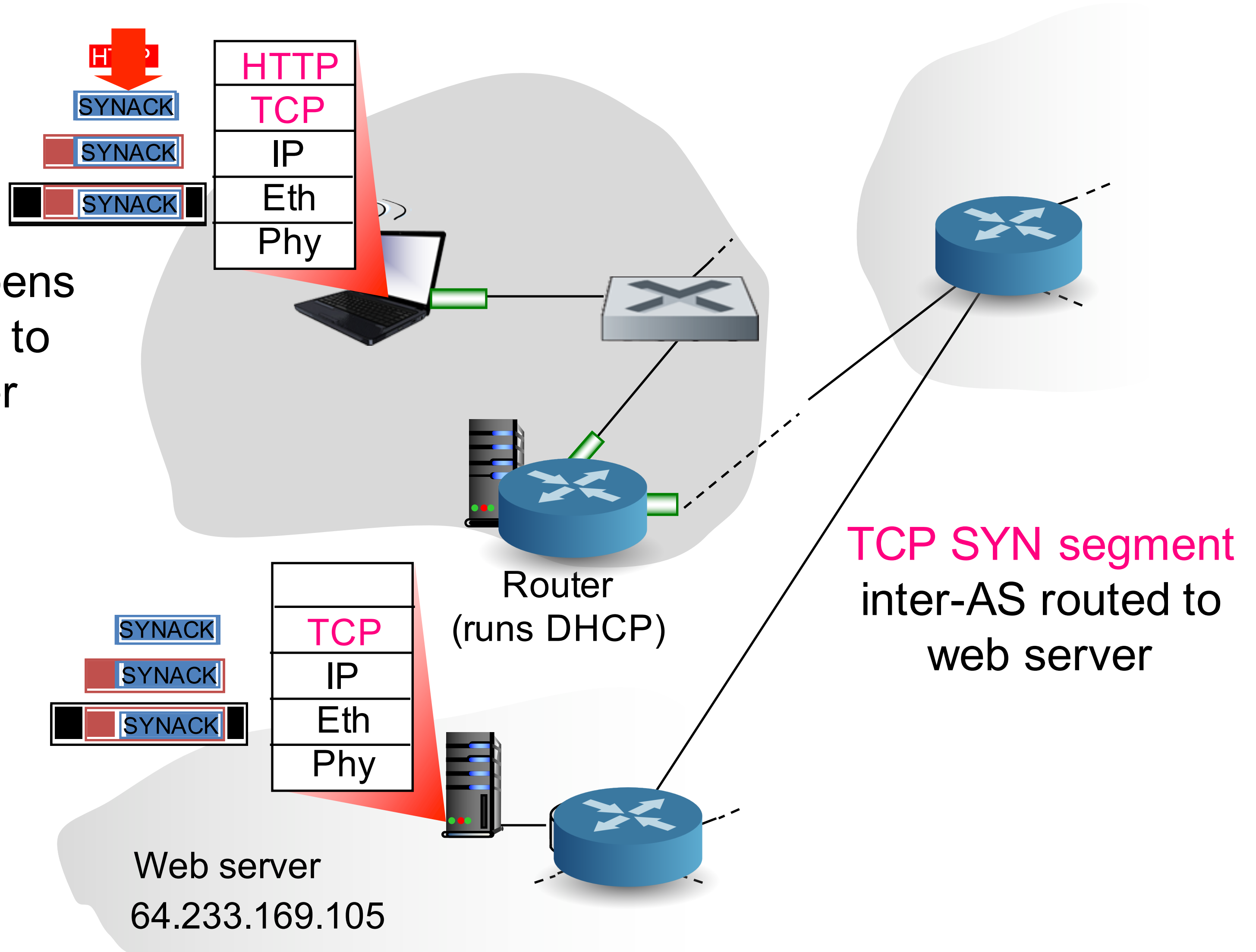
Client now needs IP addr of www.google.com



Client now has **IP addr of www.google.com**, can now open TCP conn to send HTTP request

