CS161 Midterm 2 Review

Midterm 2: April 29, 18:30-20:00

Same room as lecture

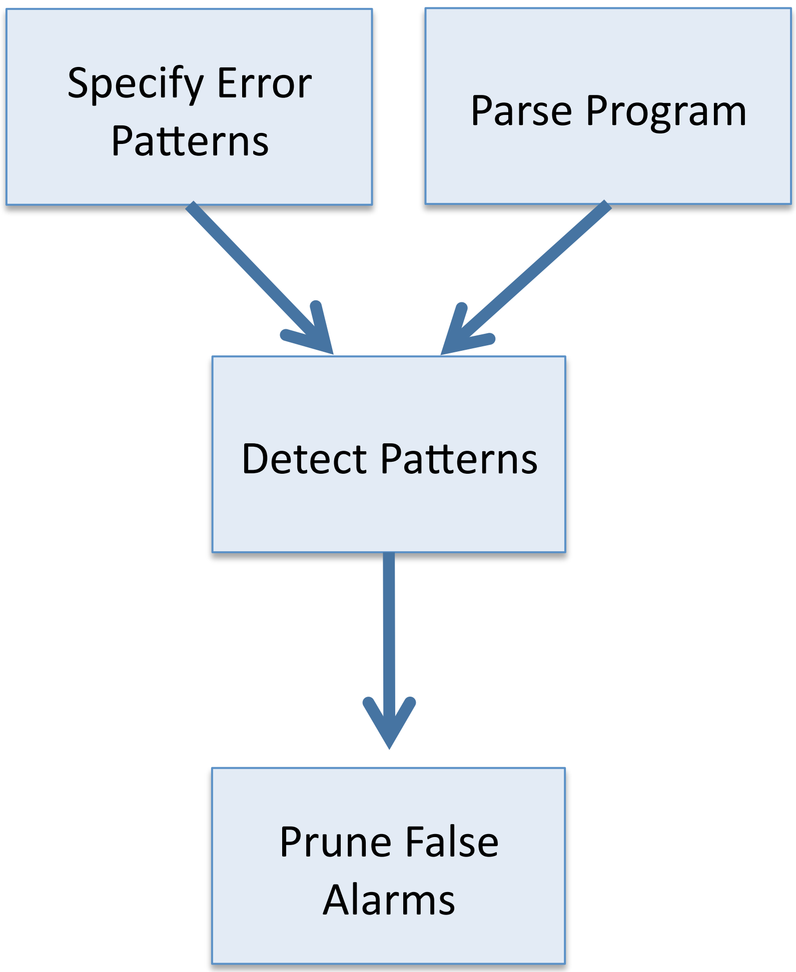
Overview

- Static analysis and program verification
- Security architecture and principles
- Web security
- Crypto
- Network security

Static Analysis

- Syntactic analysis
  - Does not interpret the statements
- Semantic analysis
  - Interpret statements

Syntactic Analysis



Error patterns: Heuristically observed common error patterns in practice

Parsing: generates data structure used for error detection

Detection: match pattern against program representation

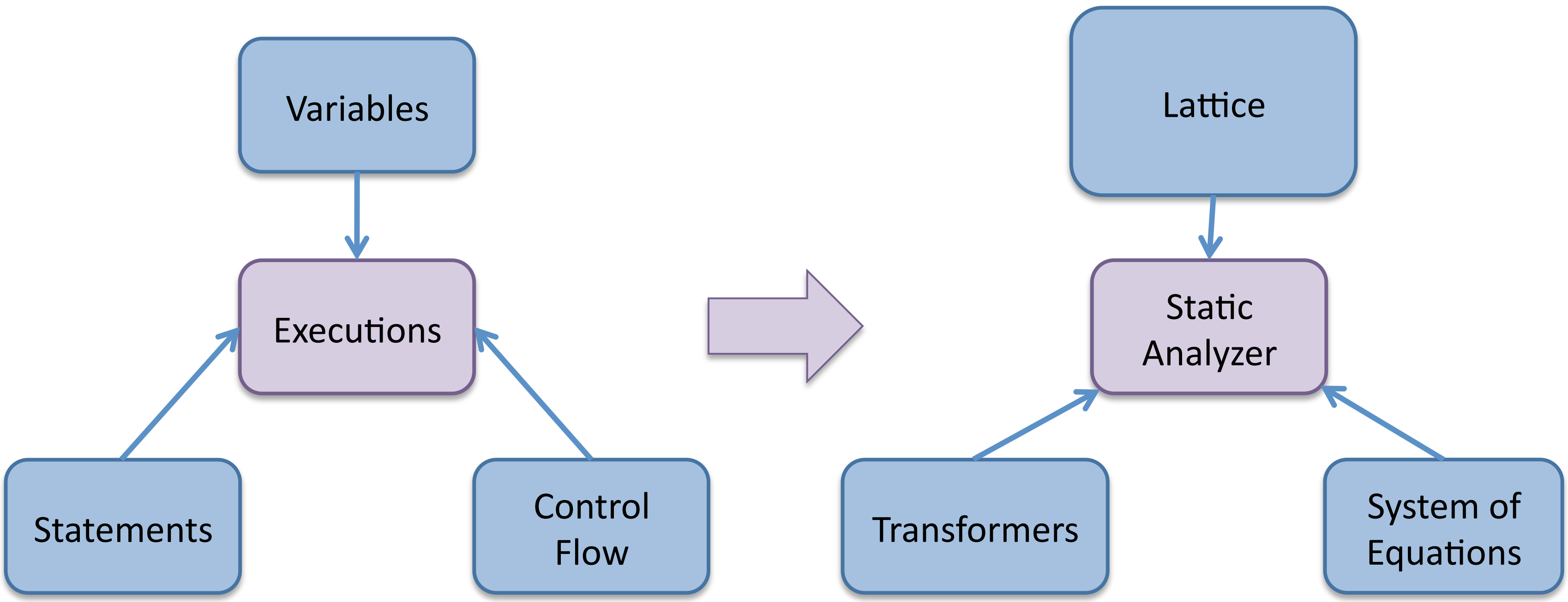
Pruning: Used to eliminate common false alarms

