Today in Cryptography (5830)

Digital signatures
RSA signatures and full domain hash
PKI

TLS handshake for Diffie-Hellman Key Exchange

Client

Server

Pick random Nc

ClientHello, MaxVer, Nc, Ciphers/CompMethods →

Check CERT using CA public verification key
Check σ

← ServerHello, Ver, Ns, SessionID, Cipher/CompMethod

Pick random Ns

← CERT = (pk_s , signature over it)

Pick random x
$X = g^x$

← p , g , X , σ = Sign(sk_s, p || g || X)

Pick random y
$Y = g^y$

Y →

$PMS = g^{xy}$

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ChangeCipherSpec,
{ Finished, PRF(MS, "Client finished" || H(transcript)) } →

ChangeCipherSpec,
{ Finished, PRF(MS, "Server finished" || H(transcript')) } ←

Bracket notation means contents encrypted

MS <- PRF(PMS, "master secret" || Nc || Ns)

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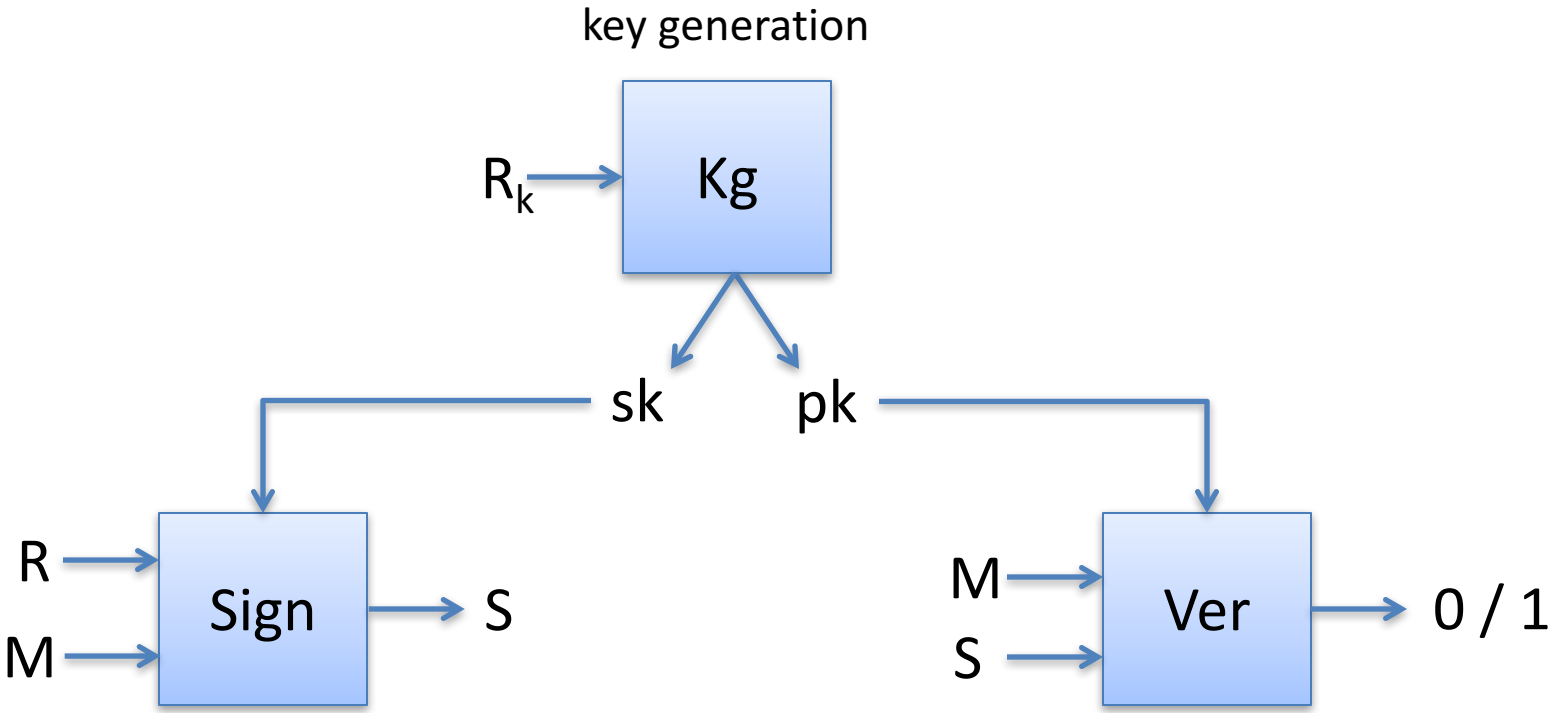
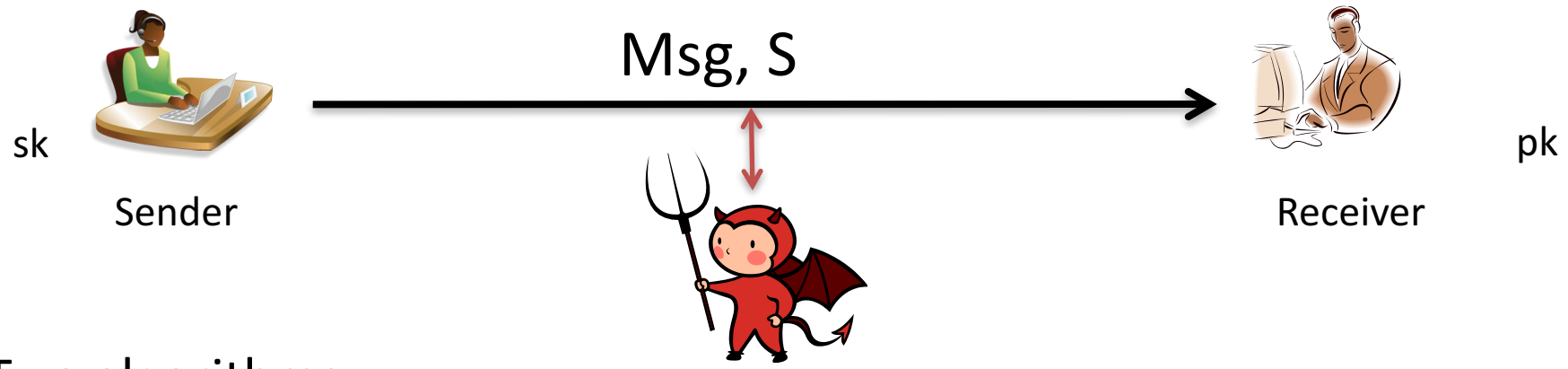
Digital signatures



