Certificates, Trust & PKI

Brian A. LaMacchia
bal@cs.washington.edu
bal@microsoft.com

Certificates

Why do I trust the server key?

- How do I know I'm really talking to Amazon.com?
- What defeats a man-in-the-middle attack?

SSL/TLS

You (client) **Merchant (server)**

Let's talk securely.
Here are the protocols and ciphers I understand.

I choose this protocol and ciphers.
Here is my public key and
some other stuff that will make you
trust this key is mine.

Here is a fresh key encrypted with your key.

What's the "some other stuff"

How can we convince Alice that some key belongs to Bob?

- Alice and Bob could have met previously & exchanged keys directly.
  - *Jeff Bezos isn't going to shake hands with everyone he'd like to sell to…*
- Someone Alice trusts could vouch to her for Bob and Bob's key
  - *A third party can certify Bob's key in a way that convinces Alice.*

What is a certificate?

- A certificate is a digitally-signed statement that binds a public key to some identifying information.
  - The signer of the certificate is called its issuer.
  - The entity talked about in the certificate is the subject of the certificate.
- That's all a certificate is, at the 30,000' level.

Certificates are Like Marriage

By the power vested in me I now declare this text and this bit string "name" and "key." What RSA has joined, let no man put asunder.

--Bob Blakley

Certs in the "real world"

- A driver's license is *like* a certificate
  - It is a "signed" document (sealed, tamper-resistant)
  - It is created and signed by an "issuing authority" (the WA Dept. of Licensing)
  - It binds together various pieces of identifying information
    - Name
    - License number
    - Driving restrictions (must wear glasses, etc.)

More certs in the real world

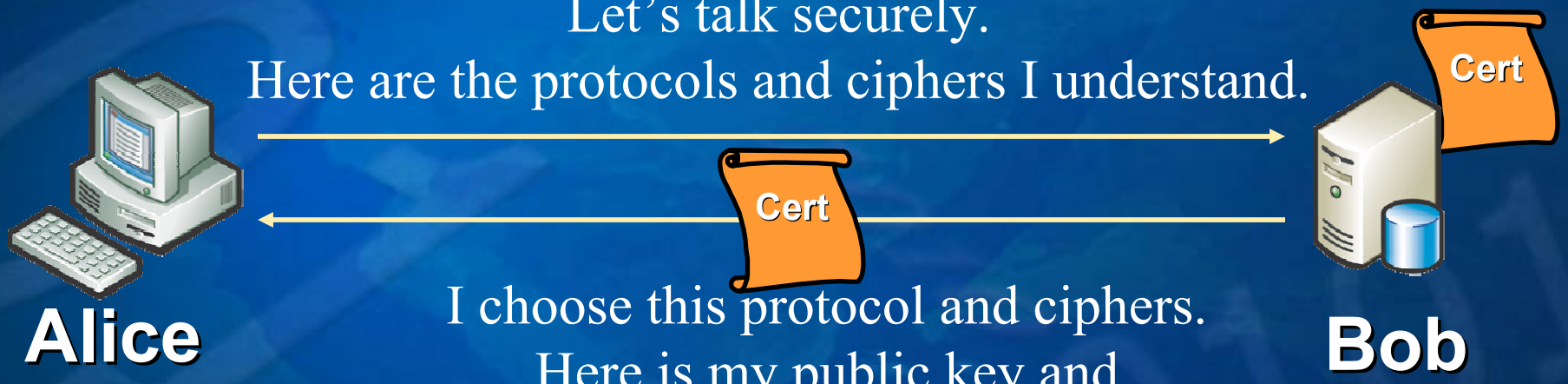
- Many physical objects are like certificates:
  - Any type of license – vehicle tabs, restaurant liquor license, amateur radio license, etc.
  - Government-issued IDs (passports, green cards)
  - Membership cards (e.g. Costco, discount cards)
- All of these examples bind an identity and certain rights, privileges or other identifiers
  - "BAL ==N1TJT" signed FCC

Why do we believe what certs say?

- In the physical world, why do we trust the statements contained on a physical cert?
  - We believe it's hard to forge the cert
  - We trust the entity that "signed" the cert
- In the digital world we need those same two properties
  - We need to believe it's hard to forge the digital signature on a signed document
  - We need to trust the issuer/signer not to lie to us

Defeating Mallet

Bob can convince Alice that his key really does belong to him if he can also send along a digital certificate Alice will believe & trust



Getting a certificate

- How does Bob get a certificate for his key?
- He goes to a Certificate Authority (CA) that issues certificates and asks for one…
- The CA *issues* Bob a certificate for his public key.
  - CA is the issuer
  - Bob is the subject

Using Certificates

- Now that Bob has a certificate, is it useful?
- Alice will believe Bob's key belongs to Bob if Alice believes the certificate Bob gives her for his key.
- Alice will believe Bob's key belongs to Bob if Alice trusts the issuer of Bob's certificate to make key-name binding statements
- Have we made the situation any better?

Does Alice Trust Bob's CA?

How can we convince Alice to trust Bob's CA?

- **Alice and Bob's CA could have met previously & exchanged keys directly.**
  - ***Bob's CA isn't going to shake hands with everyone he's certified, let alone everyone whom Bob wants to talk to.***

Does Alice Trust Bob's CA?

How can we convince Alice to trust Bob's CA?

- **Alice and Bob's CA could have met previously & exchanged keys directly.**
  - ***Bob's CA isn't going to shake hands with everyone he's certified, let alone everyone whom Bob wants to talk to.***
- **Someone Alice trusts could vouch to her for Bob's CA and Bob's CA's key**
  - ***Infinite Loop: See Loop, Infinite.***
  - **Actually, it's just a bounded recursion…**

What's Alice's Trust Model

- Alice has to implicitly trust *some* set of keys
  - Once she does that, those keys can introduce others to her.
- In the model used by SSL/TLS, CAs are arranged in a hierarchy
  - Alice, and everyone else, trusts one or more "root CA" that live at the top of the tree
- Other models work differently

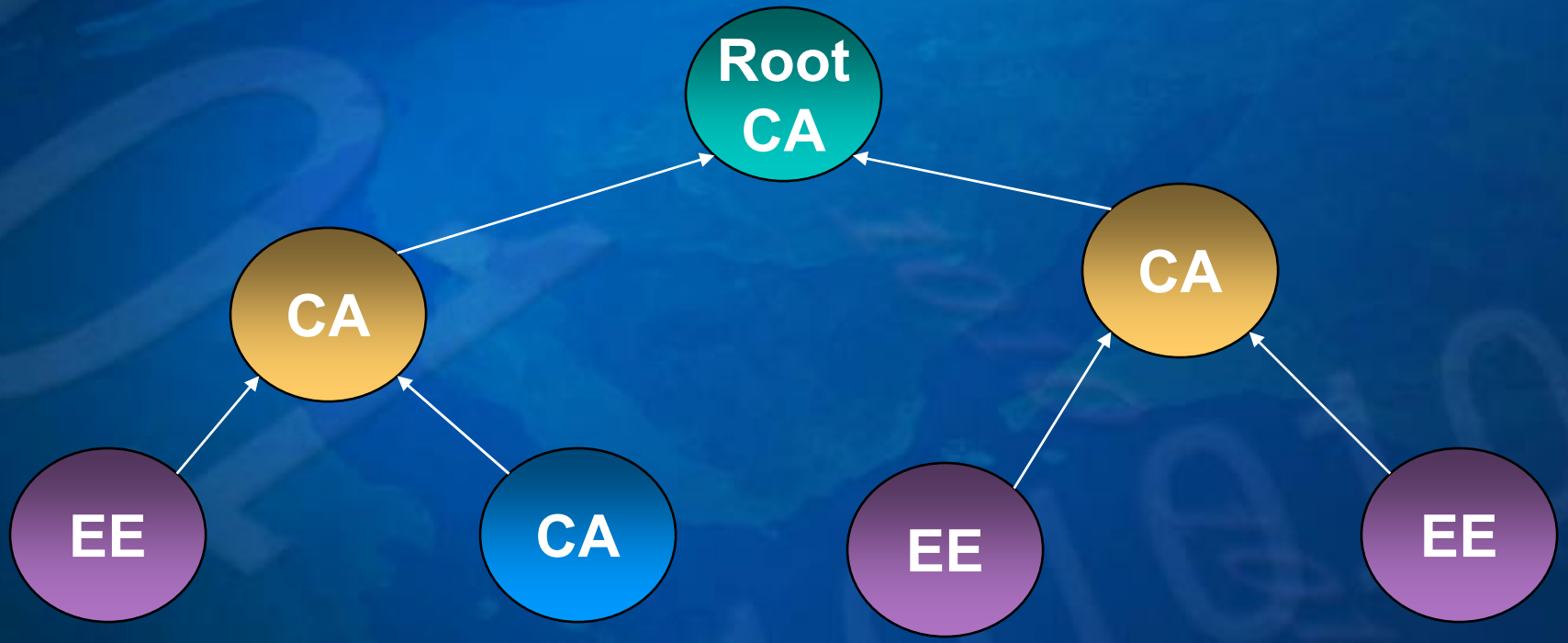
Public Key Infrastructure

Certificate Authorities

- A certificate authority (CA) guarantees the connection between a key and another CA or an "end entity."
- An end entity is:
  - A person
  - A role ("VP of sales")
  - An organization
  - A pseudonym
  - A piece of hardware or software
  - An account
- Some CA's only allow a subset of these types.