Client opens TCP connection to carry HTTP

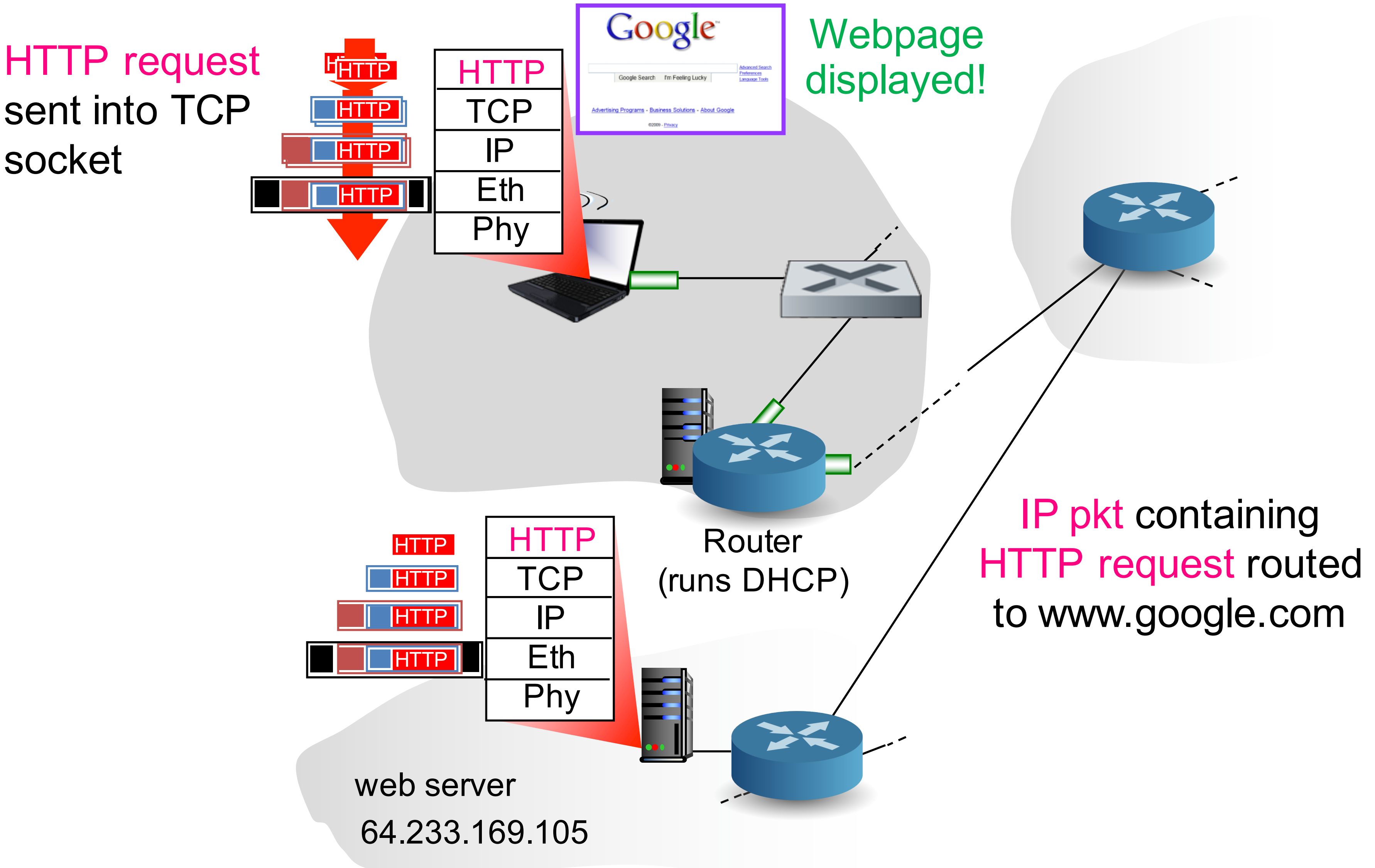
Client first opens TCP socket to web server



TCP SYN segment inter-AS routed to web server

Web server responds with TCP SYNACK and client replies with TCP ACK. Connection established!

Client sends HTTP request and receives reply



Web server responds with IP pkt containing HTTP reply (containing webpage) routed back to client

Network Security

OVERVIEW

What is network security?