Anyone with public key can verify a signature

Only holder of secret key should be able to generate a signature

Digital signatures



Two algorithms:

(1) Key generation outputs (pk,sk)

(2) Sign (sk,Msg) outputs a signature S (may be randomized)

(3) Verify(pk,Msg,S) outputs 0/1 (invalid / valid)

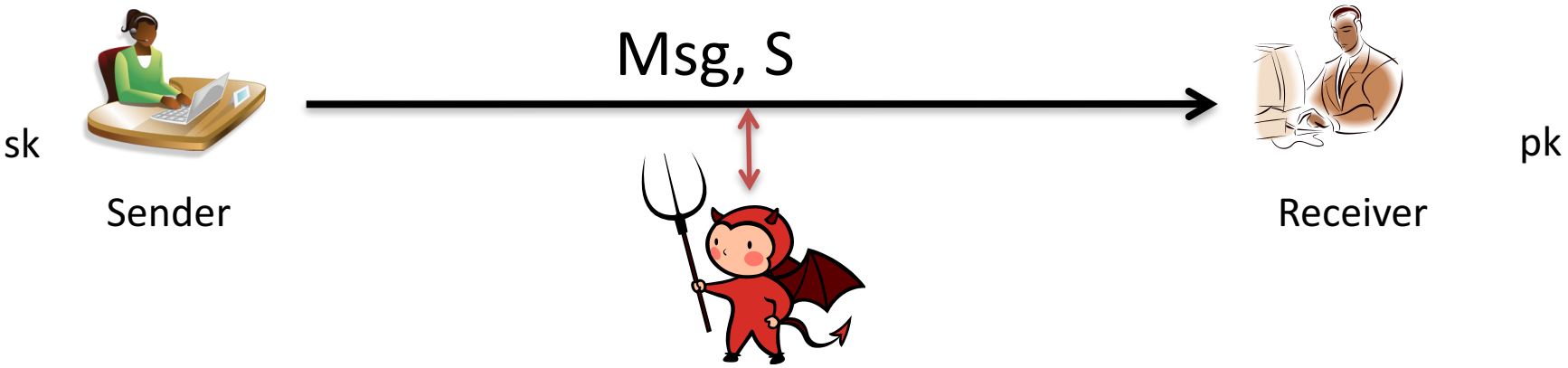
Correctness: Verify(pk,Msg,Sign(sk,Msg)) = 1 always

Security: No computationally efficient attacker can forge signatures for a new message even when attacker gets

$(Msg_1 , S_1) , (Msg_2 , S_2), \ldots , (Msg_q , S_q)$

for messages of his choosing and reasonably large q.