CA Hierarchies

- CAs can certify other CAs or "end entities"
- Certificates are links in a tree of EEs & CAs

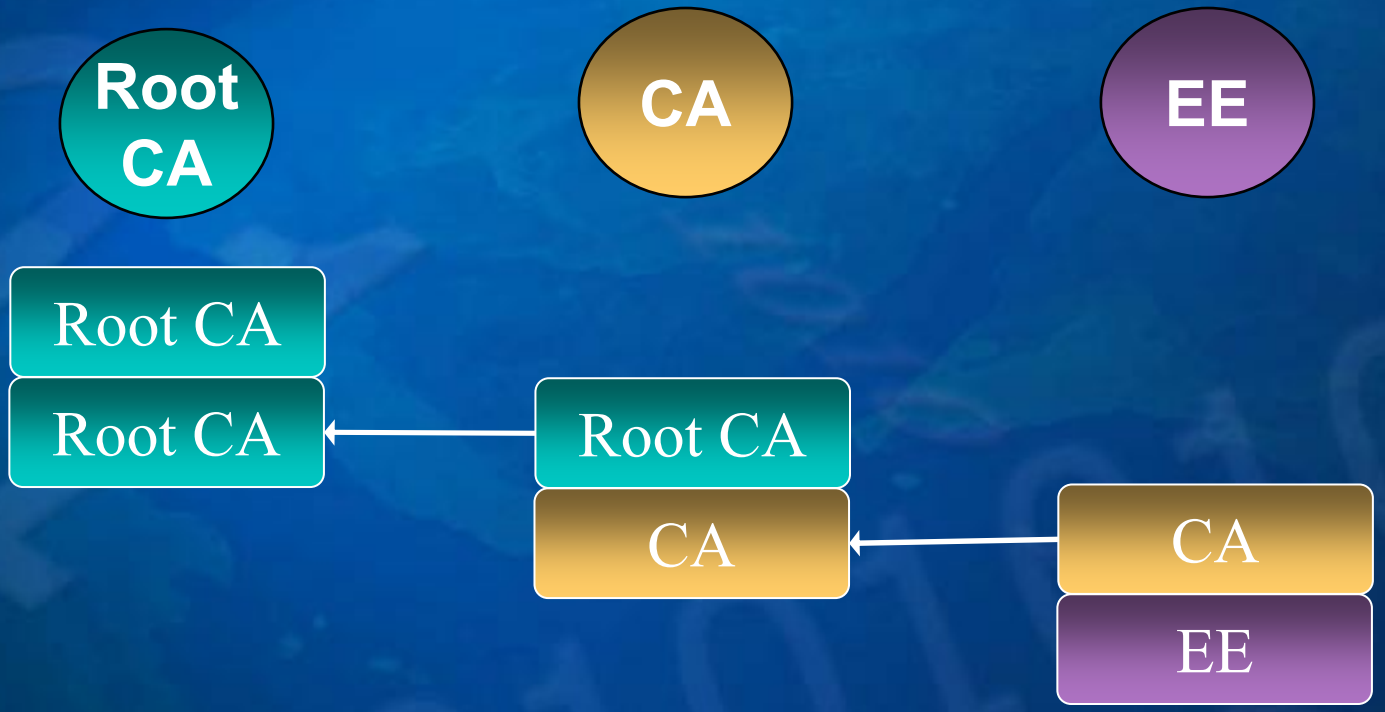


BAL's No-Frills Certs

- Certificates can contain all sorts of information inside them
  - We'll talk about the details in a little bit
- In the abstract, though, they're just statements by an issuer about a subject:

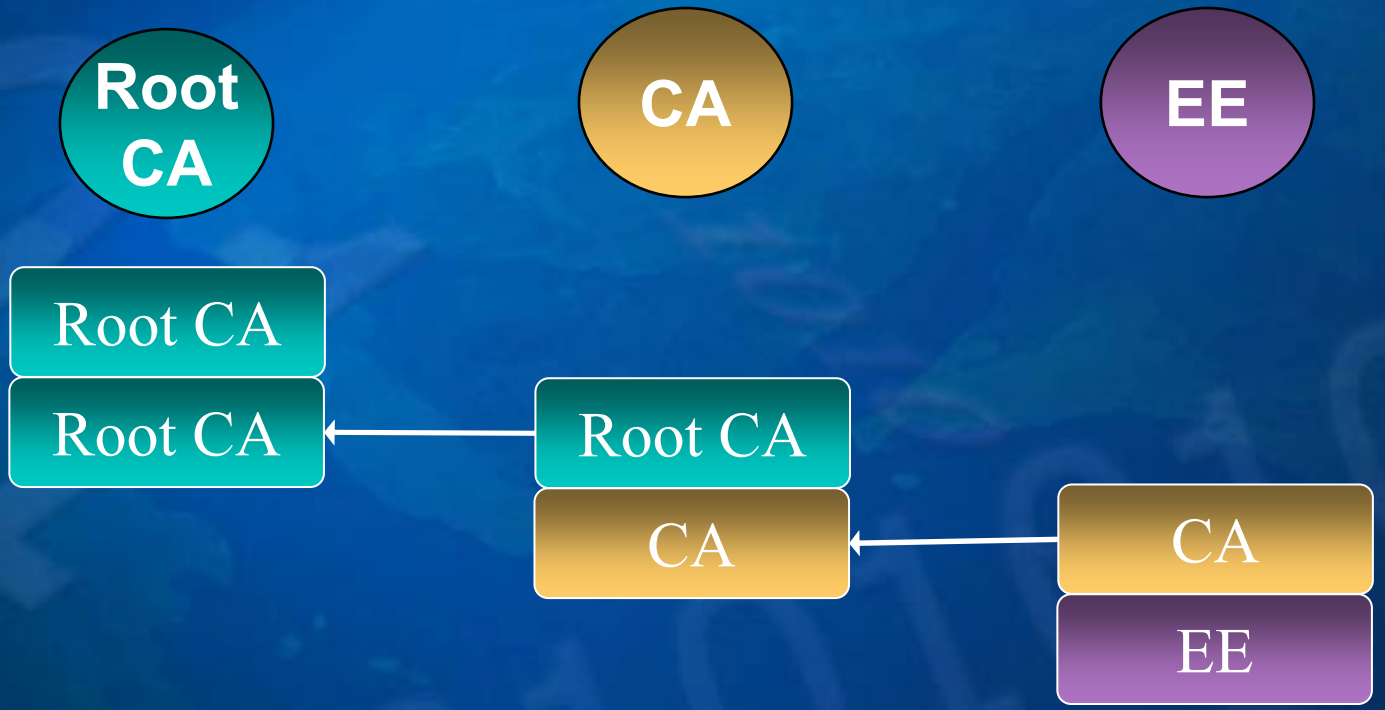
Does Alice trust Bob's Key?

- Alice trusts Bob's key if there is a chain of certificates from Bob's key to a root CA that Alice implicitly trusts