Semantic Analysis

- Sign analysis
- Zero propagation
- Interval analysis
- Product analysis
  - Disjunctive refinement

Architecture of a Static Analyzer

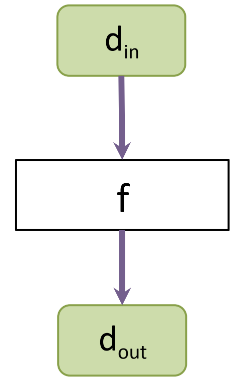
The behavior of a program can be approximated by separately approximating variable values, statements and control flow.



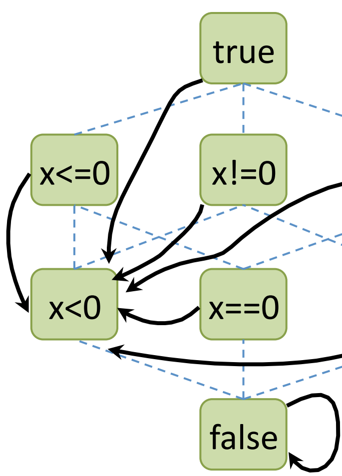
Quiz: Sign Analysis Transformers

Which of the following is the right transformer for `x=x-1` ?

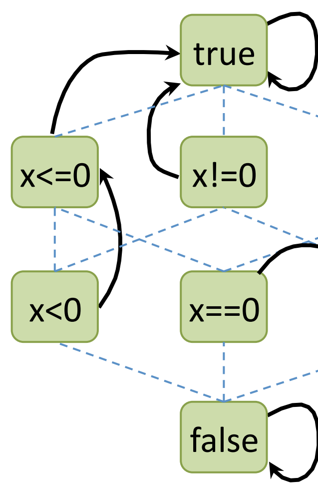
Answer: C



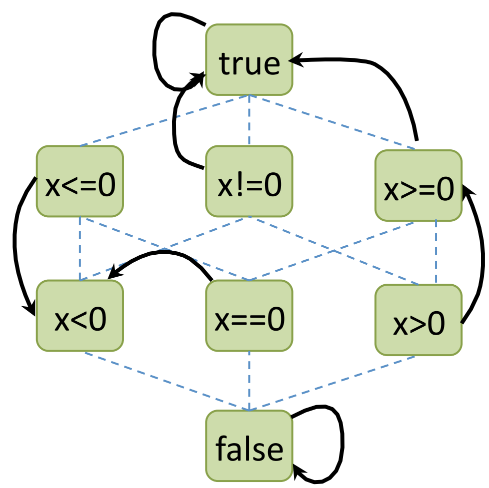
(a)



(b)

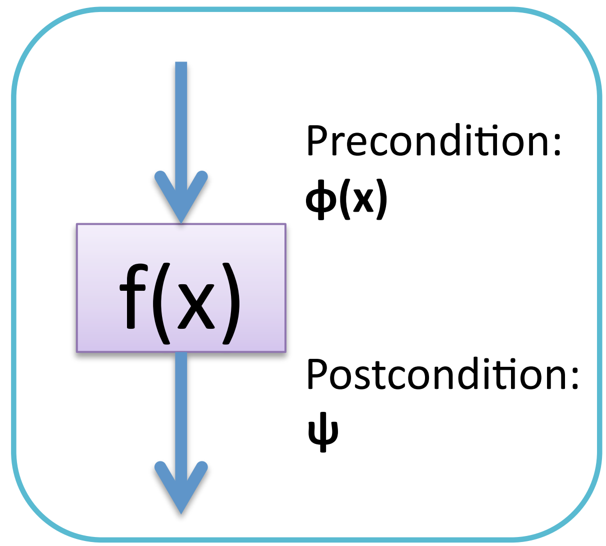


(c)



Program Verification

- E.g., how to prove a program free of buffer overflows?
- Precondition
  - An assertion that must hold at input to `f()`
- Postcondition
  - An assertion that holds when `f()` returns
- Loop invariant
  - An assertion that is true at entrance to a loop, on any path through the code
  - Prove by induction