How to enable secure communication over insecure channel?

Confidentiality

- only sender, intended receiver able to understand message contents
  - sender encrypts message
  - receiver decrypts message

Authentication

- sender, receiver want to confirm identity of each other

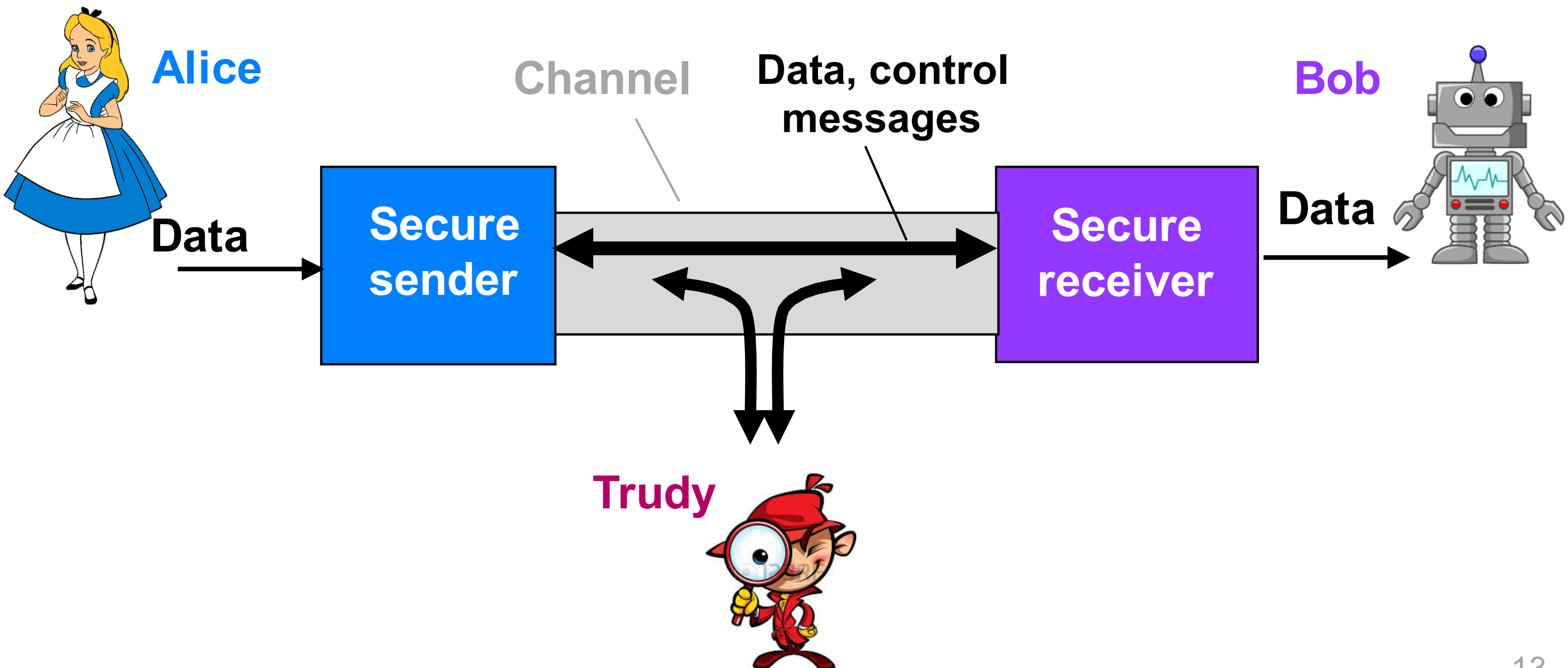
Message integrity

- sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

Friends and enemies: Alice, Bob, Trudy

Well-known in network security world

- Alice and Bob want to communicate securely
- Trudy (intruder) may intercept, delete, add messages



Real-life Alices and Bobs?

Web browser and server for on-line purchases

On-line banking client and server

Email client and server

DNS servers

Routers exchanging routing table updates

Other examples?

What can enemies do?