Chain Building & Validation

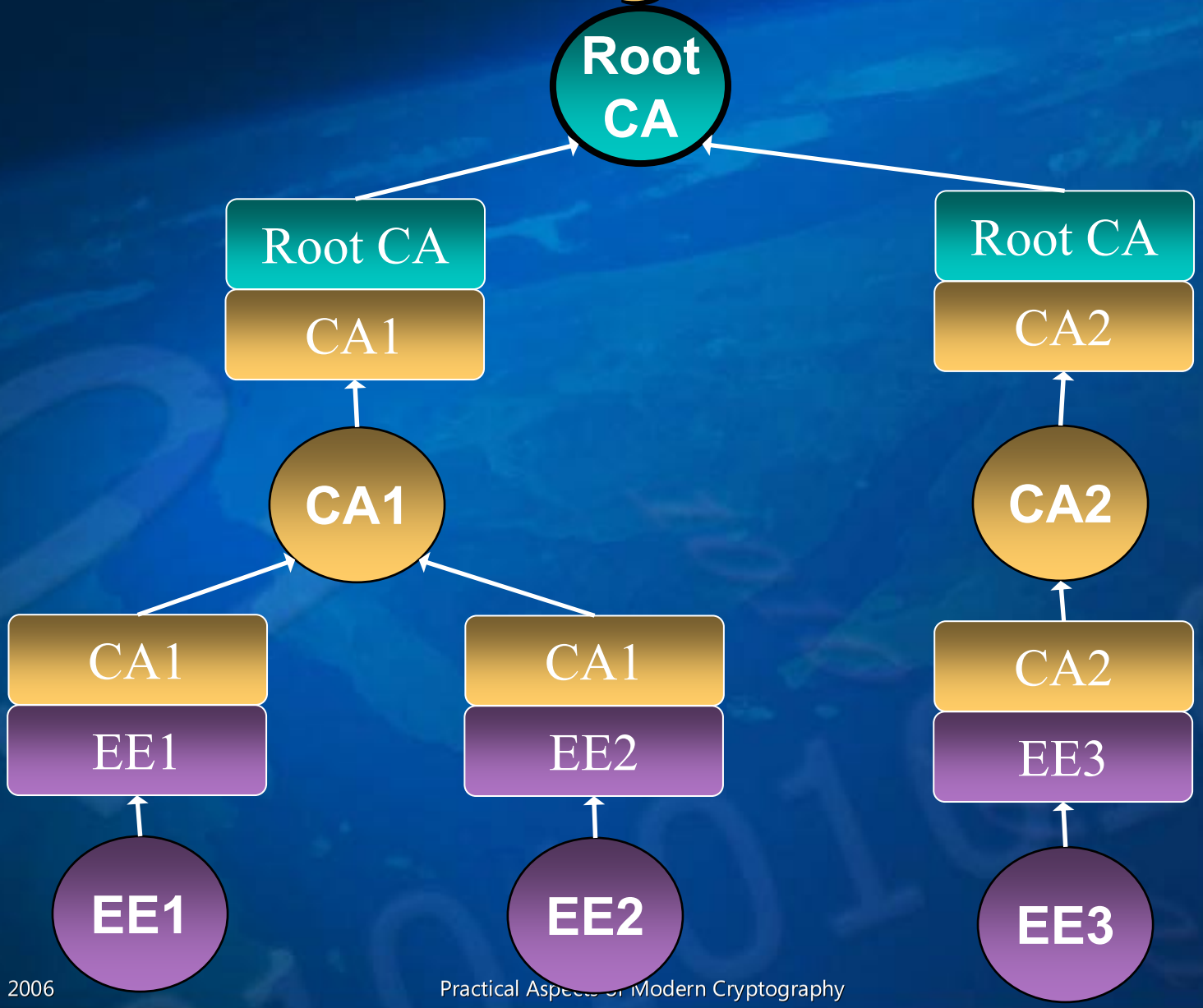
- "Given an end-entity certificate, does there exist a cryptographically valid chain of certificates linking it to a trusted root certificate?"



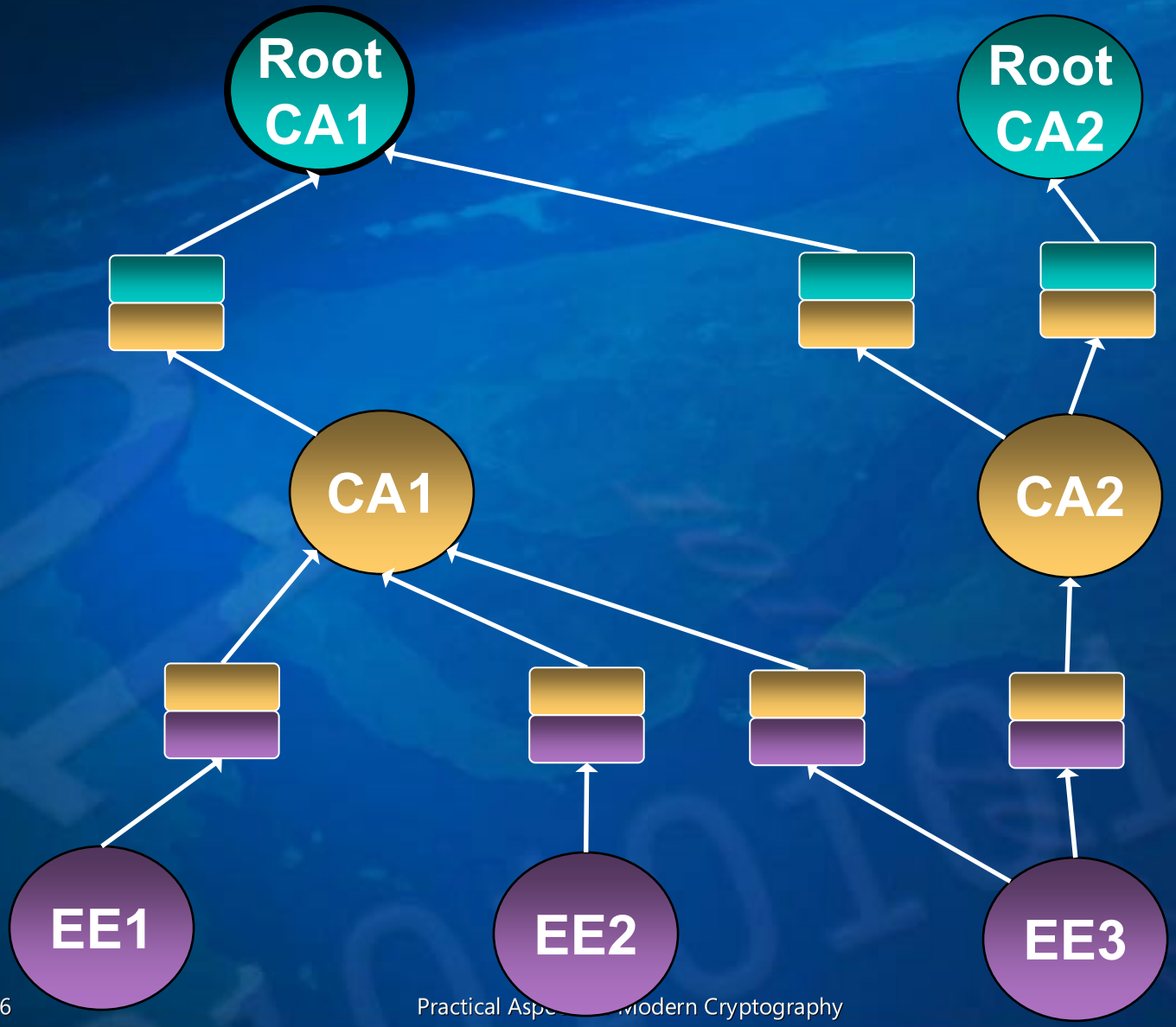
Chaining Certificates

- In theory, building chains of certificates should be easy
  - "Just link them together like dominos"
- In practice, it's a lot more complicated…

Chain Building Details (1)



Chain Building Details (2)



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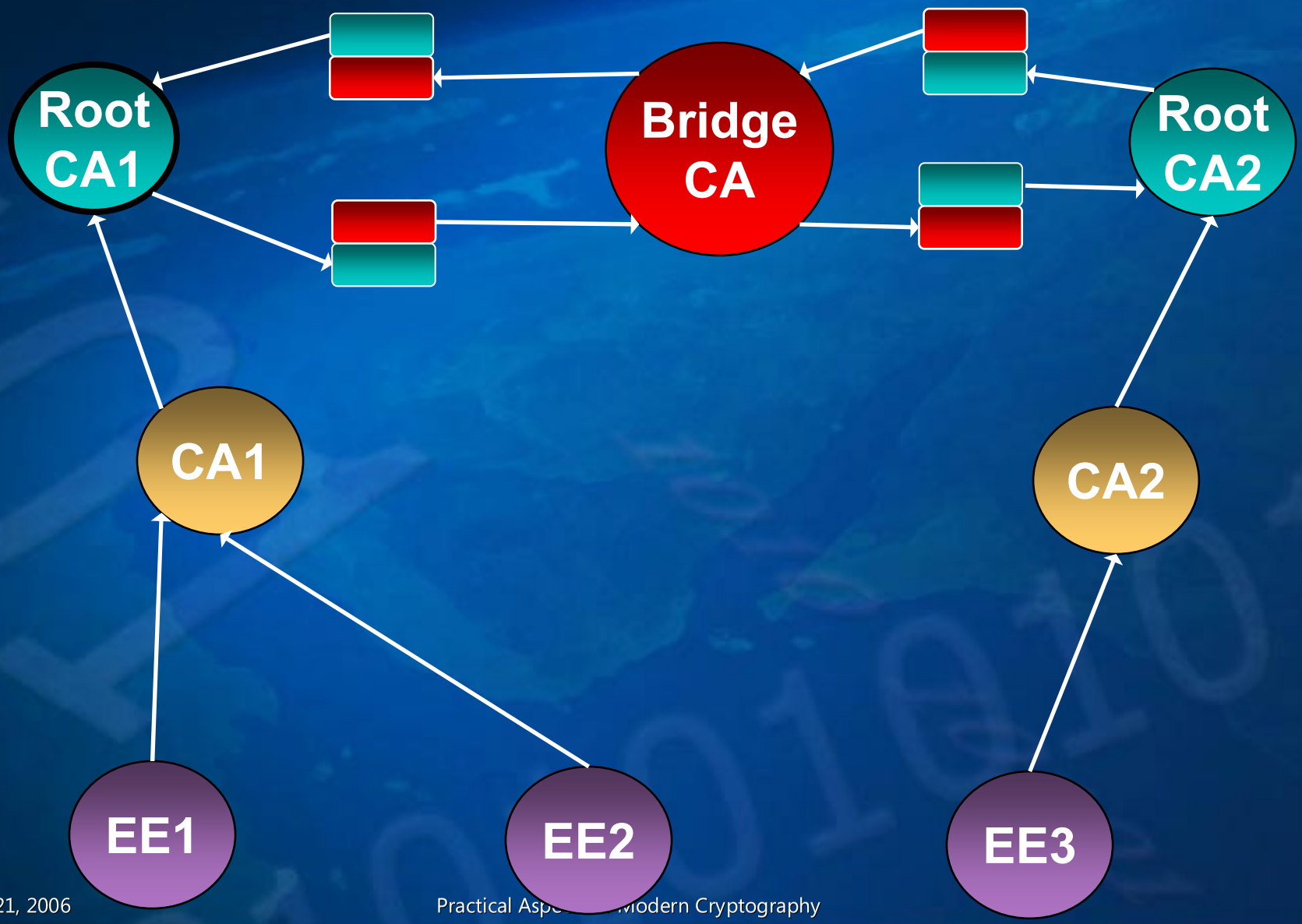