Security Architecture and Principles

- Access control
  - ACL/Capability
  - Role-based access control
  - Reference monitor
- Principle of least privilege
- Defense in depth
- Consider human factors
- Separation of responsibility
- Don’t rely on security through obscurity
- Fail safe
- Design security in from the start
- Ensure complete mediation
- Detect if you cannot prevent

Malware

- Virus
  - Propagation requires human intervention
- Polymorphic virus
  - Creates a random encryption of the virus body
- Metamorphic virus
  - Mutate the virus body, too
  - Code obfuscation/mutation

Malware

- Worm
  - Propagates automatically without human intervention
- Botnet
  - A network of programs capable of acting on instructions
    - Bot master and bots
  - Used for spamming, click fraud, and DDoS

Web Security

- Same-origin Policy (SOP)
- Command injection
- SQL injection
- Cross-site Scripting (XSS)
- Cross-site Request Forgery (CSRF)
- Session hijacking

Same-origin Policy (SOP)
(for javascript and DOM)

Two documents have the same origin if:

Same **protocol**	(https, http, ftp, etc)
Same **domain**	(safebank.com, etc)
Same **port**	(80, 23, 8080, etc)

Results of same-origin checks against “http://cards.safebank.com/c1/info.html”

Same origin:

“http://cards.safebank.com/c2/edit.html”
“http://cards.safebank.com/”

Different origin:

“http://www.cards.safebank.com”
“http://catville.com”
“https://cards.safebank.com”
“http://cards.safebank:8080”

Command Injection

- Inject malicious code into data
  - Malicious code in the parameters of URLs
- Defenses
  - Input validation
    - Backlisting
    - Whitelisting
  - Input escaping
  - Use of less powerful APIs

SQL Injection

- Caused when attacker controlled data interpreted as a (SQL) command
  - Goal is to manipulate a SQL database
- Defenses
  - Input validation
    - Backlisting
    - Whitelisting
  - Input escaping
  - Use of less powerful APIs
    - Prepared statements

Cross-site Scripting (XSS)

- Vulnerability in web application that enables attackers to inject client-side scripts into web pages viewed by other users.
- Three types
  - Persistent or stored
    - Malicious code is stored at the server
  - Reflected
    - Malicious code is reflected back by the server
  - DOM based
    - The vulnerability is in the client side code

Cross-site Request Forgery (CSRF)

- An attack which forces an end user to execute unwanted actions on a web application in which he/she is currently authenticated.
- Caused because browser automatically includes authorization credentials such as cookies.
- Defenses
  – Origin headers
  – Nonces

Session Hijacking

- Get the user's session token and act on behalf of the user
- How to get session tokens?
  - Session token theft
    - Eavesdropping network communication, e.g., http
    - XSS
  - Session fixation
    - Attacker sets the user's session token
    - Defense: issue a new session token when logging in

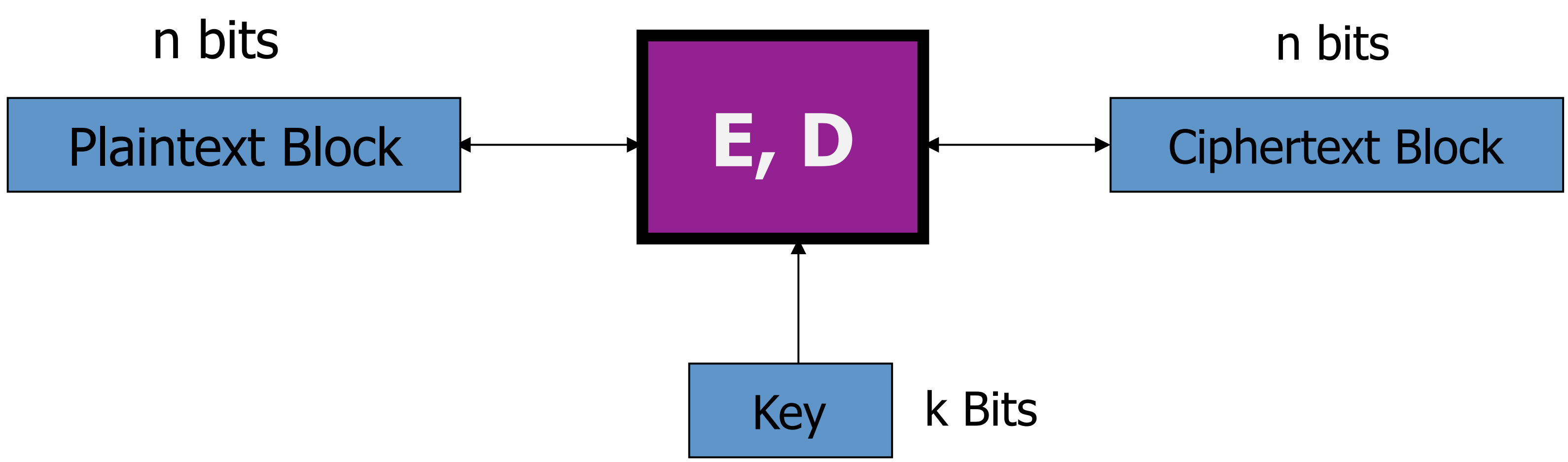
Crypto

- Symmetric-key crypto
  - Blocker cipher
  - Modes of operation
  - HMAC
- Public-key crypto
  - Encryption
  - Digital signature
  - Digital certificate
  - Diffie-Hellman key exchange
  - Shamir secret sharing
  - Secure multi-party computation
  - Zero-knowledge proof