Passive attack

- sniff and record messages
- analyze traffic patterns of messages

Active attack

- replay and/or modify messages
- impersonate: spoof source addr (or any other field) in new packet
- hijack: take over ongoing connection
  - by removing sender or receiver, and inserting oneself in their place
- denial of service: prevent service from being used by others
  - e.g., by overloading resources

Network Security

PRINCIPLES OF CRYPTOGRAPHY

Confidentiality

How can Alice hide msg she wants to send to Bob?

- so only Bob and no-one else can read msg?

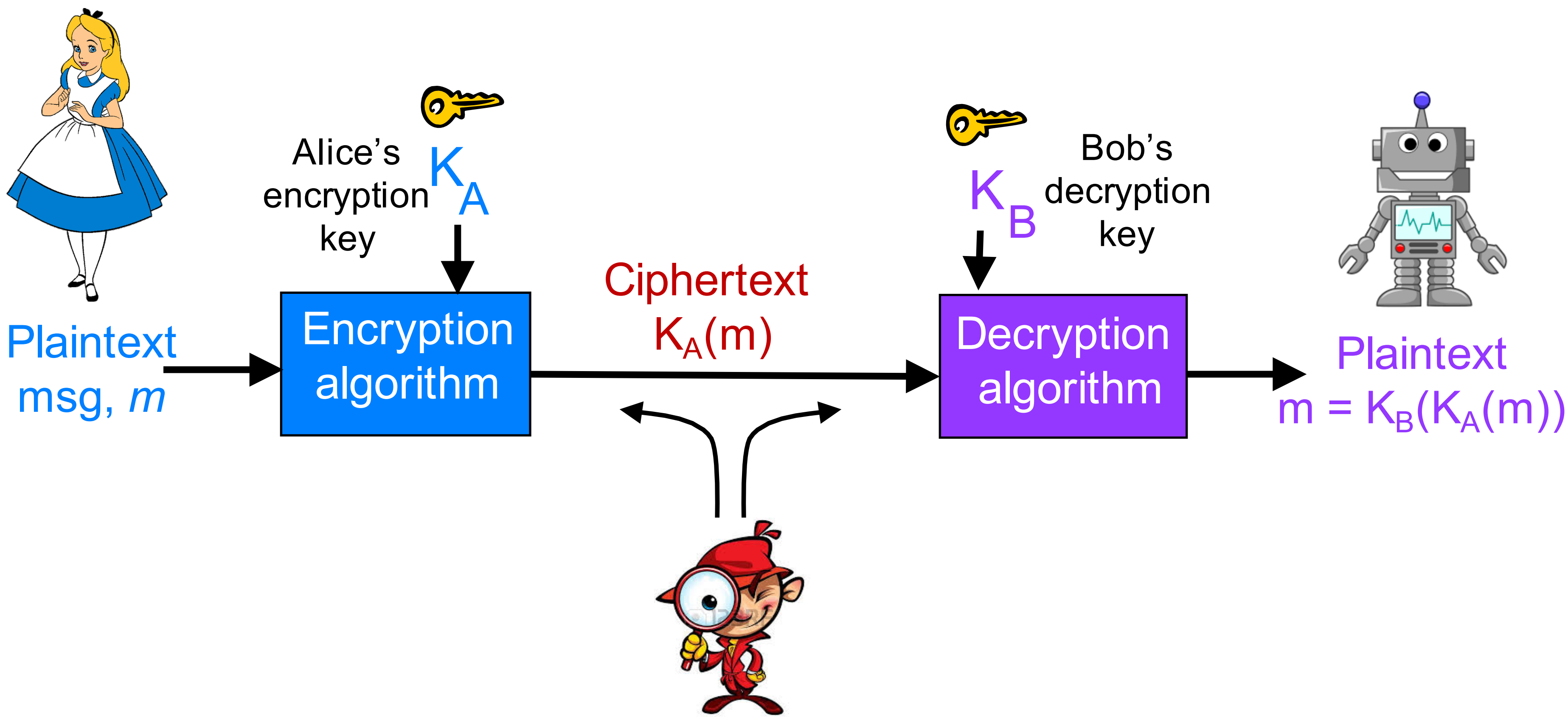
Encryption

- used to disguise a msg and hide its contents
- plaintext: unencrypted msg
- ciphertext: encrypted msg

Encryption algorithm

- substitute/rearrange pieces of plaintext with pieces of ciphertext
- known and publicly available
  - keys (secret info) used to prevent intruder from decrypting data

The language of cryptography



How to break an encryption scheme?