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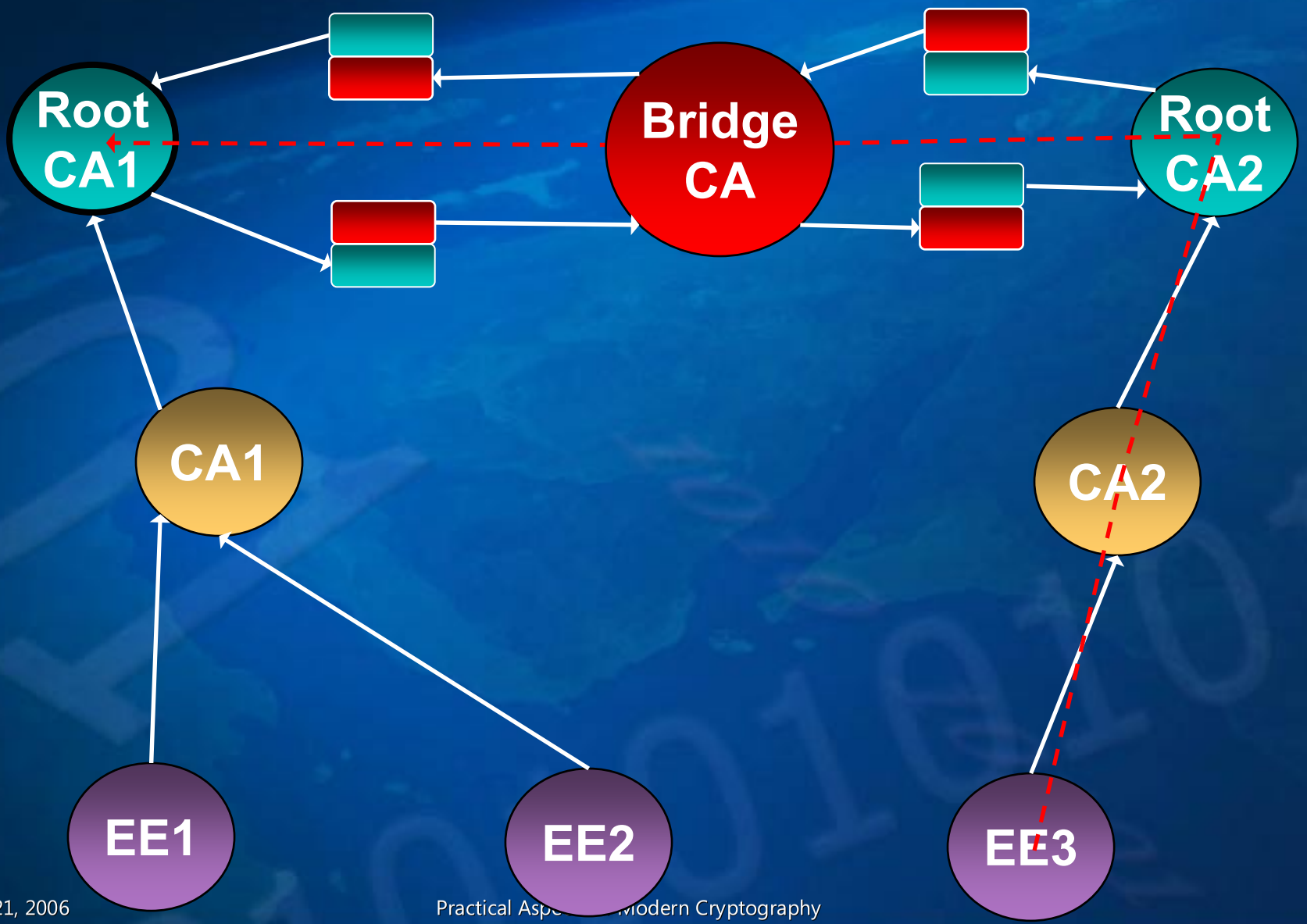

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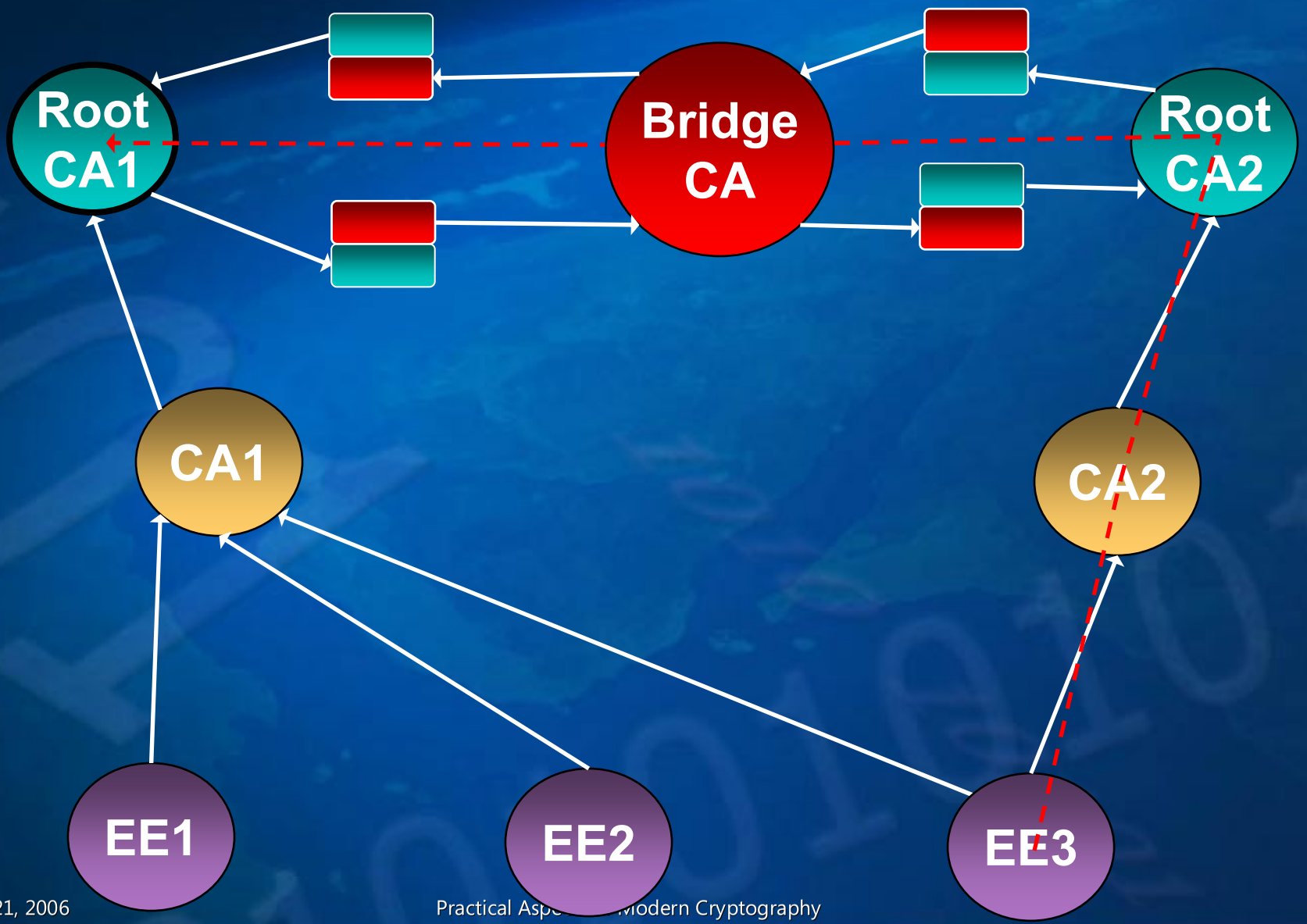