Block Cipher

- Encrypt/Decrypt messages in fixed size blocks using the same secret key
  - k-bit secret key
  - n-bit plaintext/ciphertext

Examples: DES, AES



Modes of Operation

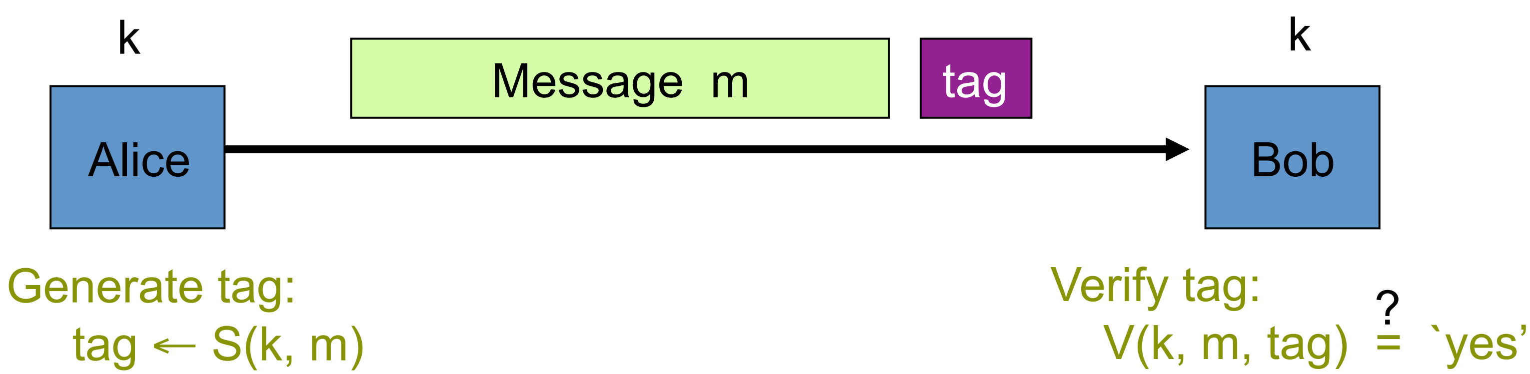
- Electronic Code Book (ECB)
  - Blocks are encrypted independently
- Cipher Block Chaining (CBC)
  - Encryption of one block depends on the ciphertext of the previous block
- Counter (CTR)
  - Encrypts counter value

Cryptographic Hash Functions

- Preimage resistance
  - Given *h*, intractable to find *y* such that $H(y)=h$
- Second preimage resistance
  - Given *x*, intractable to find $y \neq x$ such that $H(y)=H(x)$
- Collision resistance
  - Intractable to find *x, y* such that $y \neq x$ and $H(y)=H(x)$

Message Integrity: MACs

- Goal: provide message integrity. No confidentiality.
  - ex: Protecting public binaries on disk.



note: non-keyed checksum (CRC) is an insecure MAC !!

HMAC (Hash-MAC)

Most widely used MAC on the Internet.

H: hash function.
example: SHA-256 ; output is 256 bits

Building a MAC out of a hash function:

opad, ipad: fixed strings

– Standardized method: HMAC

$$S(k, m) = H(k \oplus opad, \mathbf{H(k \oplus ipad, m)})$$

Public Key Encryption

<u>Def</u>: a public-key encryption system is a triple of algs. (G, E, D)

- G(): randomized alg. outputs a key pair (pk, sk)
- E(pk, m): randomized alg. that takes $m \in M$ and outputs $c \in C$
- D(sk, c): det. alg. that takes $c \in C$ and outputs $m \in M$ or $\perp$

Consistency: $\forall$(pk, sk) output by G :

$$\forall m \in M: \quad D(sk,\ E(pk, m)) = m$$

Building Block: Trapdoor Functions (TDF)

Def: a trapdoor function over X is a triple of efficient algs. (G, F, F^{-1})

- **G**(): randomized alg. outputs a key pair (pk, sk)
- **F**(pk, ⋅): deterministic alg. that defines a function $X \longmapsto Y$
- $\mathbf{F^{-1}}$(sk, ⋅): defines a function $Y \longmapsto X$ that inverts F(pk, ⋅)

$$\text{for all } x \text{ in } X: \quad F^{-1}(sk, \; F(pk, x)) = x$$

Security: (G, F, F^{-1}) is secure if F(pk, ⋅) is a "one-way" function:

given **F(pk, x)** and **pk** it is difficult to find **x**

Example TDF: RSA

- alg. G(): generate two equal length primes p, q

  set $N \leftarrow p \cdot q$ (3072 bits ≈ 925 digits)

  set $e \leftarrow 2^{16}+1 = 65537$; $d \leftarrow e^{-1} \pmod{\varphi(N)}$

  pk = (N, e) ; sk = (N, d)