Cipher-text only attack

- Trudy has ciphertext she can analyze
  - brute force: search through all keys
  - statistical analysis

Known-plaintext attack

- Trudy has plaintext corresponding to ciphertext
  - e.g., monoalphabetic cipher, Trudy determines pairings for a,l,i,c,e,b,o,

Chosen-plaintext attack

- Trudy can get ciphertext for chosen plaintext

Q: When is an encryption scheme computationally secure?

- if cost to break cipher > value of info
- If time to break cipher > time info is useful

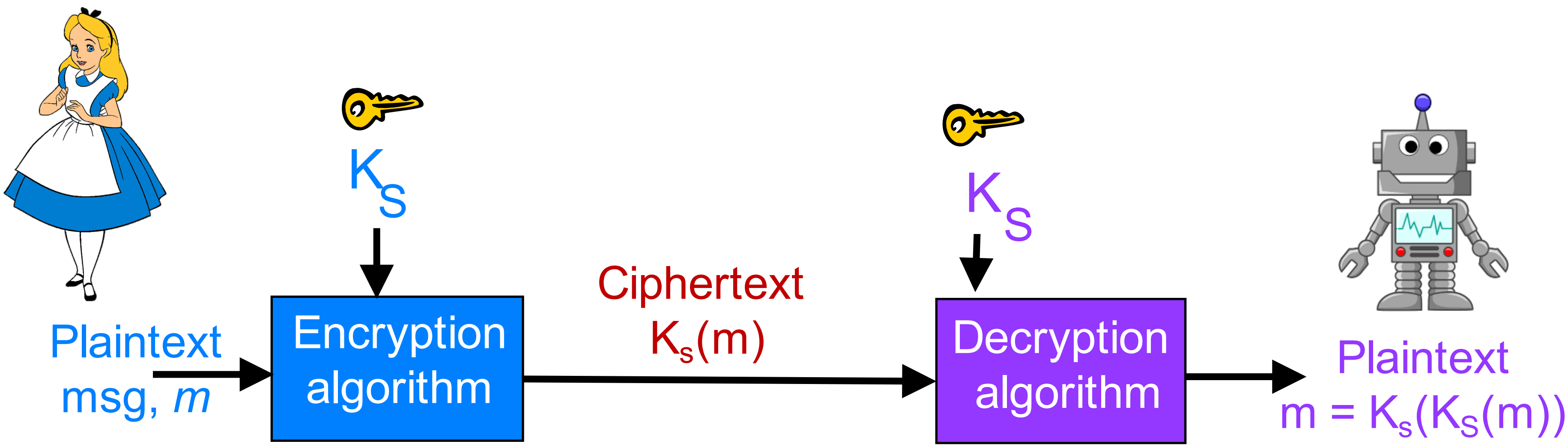
Symmetric Key Cryptography

OVERVIEW

Symmetric key cryptography

Both Alice and Bob use same encryption/decryptinon key: K_s

- e.g., key is substitution pattern in mono alphabetic substitution cipher



Q: how do Bob and Alice agree on key value?

Caesar cipher

Take each letter of plaintext

- substitute letter that is k letters later in alphabet

```
plaintext:   abcdefghijklmnopqrstuvwxyz

ciphertext:  defghijklmnopqrstuvwxyzabc
```

e.g.,

```
 plaintext: hello world
ciphertext: khoor zruog
```

Encryption key: k=3

# of possible keys? 25

A more sophisticated encryption scheme

Substitution cipher: substitute one thing for another

– monoalphabetic cipher: substitute one letter for another

```
plaintext:   abcdefghijklmnopqrstuvwxyz

ciphertext:  mnbvcxzasdfghjklpoiuytrewq
```