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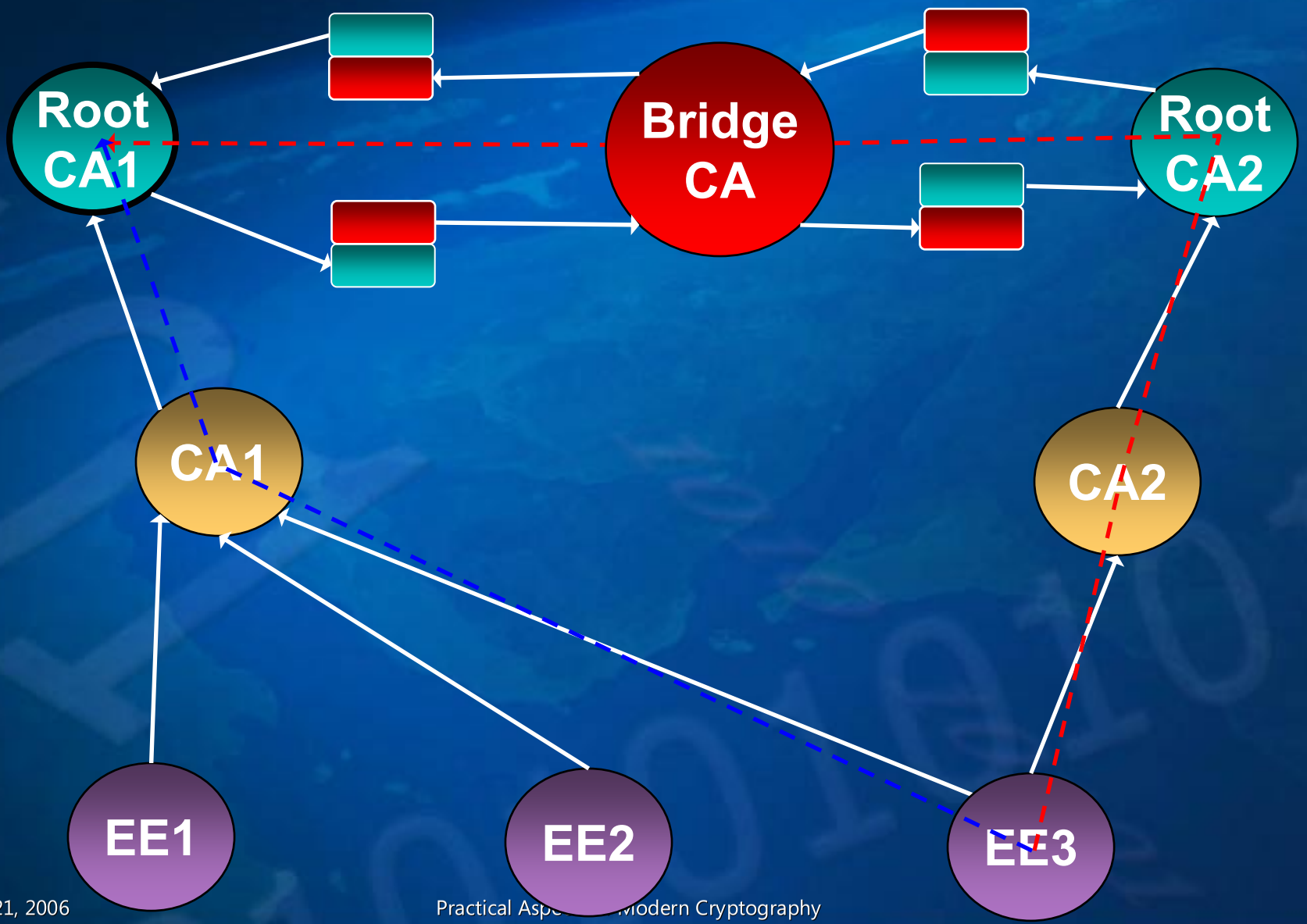


Chaining Certificates

- How do we determine whether two certificates chain together?
  - *You'd think this was an easy problem…*
  - *But it's actually a question with religious significance in the security community*
  - *"Are you a believer in names, or in keys?"*
- In order to understand the schism, we need to digress for a bit and talk about names and some history

PKI Alphabet Soup

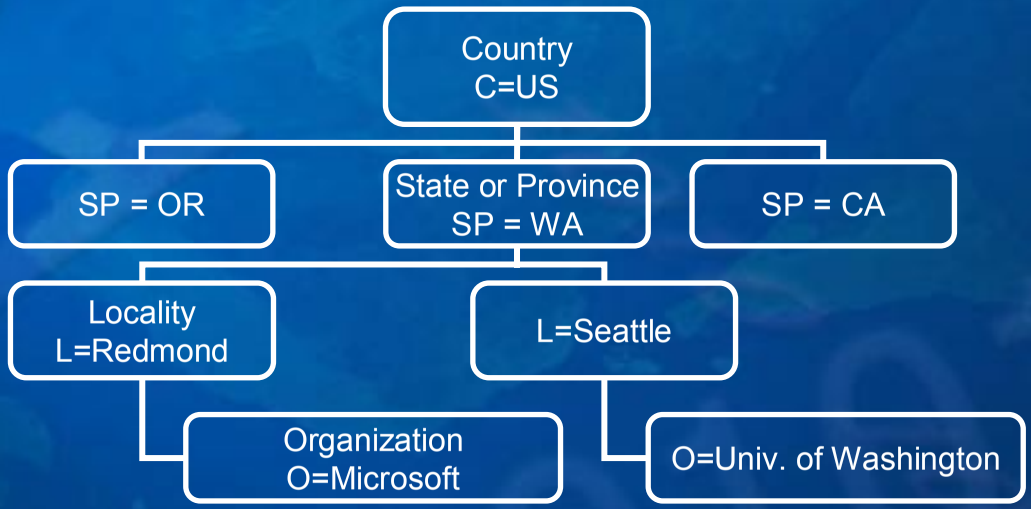
- X.509v3 - standard content of a certificate
- PKIX – IETF Working Group on PKI interoperability
  - PKIX == Public Key Infrastructure using X.509v3 certificates
- ASN.1 - Abstract Syntax Notation, exact description of a certificate format
- DER - Distinguished Encoding Rules, how to physically package a certificate

The X.500 Directory Model

- The model SSL/TLS uses, the X.509 certificate model, is based on names
  - *Names as principles*
- Specifically, X.509 is based on the X.500 directory model
- X.500 defined a global, all-encompassing directory, to be run by the telcos
  - *One directory to rule them all, one directory to define them…*

X.500 Distinguished Names

- In the X.500 model, everything has a single, unique, global, assigned name
  - There is a worldwide hierarchy, and you're in it!



DNs in Practice

- Name is unique within the scope of the CA's name
- Public CAs (e.g. Verisign) typically set
  - C = CA Country
  - O = CA Name
  - OU = Certificate type/class
  - CN = User name
  - E= email address

Private-label DNs

- If you own the CA, you get to decide what fields go in the DN
  - Really varies on what the software supports
- Can get really strange as people try to guess values for fields that are required by software
  - Software requires an OU, we don't have OUs, so I better make something up!

DNs in X.509 Certificates

- The X.509 certificate standard began as a way to associate a certificate with a node in the directory.
- How is the subject of a cert identified?
  - By its DN.
- How is the issuer of a cert identified?
  - By its DN.
- How are certificates linked together?
  - By DNs.

Key fields in a certificate

- The core fields of an X.509 certificate are
  - The subject public key
  - The subject Distinguished Name
  - The issuer Distinguished Name
- What's missing here?

Key fields in a certificate

- The core fields of an X.509 certificate are
  - The subject public key
  - The subject Distinguished Name
  - The issuer Distinguished Name
- What's missing here?
  - The issuer's public key is not present in the certificate.
  - You can't verify the signature on the cert without finding a parent cert!

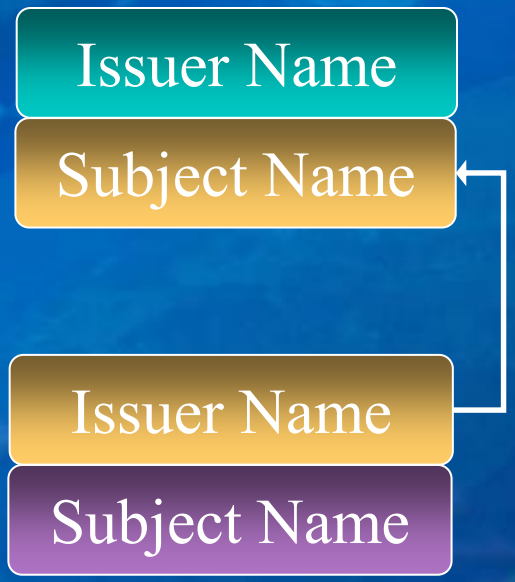
Back to Chain Building

- OK, assume we're a "relying party application" -- something that received an end-entity certificate and wants to verify it.
  - Our task is to build a cert chain from that end-entity cert to one of our trusted roots
- How do we do that?
  - We start with our EE cert, and using the information contained within we look for possible parent certificates.