- RSA(pk, x) : $x \rightarrow (x^e \bmod N)$

  Inverting this function is believed to be as hard as factoring N

- RSA^{-1}(sk, y) : $y \rightarrow (y^d \bmod N)$

Public Key Encryption with a TDF

G(): generate pk and sk

E(pk, m):

- choose random $x \in \text{domain}(F)$ and set $k \leftarrow H(x)$
- $c_0 \leftarrow F(pk, x)$, $c_1 \leftarrow E(k, m)$ (E: symm. cipher)
- send $c = (c_0, c_1)$

D(sk, $c=(c_0,c_1)$): $x \leftarrow F^{-1}(sk, c_0)$, $k \leftarrow H(x)$, $m \leftarrow D(k, c_1)$

Digital signatures

Example: signatures from trapdoor functions (e.g. RSA)

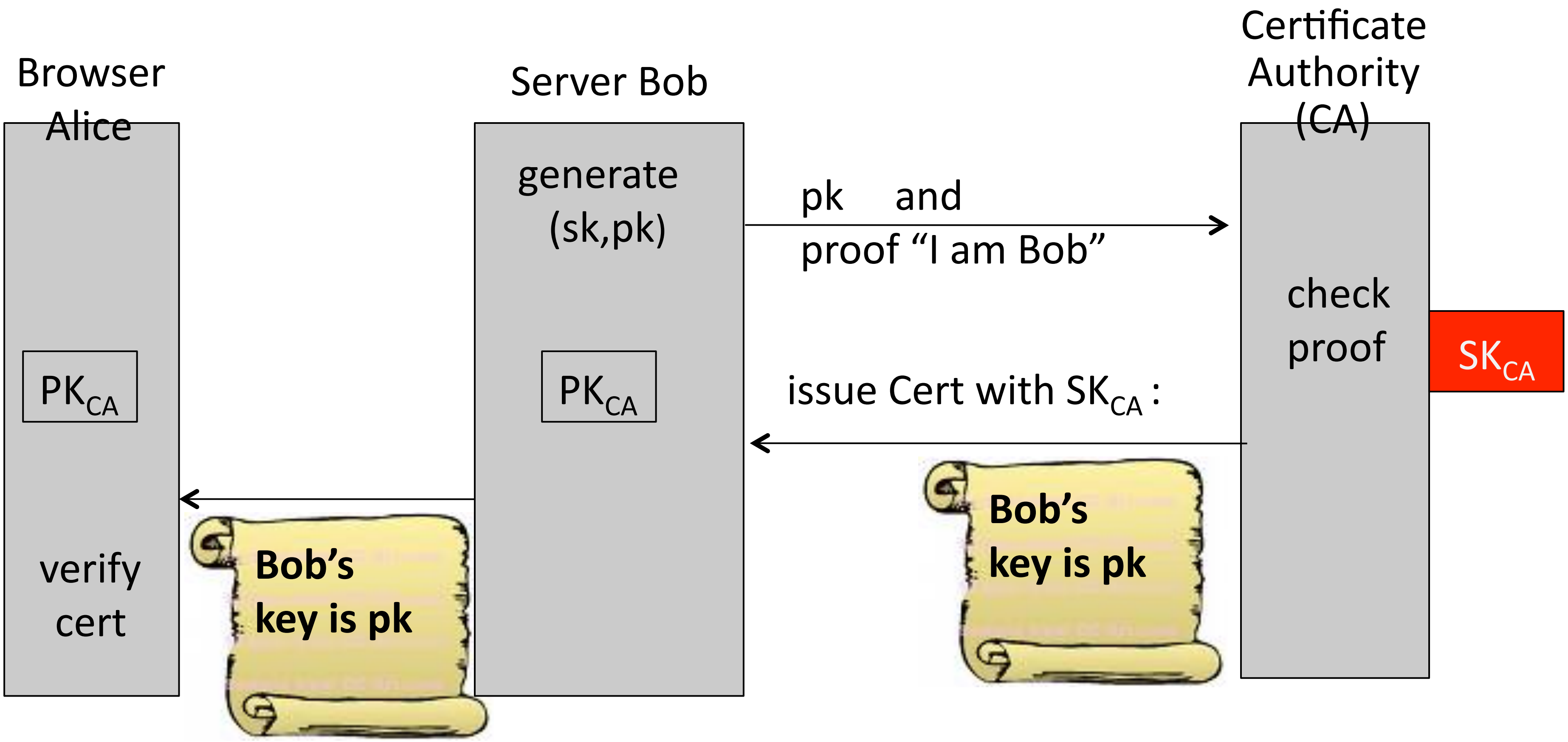
sign(sk, m) := F^{-1} (sk, H(m))

Verify(pk, m, sig) := accept if **F(pk, sig) = H(m)**

reject otherwise

Digital Certificates

CA signs a user's public key. The certificate includes both the public key and the CA's signature.