Digital signatures



"Raw" RSA as a signature scheme:

Key generation gives (N,e) , (N,d)
Sign((N,d),M) = M^d mod N
Verify((N,e),M,S) checks if S^e mod N = M

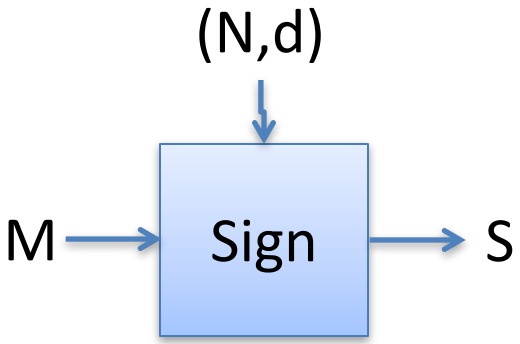
Secure? No!

PKCS #1 v1.5 RSA signing

Kg outputs (N,e),(N,d) where $|N|_8 = n$

Want to sign using hash with output length m bytes

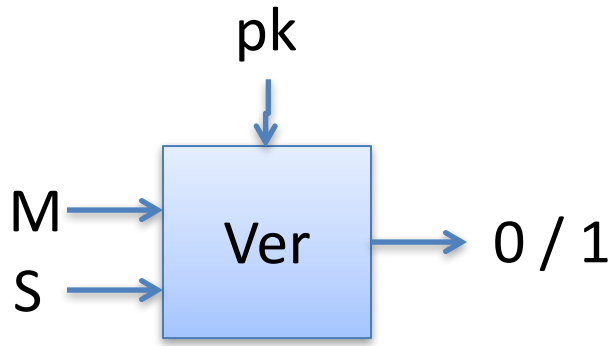
Let p = n – m - 3



Sign((N,d), M)

Y = 00 || 01 || FF^p || 00 || H(M)

Return Y^d mod N



Verify((N,e), M, S)

$Y = S^e$ mod N ; aa||bb||cc||dd||h = Y

If (aa ≠ 00) or (bb ≠ 01) or (cc ≠ FF^p)

or (dd ≠ 00)

Return error

Return H(M) = h

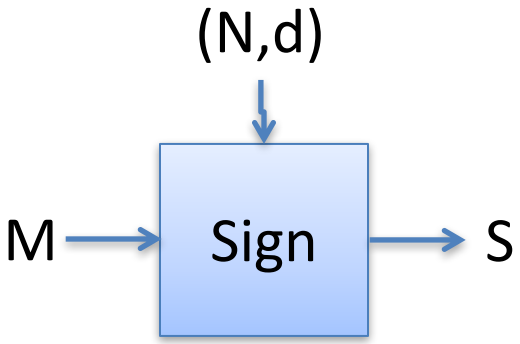
PKCS#1 v1.5 digital signature security

Padding oracle attacks that work against RSA PKCS#1 v1.5 decryption can be used to forge PKCS#1 v1.5 signatures as well

Full Domain Hash RSA

Kg outputs pk = (N,e) , sk = (N,d) where $|N|_8 = n$

H is hash with m-byte output k = ceil((n – 1)/m)

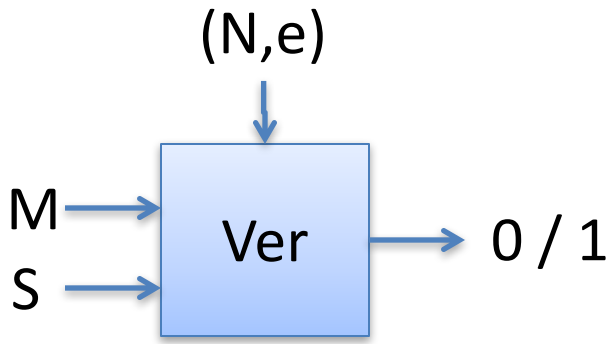


Sign((N,d), M)

X = 00 || H(1||M) || … || H(k||M)

$S = X^d \bmod N$

Return S



Ver((N,e), M, S)

$X = S^e \bmod N$

X' = 00 || H(1||M) || … || H(k||M)