Parent certs

- What's a valid parent certificate?
  - In the raw X.509 model, parent-child relationships are determined solely by matching Issuer DN in the child to Subject DN in the parent
  - Recall that there's an assumption that you have a big directory handy to find certs.
- If you don't have a directory handy, you need to do the matching yourself
  - This is not as easy as you might think…

Name matching



Matching Names

- How do we determine if two DNs match?
  - "Use directory name matching rules!"
  - Try to be mildly smart about it
    - Remove spaces, case-fold, etc.
    - Disaster…
  - Try to be really dumb about it
    - Exact binary match
    - Less of a disaster, but there are still problems we can't work around…

Unicode Names

- Are these two character equal?

  é é

- They look equal…

Unicode Names

- Are these two character equal?

  é é

- They look equal…
- …but may not be
- In Unicode, you can compose characters, so:
  - "é" as one character
  - "é" as two characters – "e" followed by non-spacing accent
  - "é" as two characters – non-spacing accent followed by "e"
- Ick!

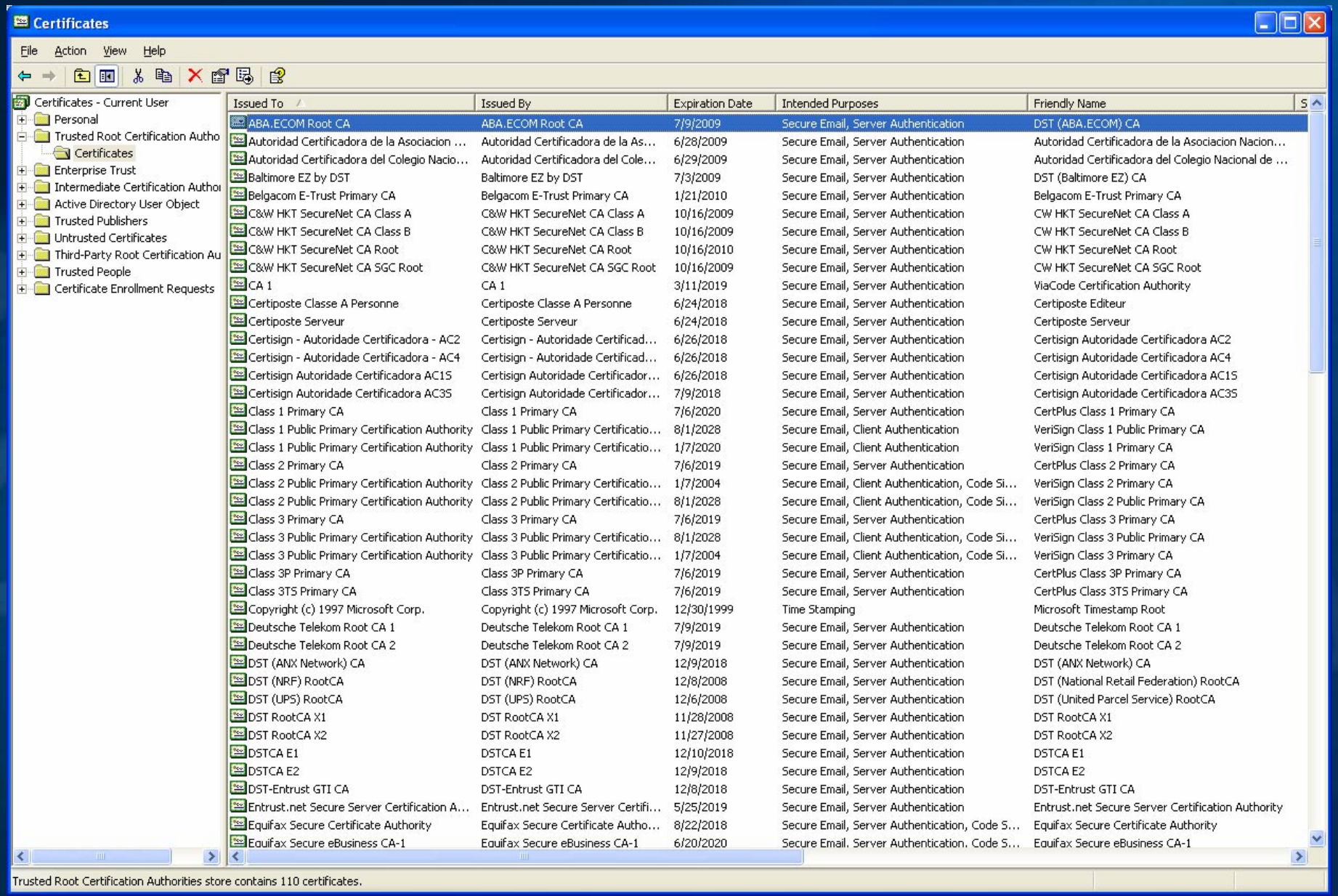
Even More Chain Building

- Name matching is just the beginning of the chain-building process
  - It is necessary that subject and issuer DNs exactly match for two certs to chain, but not always sufficient
- The chain building process is also influenced dynamically by other information contained within the certs themselves
  - *What other information is there in certs?*

Trusted Root Certificates

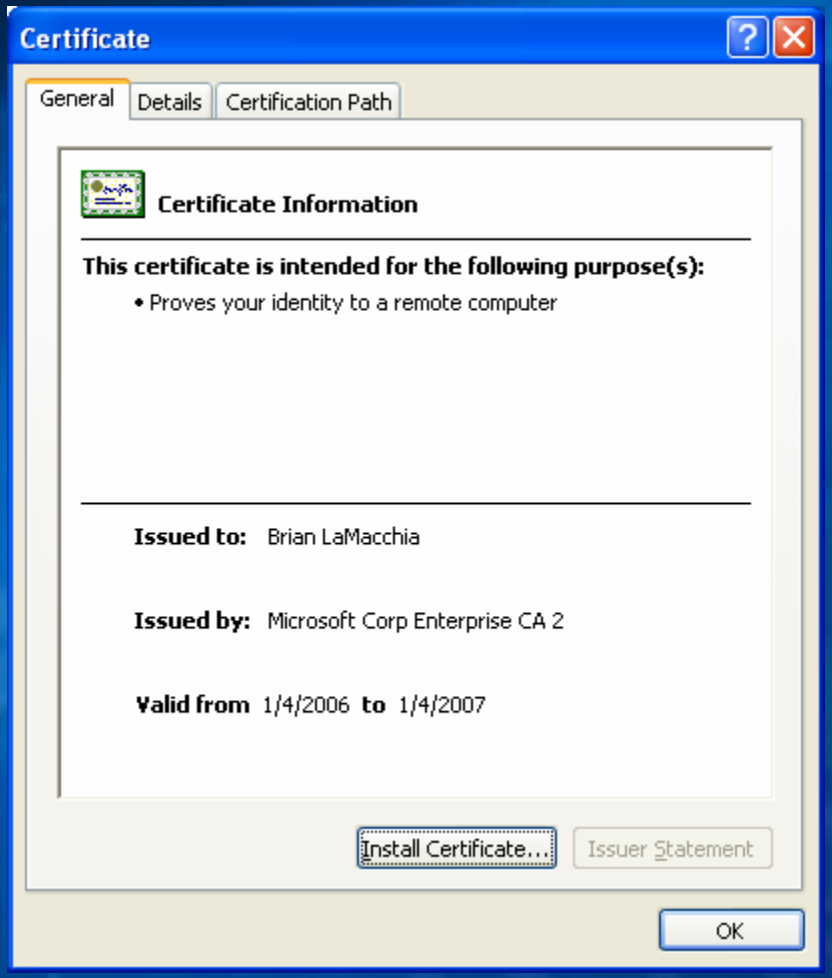
- Who do I trust to be roots at the top of the cert chain?
- In theory, "anyone you want"
- In practice, trusted roots come from two sources
  - They're baked into your web browser or operating system
  - They're pushed onto your "enterprise managed desktop"