e.g., **`plaintext: bob. meet me in wonderland`**

`ciphertext: nkn. hccu hc sj rkjvcogmjv`

Encryption key: mapping from set of 26 letters to set of 26 letters

# of possible keys? 26!

An even more sophisticated encryption scheme

Polyalphabetic cipher

- use n substitution ciphers, $M_1,M_2,\ldots,M_n$ + cyclic pattern
  - e.g., n=4: M_1,M_3,M_4,M_3,M_2; M_1,M_3,M_4,M_3,M_2; ..
- for each new plaintext symbol
  - use subsequent substitution pattern in cyclic pattern

e.g., **plaintext: dog**

ciphertext: d from M

o from M_3

g from M_4

Encryption key: n substitution ciphers, and cyclic pattern

# of possible keys? $(26!)^n$

Back to the modern world

2 classes of symmetric key encryption techniques

Block ciphers

- process one block of elements at a time
- produce output block for each input block
- used in many secure Internet protocols
  - PGP: secure email
  - TLS/SSL: secure TCP connections
  - IPSec: secure network layer communication

Our focus

Stream ciphers

- process input elements continuously
- produce output one element at a time as it goes along
- used for wireless LANs

Symmetric Key Cryptography

BLOCK CIPHER

Block cipher

Process msg to encrypt in *k*-bit blocks

- *k=64:* msg broken into 64-bit blocks
  - each block encrypted independently
  - each *k*-bit block of plaintext mapped to *k*-bit block of ciphertext

2 approaches

1. Electronic Codebook (ECB) mode
   - 1 block of plaintext encrypts to same block of ciphertext

2. Cipher Block Chaining (CBC) mode
   - 1 block of plaintext can encrypt to different blocks of ciphertext

Q: which do you think is more secure?

Electronic Codebook (ECB) mode

1 block of plaintext always encrypts to same block of ciphertext

Electronic Codebook, k=3

Input	***Output***
000	**110**
001	**111**
010	**101**
011	**100**
100	**011**
101	**010**
110	**000**
111	**001**

$2^3!$ choices for map.
Huge table for even just k=64,
so use functions that simulate
randomly permuted table

```
 plaintext: 010 110 001 111
ciphertext: 101 000 111 001
```

Problems with ECB

Trudy can start to build codebook without knowing key

- given plaintext and ciphertext for a few msgs
  - bits of msgs repeat in real world
    - 2 or more blocks of plaintext may be identical
  - msg to be encrypted may have regular structure, similar start/end
    - e.g., email, webpage

Trudy can modify ciphertext without knowing key

- transfers $100 between 2 banks several times, watches exchange
- correlates msgs that authorize transaction, replays that msg

Cipher-block chaining (CBC) mode

1 block of plaintext maps to different blocks of ciphertext

Assume 64 bit blocks

- m(i): i^{th} plaintext block
- c(i): i^{th} ciphertext block
- c(0): initialization vector (iv), random 64 bit string
- k_s: symmetric key

$a \oplus b$: exclusive or (XOR) of 2 bit strings, a and b

- 1 if and only if 1 of bits is 1
- 0 otherwise

CBC steps

1. Sender generates IV and sends to receiver in plaintext

2. Sender computes 1st block, c(1), and sends to receiver

   $c(1) = k_s(m(1) \oplus c(0))$

   c(1): 1st ciphertext block; m(1): 1st plaintext block; c(0): initialization vector

3. Sender computes ith block, c(i), and sends to receiver

   $c(i) = k_s(m(i) \oplus c(i-1))$

   c(i): ith ciphertext block

4. Receiver decrypts c(i) to get $m(i) \oplus c(i-1)$
   - knows initialization vector, c(0), does $\oplus$ to recover original msg

Identical plaintext blocks will almost certainly map to different ciphertexts

Symmetric Key Cryptography

DATA ENCRYPTION STANDARD

Data Encryption Standard (DES)

Features

- 56-bit symmetric key, 2^{56} possible keys
- 64-bit plaintext block input
- block cipher with CBC

How secure is DES?