If X = X' then

  Return 1

Return 0

Probabilistic Signature Scheme (PSS) provides stronger security bounds and also deployed now, see PKCS#1 v2

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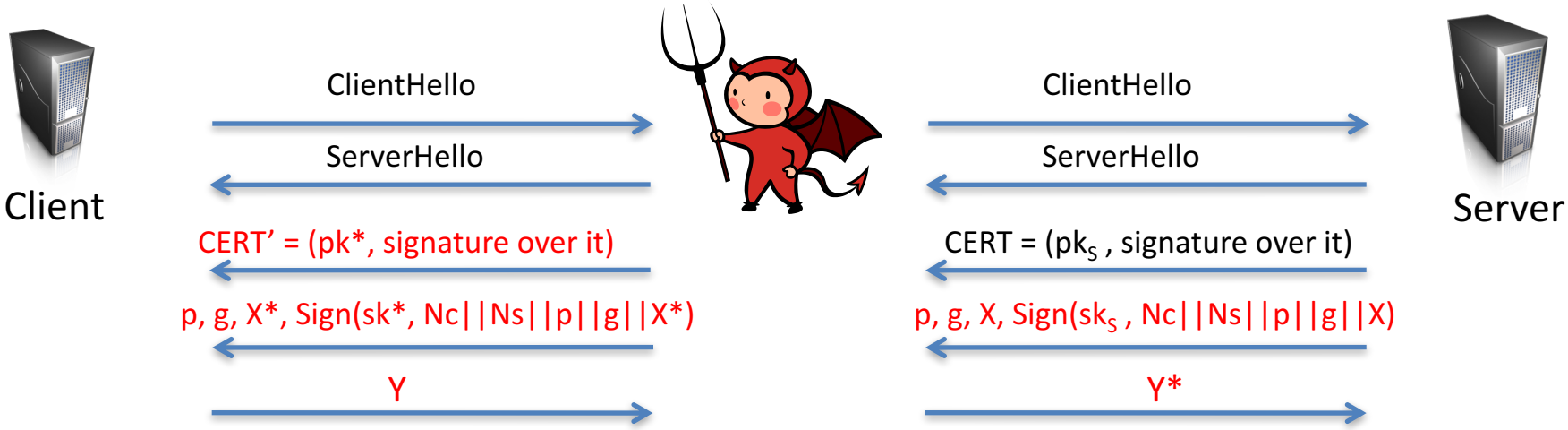
Man-in-the-middle attacks

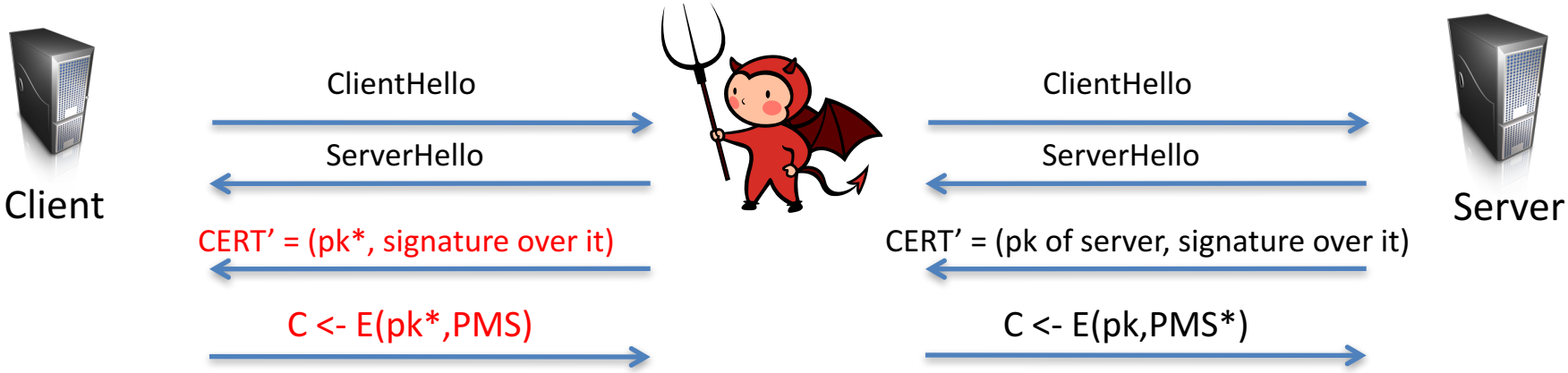
Suppose authentication vulnerability:
CERT can be forged, Client doesn't check CERT, etc.