Trusted Root Certificates

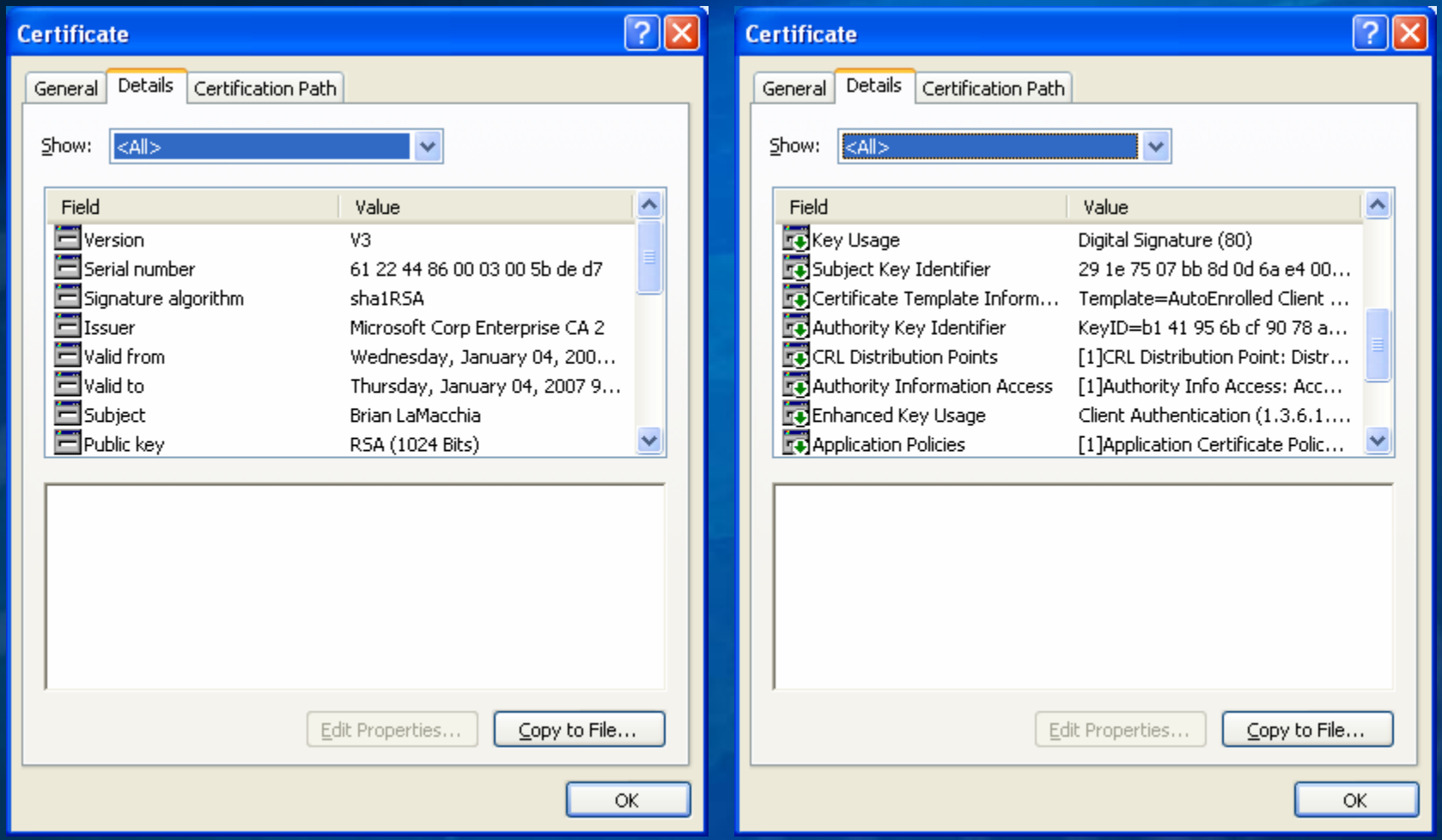


Certificate Extensions

Exploring inside an X.509 Cert



Exploring inside an X.509 Cert



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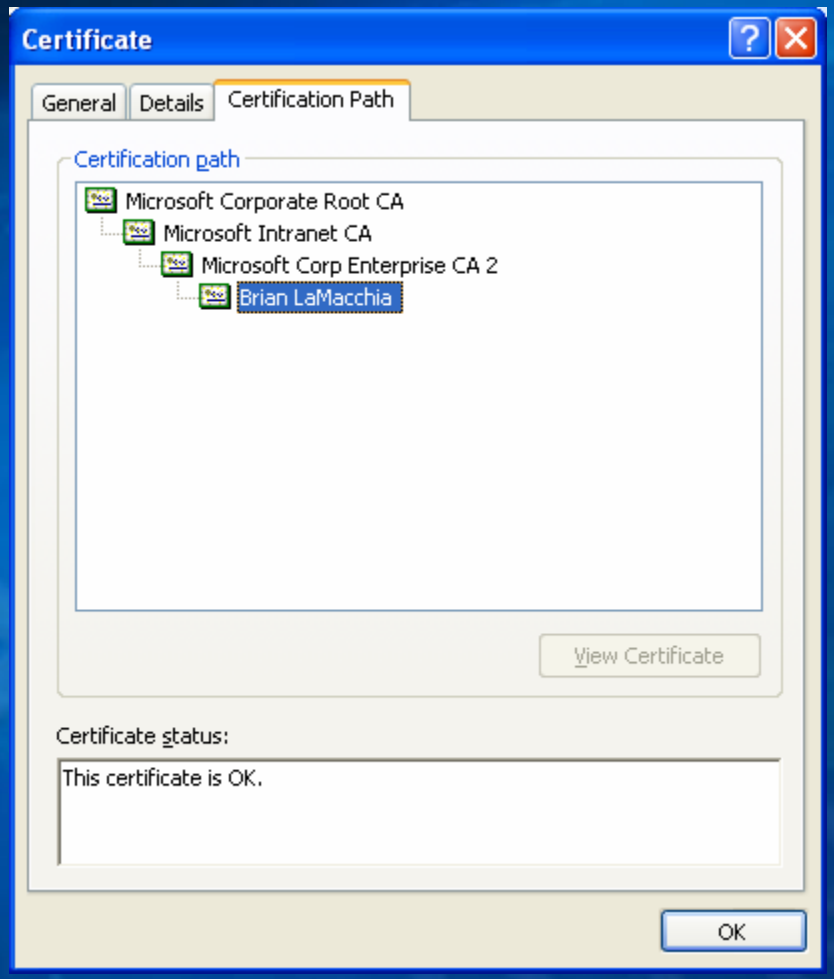
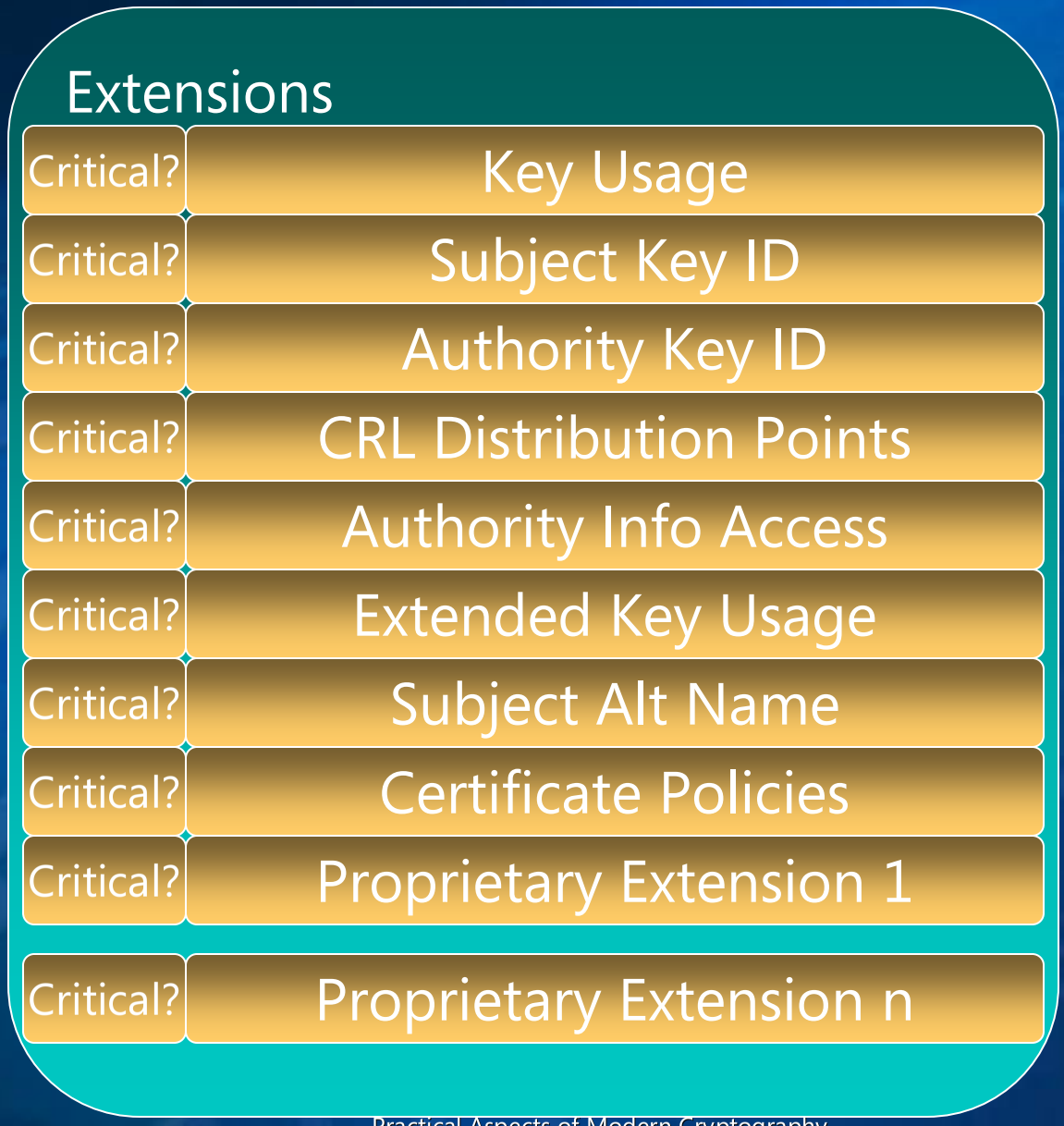