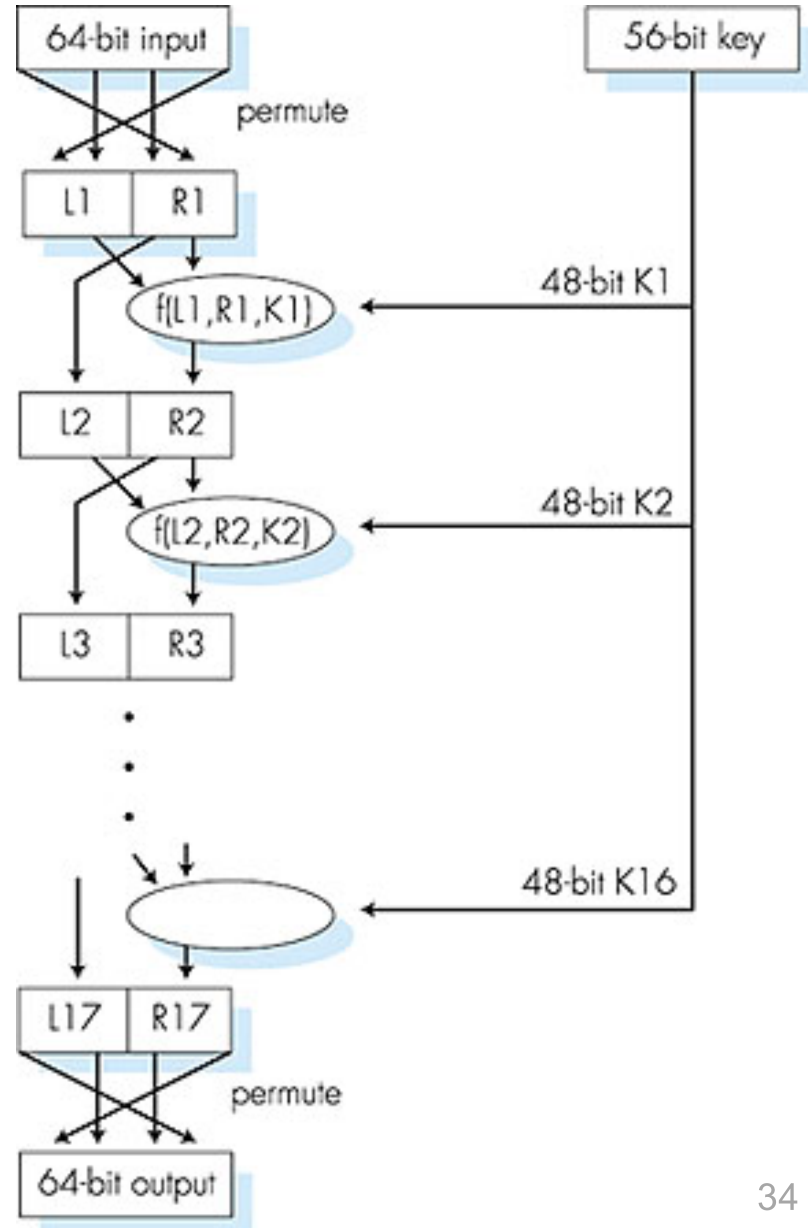
- brute force attack
  - 56-bit-key-encrypted phrase decrypted in less than a day
- no known good analytic attack

Making DES more secure

- 3DES: encrypt 3 times with 3 different keys

DES operation uses Feistel cipher structure

1. Divide plaintext block in half
   - L_1 and R_1
2. L_1 and R_1 pass through n=16 rounds of processing
   - each round *i* uses
     - inputs L_{i-1} and R_{i-1} from previous round
     - different 48 bits of 56-bit key
3. Combine halves at end to produce the ciphertext block



Symmetric Key Cryptography

ADVANCED ENCRYPTION STANDARD

Advanced Encryption Standard (AES)

Replaced DES (Nov 2001)

- Q: why?
  - DES is insecure, (3)DES is slow in software, small block size

Features

- 128, 192, or 256 bit symmetric keys, up to 2^{256} possible keys
- 128-bit plaintext block input
- block cipher with CBC
- does **not** use a Feistel structure

How secure is AES?

- brute force attack
  - 1 sec for DES
  - 149 trillion years for AES