Attacker can choose X*, Y*, so it knows discrete logs
Completes handshake on both sides
Client thinks its talking to Server
All communications decrypted by adversary, re-encrypted and forwarded to server

Man-in-the-middle attacks

Suppose authentication vulnerability:
CERT can be forged, Client doesn't check CERT, etc.



Attacker can choose pk*, thus knowing sk*
Completes handshake on both sides
Client thinks its talking to Server
All communications decrypted by adversary, re-encrypted and forwarded to server

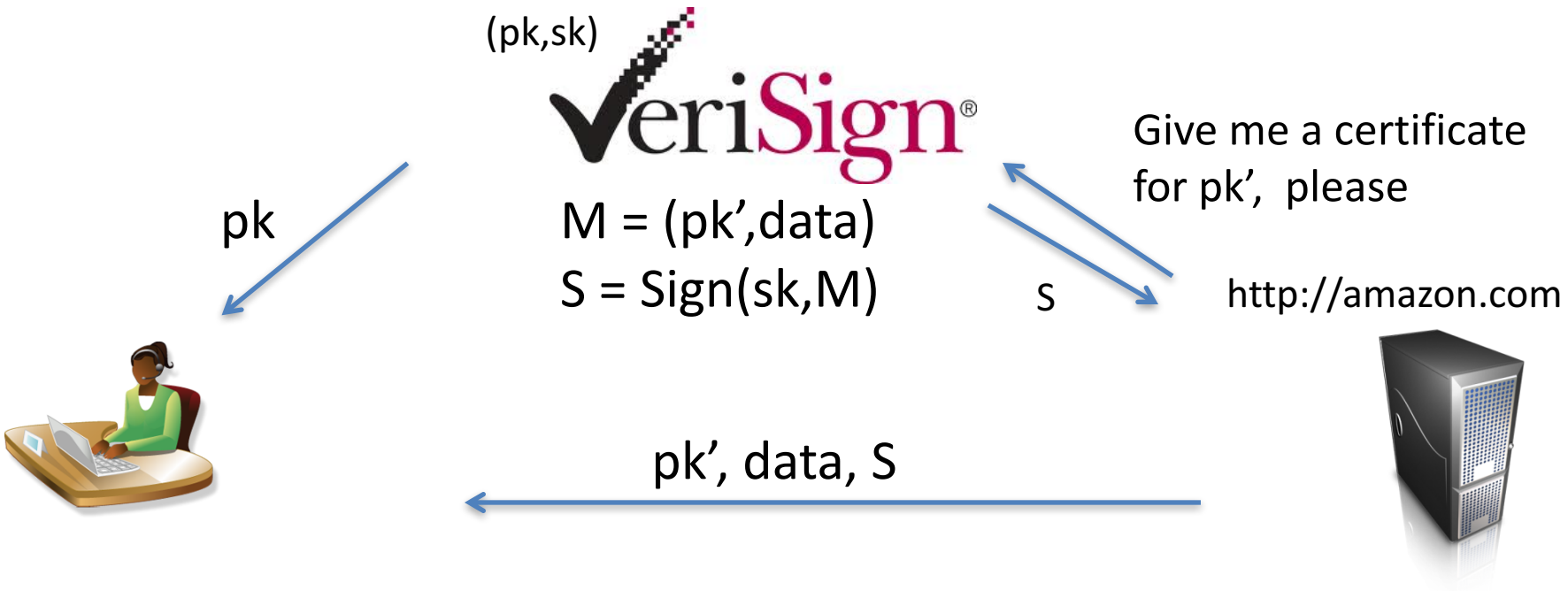
Apple iOS <7.0.16 signature verification code

```
    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
        goto fail;
    if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
        goto fail;
        goto fail;
    if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
        goto fail;

        err = sslRawVerify(ctx,
                           ctx->peerPubKey,
                           dataToSign,                          /* plaintext */
                           dataToSignLen,                  /* plaintext length */
                           signature,
                           signatureLen);
        if(err) {
                sslErrorLog("SSLDecodeSignedServerKeyExchange: sslRawVerify "
                    "returned %d\n", (int)err);
                goto fail;
        }

fail:
    SSLFreeBuffer(&signedHashes);
    SSLFreeBuffer(&hashCtx);
    return err;
```