Diffie-Hellman Key Exchange

Alice

Prime p, number g, 0< g < p

Bob

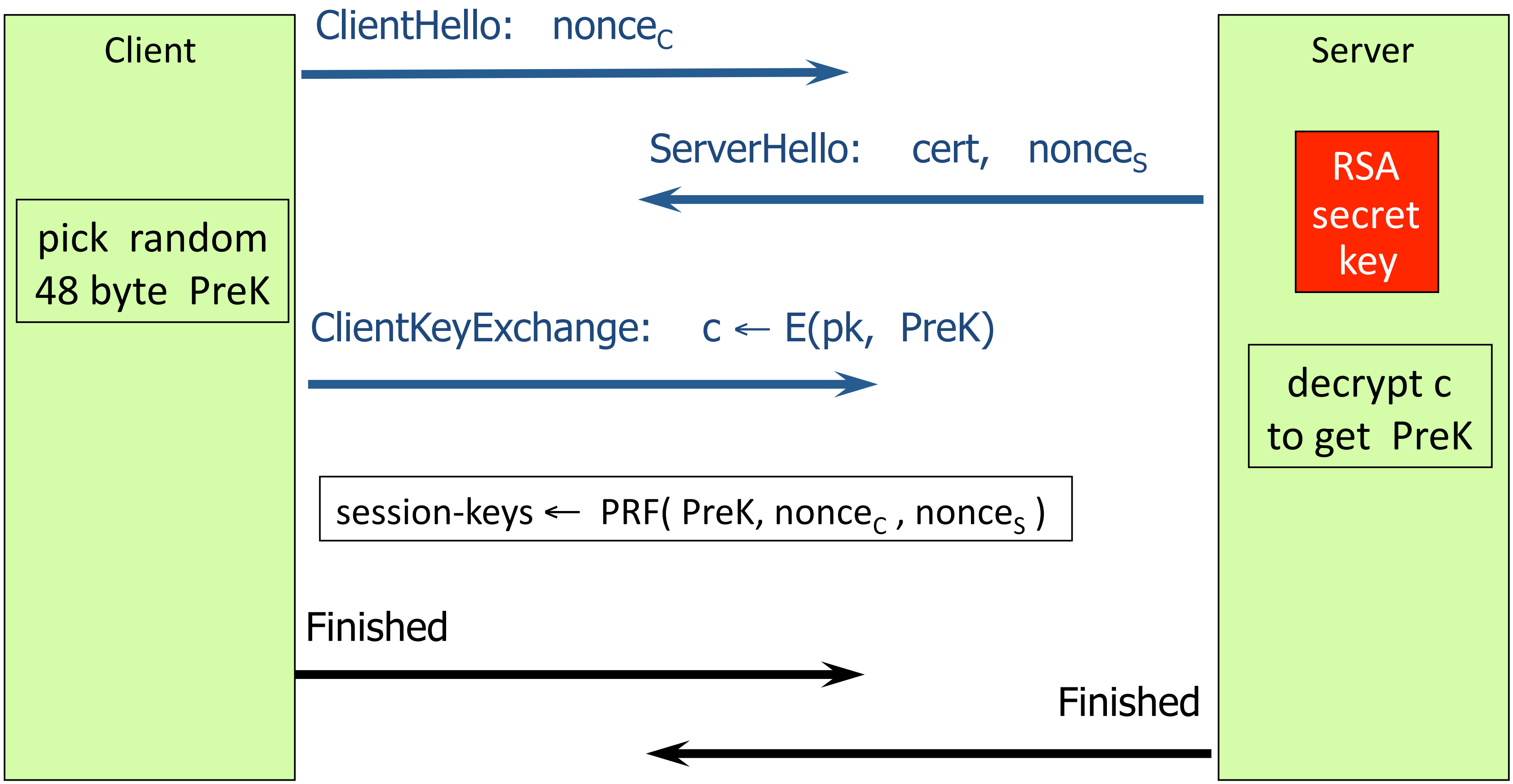
$g^A \bmod p$ →

$g^B \bmod p$ ←

$(g^A)^B \bmod p$

$(g^B)^A \bmod p$

SSL Session Setup (Simplified)



Attacks to Passwords

- Online guessing attacks
- Social engineering and phishing
- Eavesdropping
- Client-side malware
- Server compromise

Shamir Secret Sharing

- Make a random polynomial curve *f(x)* of degree *q-1*:
- Secret is *f(0)*
- Distribute *n* points
- *q* points determine the curve
- *q-1* or less points do not determine the curve
- All calculations are mod *p,* where *p* is a prime