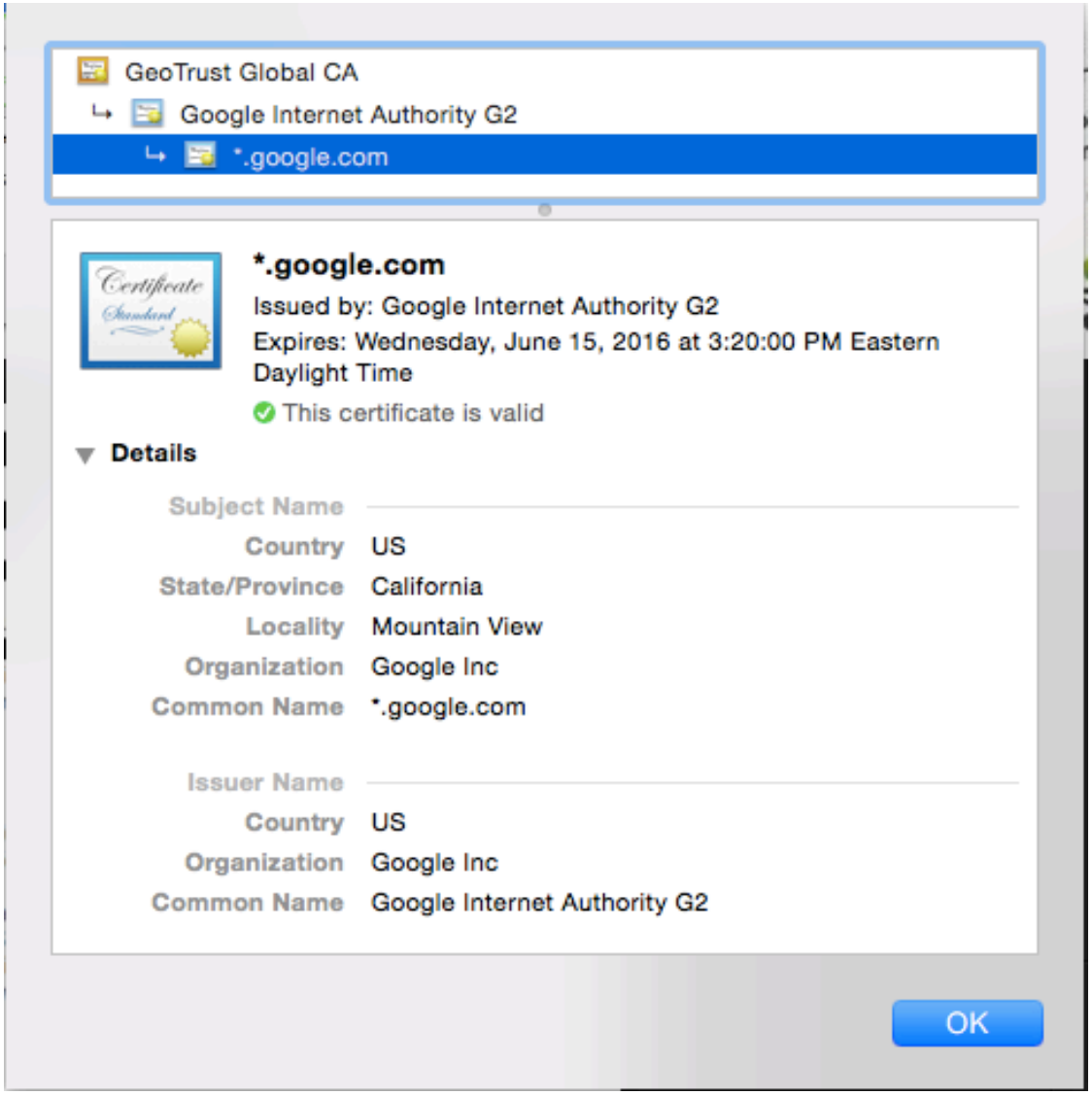
Certificate Authorities and Public-key Infrastructure



M = (pk',data)
If Ver(pk,M,S) then
trust pk'

This prevents man-in-the-middle (MitM) attacks if implemented properly

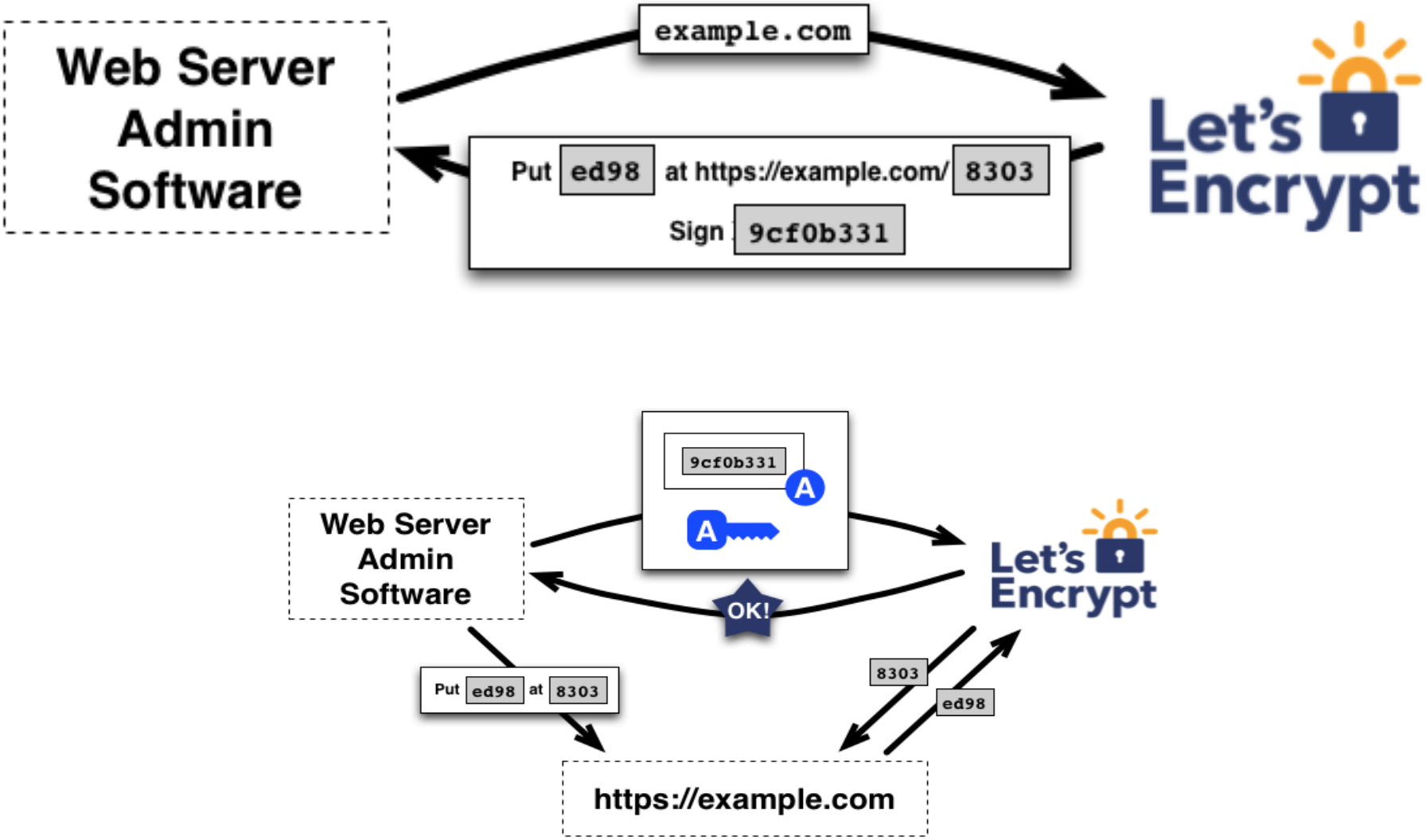
Certificate chains



Identity checks?

- CA's must check that requestor of cert is who they say they are
- Domain validated
  - Prove ownership of domain
- Extended validation
  - Establish legal identity of requestor
  - Physical presence of website owner
  - Confirm ownership of domain
  - Etc.

Free CAs


Web Server Admin Software
example.com
Put ed98 at https://example.com/ 8303
Sign 9cf0b331
Let's Encrypt
9cf0b331
A
A
OK!
Web Server Admin Software
Let's Encrypt
Put ed98 at 8303
8303
ed98
https://example.com