More Crypto Tools

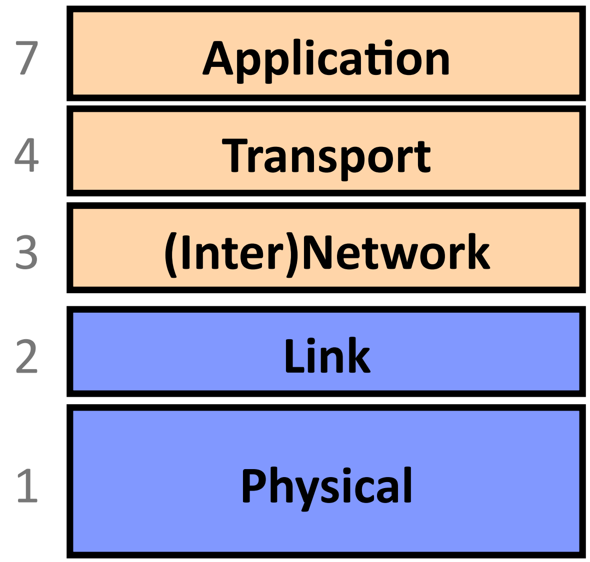
- Secure Multi-party Computation (SMC)
  - Suppose *n* participants, each has a private data point p_i. SMC computes the value of a public function *F* on the *n* data points such that each participant does not learn others' private data except what the result reveals.
  - Anything that can be done with a trusted authority can also be done without

- Zero-knowledge proof
  - Prove something without revealing the proof

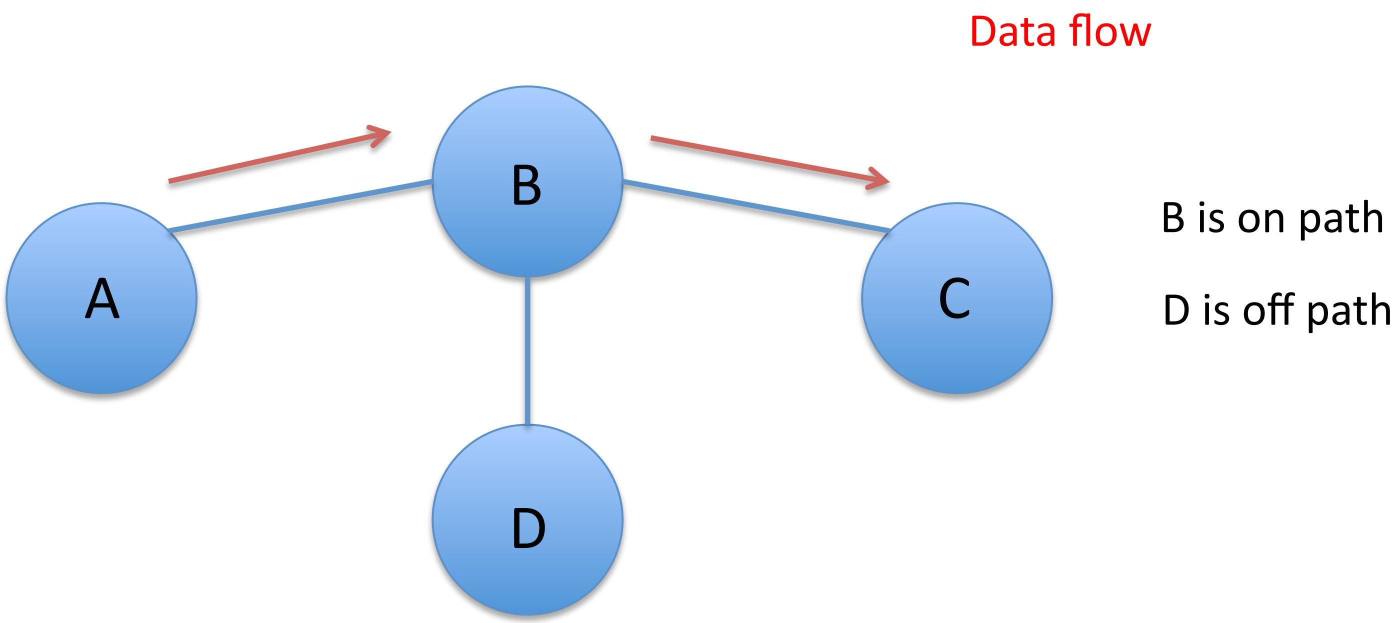
An Example: ZKP for Discrete Logs

- Suppose a prover has an identity x, which is a number satisfying $B=A^x$ (mod p). (A,B,p) is publicly available. The prover wants to prove he/she has x but does not want to reveal x to the verifier.
  - Prover chooses a random number $0 \leq r < p-1$ and sends the verifier $h=A^r$ (mod p)
  - Verifier sends back a random bit b
  - Prover sends $s=(r+bx)$ (mod (p-1)) to verifier
  - Verifier computes A^s (mod p) which should equal hB^b (mod p)

Network Protocol Stack



On-path vs. off-path



Topology with 4 nodes

Threats to Link/Physical Layers

- Eavesdropping
  - Wireshark to collect public WiFi packets
- Disruption
  - Jamming signals
  - Routers & switches can simply "drop" traffic
- Spoofing
  - Create messages attackers like