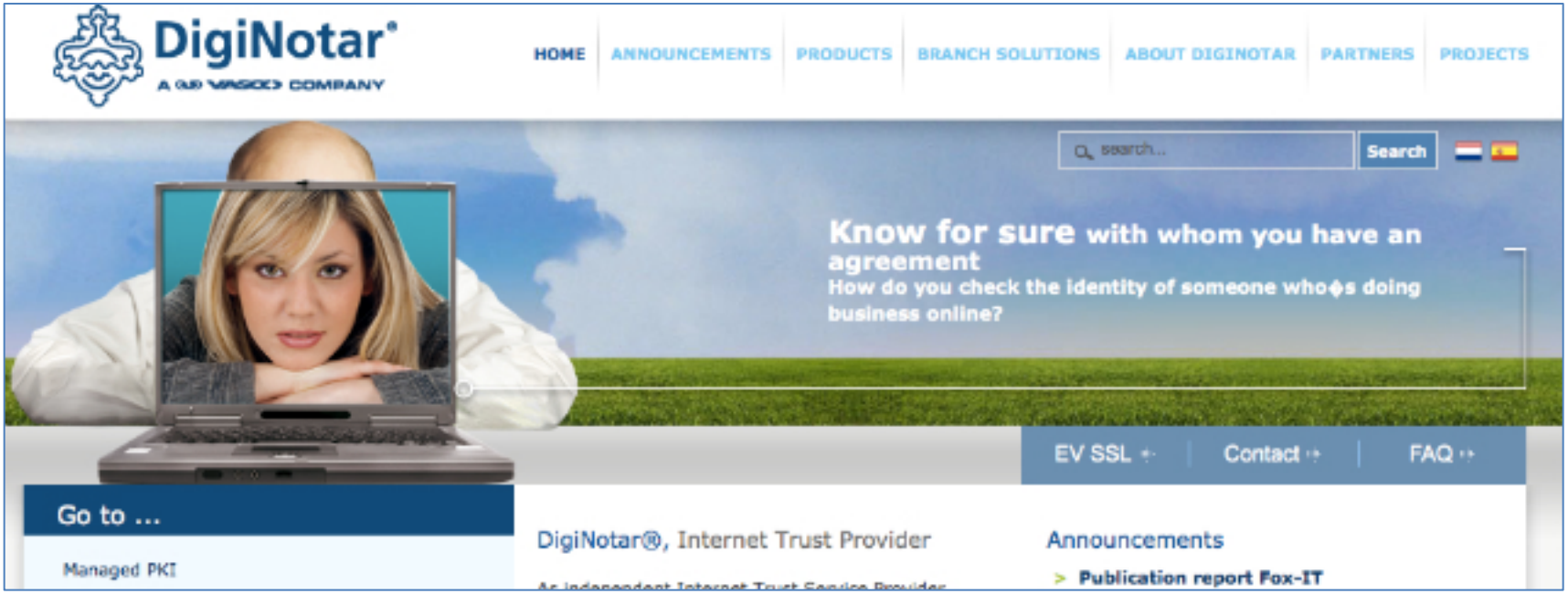
Revocation

- Certificates must often be revoked
  - Short expirations
  - CRLs (Certificate revocation lists)
  - OCSP (online certificate status protocol)
    - Client queries CA to check on validity of cert
      - privacy concerns, performance / scalability issues
    - Stapling: server periodically gets fresh, time-stamped OCSP signature from CA. Sends to clients

The Web PKI Ecosystem

- http://conferences.sigcomm.org/imc/2013/papers/imc257-durumericAemb.pdf

- ~1800 CAs that can sign *any* domain controlled by 683 organizations



Today, Microsoft issued a Security Advisory warning that fraudulent digital certificates were issued by the Comodo Certificate Authority. This could allow malicious spoofing of high profile websites, including Google, Yahoo! and Windows Live.

https://nakedsecurity.sophos.com/2011/03/24/fraudulent-certificates-issued-by-comodo-is-it-time-to-rethink-who-we-trust/

https://technet.microsoft.com/library/security/2524375

Certificate/public-key pinning

- Client knows what cert/pk to expect, rejects otherwise
  - Pre-install some keys
  - HPKP (HTTP Public Key Pinning)
    - HTTP header that allows servers to set a hash of public key they will use

```
Public-Key-Pins:
    pin-sha256="d6qzRu9zOECb90Uez27xWltNsj0e1Md7GkYYkVoZWmM=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ=";
    max-age=259200
```

https://developers.google.com/web/updates/2015/09/HPKP-reporting-with-chrome-46?hl=en

Certificate transparency

- Force CAs to log the certificates they sign in a public tamper-evident register
  - Experimental IETF standard

- Google has been pushing this
  - Chrome requires it for “extra validation” certs
  - DigiCert has implemented

Summary

- Web PKI relies on various trust assumptions
  - Can be undermined in many ways

- Digital signature schemes power PKI and verifying identities:
  - unforgeability under chosen message attack
  - RSA based schemes PKCS#1 1.5, FDH, PSS