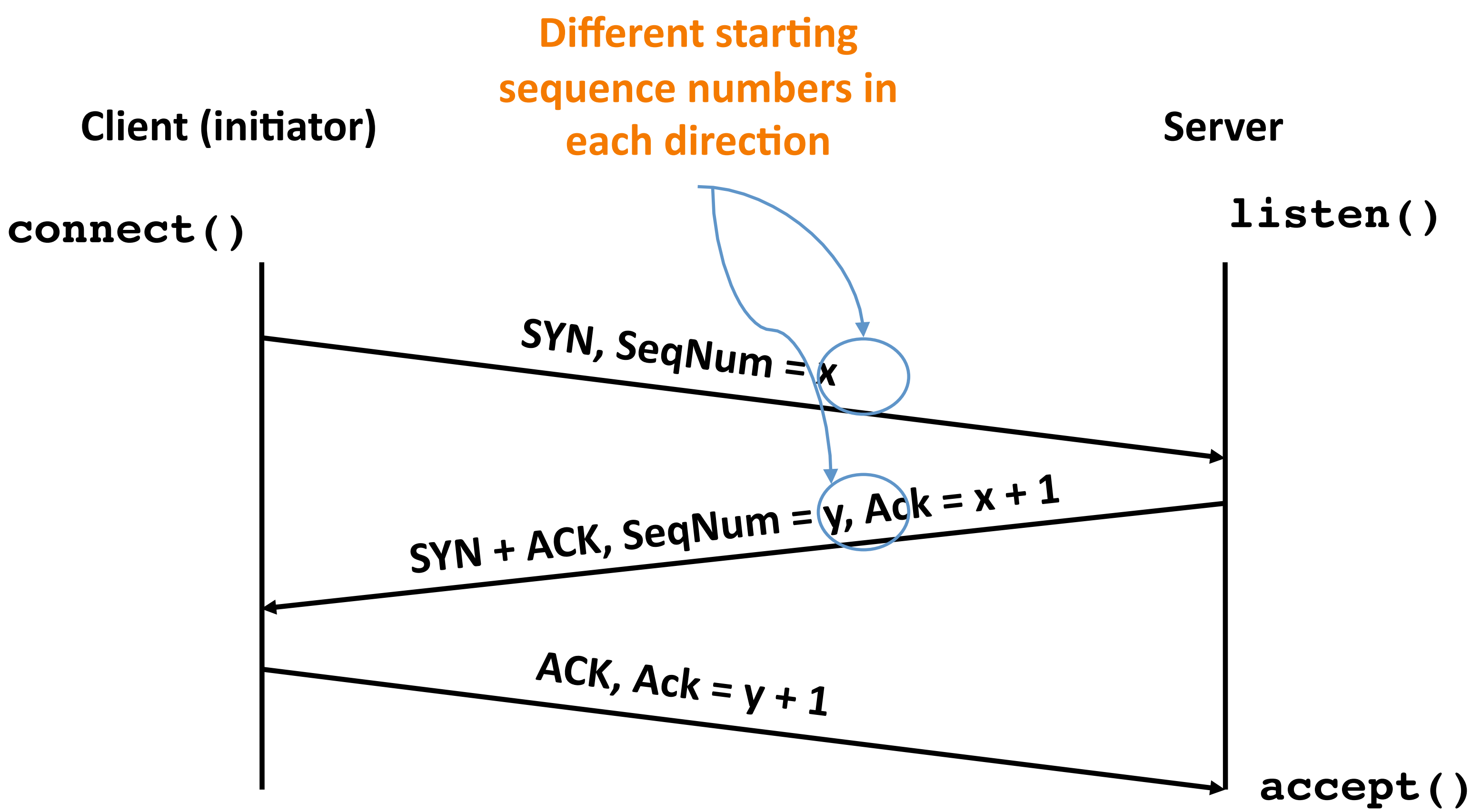
Threats to IP Layer

- Can set arbitrary source address
- Can set arbitrary destination address

Threats to TCP

- An on-path attacker who can observe your TCP connection,
  - Forcefully terminate by forging RST packet.
  - TCP hijacking/spoofing: spoof data into either direction by forging packets
    - The key is to spoof the sequence number

Establishing a TCP Connection: 3-Way Handshaking



DNS Blind Spoofing (Kaminsky 2008)

- Attacker spoofs the targeted user to generate a series of different DNS name lookups

```
<img src="http://random1.google.com" …>
<img src="http://random2.google.com" …>
<img src="http://random3.google.com" …>
                    ...
<img src="http://randomN.google.com" …>
```

- Attacker sends many DNS replies with random identification IDs to the targeted user
- Modern DNS implementation: also include randomized SRC port as ID in the UDP packet

Denial-of-Service (DoS)

- Denial-of-Service (DoS)/DDoS
  - SYN flooding: send many SYNs to start 3-way TCP handshake with the server
    - Defense: SYN Cookies (only works for spoofed source IPs)
  - DNS amplification. Send forged DNS lookups with the targeted server's IP as source address.

Firewall

- Firewall enforces an (access control) policy:
  - Who is allowed to talk to whom, accessing what service?
- Distinguish between inbound & outbound connections
  - Inbound: attempts by external users to connect to services on internal machines
  - Outbound: internal users to external services
- Default policies
  - Default allow
  - Default deny
  - Generally we use default deny
- Stateful Packet Filter
  - Checks each packet against security rules and decides to forward or drop it
  - Example: Permits TCP connection that is initiated by host 4.5.5.4