Inside an X.509v3 Certificate

Certificate Extensions

- An extension consists of three things:
  - A "critical" flag (boolean)
  - A type identifier
  - A value
    - Format of the value depends on the type identifier

Certificate Extensions



Critical Flags

- The "critical flag" on an extension is used to protect the issuing CA from assumptions made by software that doesn't understand (implement support for) a particular extension
  - If the flag is set, relying parties must process the extension if they recognize it, or reject the certificate
  - If the flag is not set, the extension may be ignored

Critical Flags (2)

- Some questions you might be asking yourself right now…
- What does "must process the extension if they recognize it" mean?
  - What does "recognize" mean?
  - What does "process" mean?
  - You've got me….
  - The IETF standards folks didn't know either…

Critical Flags (3)

- Actual definitions of flag usage are vague:
  - X.509: Non-critical extension "is an advisory field and does not imply that usage of the key is restricted to the purpose indicated"
  - PKIX: "CA's are required to support constrain extensions" but "support" is never defined.
  - S/MIME: Implementations should "correctly handle" certain extensions
  - Verisign: "All persons shall process the extension…or else ignore the extension"

Types of Extensions

- There are two flavors of extensions
  - Usage/informational extensions, which provide additional info about the subject of the certificate
  - Constraint extensions, which place restrictions on one or more of:
    - Use of the certificate
    - The user of the certificate
    - The keys associated with the certificate

Some common extensions

- Key Usage
  - digitalSignature
    - "Sign things that don't look like certs"
  - keyEncipherment
    - Exchange encrypted session keys
  - keyAgreement
    - Diffie-Hellman
  - keyCertSign/keyCRLSign
    - "Sign things that look like certs"
  - nonRepidiation

NonRepudiation

- The nonRepudiation bit is the black hole of PKIX
  - It absorbs infinite amounts of argument time on the mailing list without making any progress toward understanding what it means
  - What does it mean? How do you enforce that?
  - No one knows…
- "Nonrepudiation is anything which fails to go away when you stop believing in it"

More Extensions

- Subject Key ID
  - Short identifier for the subject public key
- Authority Key ID
  - Short identifier for the issuer's public key – useful for locating possible parent certs
- CRL Distribution Points
  - List of URLs pointing to revocation information servers
- Authority Info Access
  - Pointer to issuer cert publication location

Even More Extensions

- Basic constraints
  - Is the cert a CA cert?'
  - Limits on path length beneath this cert
- Name constraints
  - Limits on types of certs this key can issue
- Policy mappings
  - Convert one policy ID into another
- Policy constraints
  - Anti-matter for policy mappings

Still More Extensions

- Extended Key Usage
  - Because Key Usage wasn't confusing enough!
- Private Key Usage Period
  - CA attempt to limit key validity period
- Subject Alternative names
  - Everything which doesn't fit in a DN
  - RFC822 names, DNS names, URIs
  - IP addresses, X.400 names, EDI, etc.

Yet Still More Extensions

- Certificate policies
  - Information identifying the CA policy that was in effect when the cert was issued
  - Policy identifier
  - Policy qualifier
  - Explicit text
  - Hash reference (hash + URI) to a document
- X.509 defers cert semantics to the CA's issuing policy
- Most CA policies disclaim liability

Extensions and Chain Building

- When you build a cert chain, you start with the EE cert and discover possible parent certificates by matching DNs
  - "Build the chain from the bottom up."
- However, to verify a cert chain, you have to start and the root and interpret all the extensions that may constrain subordinate CAs (and EEs)
  - "Build the chain from the top down."

Certificate Lifecycle Management

Lifecycle Management

- Certificate Enrollment
  - Initial acquisition of a certificate based on other authentication information
- Renewal
  - Acquiring a new certificate for a key when the existing certificate expires
- Revocation
  - "Undoing" a certificate

Certificate Enrollment

- ***Enrollment*** **is the process of obtaining a certificate from a CA.**

1. **Alice generates a key pair, creates a message containing a copy of the public key and her identifying information, and signs the message with the private key (PKCS#10).**
   - **Signing the message provided "proof-of-possession" (POP) of the private key as well as message integrity**
2. **CA verifies Alice's signature on the message**

Certificate Enrollment (2)

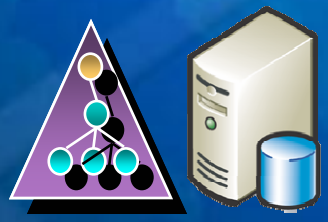
3. (Optional) CA verifies Alice's ID through out-of-band means.
4. CA creates a certificate containing the ID and public key, and signs it with the CA's own key
   - CA has certified the binding between key and ID
5. Alice verifies the key, ID & CA signature
6. Alice and/or the CA publish the certificate

Certificate Enrollment Flow

Client

Certificate Request
and Installation

CA



Directory

Publish Certificate?

More PKI Alphabet Soup

- PKCS #10 – (old) standard message format for certificate requests
- PKCS #7 – (old) standard message format for encrypted/signed data
  - Also used for certificate request responses
  - Replaced by IETF CMS syntax
- CMC – "Certificate Management with CMS"
  - Replacement for PKCS #10/PKCS#7 in a certificate management context
- CMP – "Certificate Management Protocols"
  - Alternative to CMC

Revocation

Expiration & Revocation

- Certificates (at least, all the ones we're concerned with) contain explicit validity periods – "valid from" & "expires on"
  - Expiration dates help bound the risk associated with issuing a certificate
- Sometimes, though, it becomes necessary to "undo" a certificate while it is still valid
  - Key compromise
  - Cert was issued under false pretenses
- This is called revoking a certificate

Status Info for Certificates

- Two standards within PKIX:
  - X.509v2/PKIX Part 1 Certificate Revocation Lists (CRLs)
  - Online Certificate Status Protocol (OCSP)
- Both methods state:
  - Whether a cert has been revoked
  - A "revocation code" indicating why the cert was revoked
  - The time at which the cert was revoked

Certificate Revocation

- A CA revokes a certificate by placing the cert on its Certificate Revocation List (CRL)
  - Every CA issues CRLs to cancel out issued certs
  - A CRL is like anti-matter – when it comes into contact with a certificate it lists it cancels out the certificate
  - Think "1970s-style credit-card blacklist"
- Relying parties are expected to check CRLs before they rely on a certificate
  - "The cert is valid unless you hear something telling you otherwise"

The Problem with CRLs

- Blacklists have numerous problems
  - Not issued frequently enough to be effective against a serious attack
  - Expensive to distribute (size & bandwidth)
  - Vulnerable to simple DOS attacks
    - If you block on lack of CRL access, why have off-line support in the first place?

The Problem with CRLs (2)

- CRL design made it worse
  - CLRs can contain retroactive invalidity dates
  - A CRL issued today can say a cert was invalid as of *last week*.
    - Checking that something was valid at time *t* wasn't sufficient!
    - Back-dated CRLs can appear at any time in the future
  - If you rely on certs & CRLs you're screwed because the CA can change the rules out from under you later.

The Problem with CRLs (3)

- Revoking a CA cert is more problematic than revoking an end-entity cert
  - When you revoke a CA cert, you potentially take out the entire subordinate structure, depending on what chaining logic you use
- How do you revoke a self-signed cert?
  - "The cert revokes itself."
    - Huh?
  - Do I accept the CRL as valid & bounce the cert?
  - Do I reject the CRL because the cert associated with the CRL signing key was revoked?

The Problem with CRLs (4)

- You can't revoke a CRL
  - Once you commit to a CRL, it's a valid state for the entirety of its validity period
- What happens if you have to update the CRL while the CRL you just issued is still valid?
  - You can update it, but clients aren't required to fetch it since the one they have is still valid!
- Bottom line: yikes!
  - We need something else

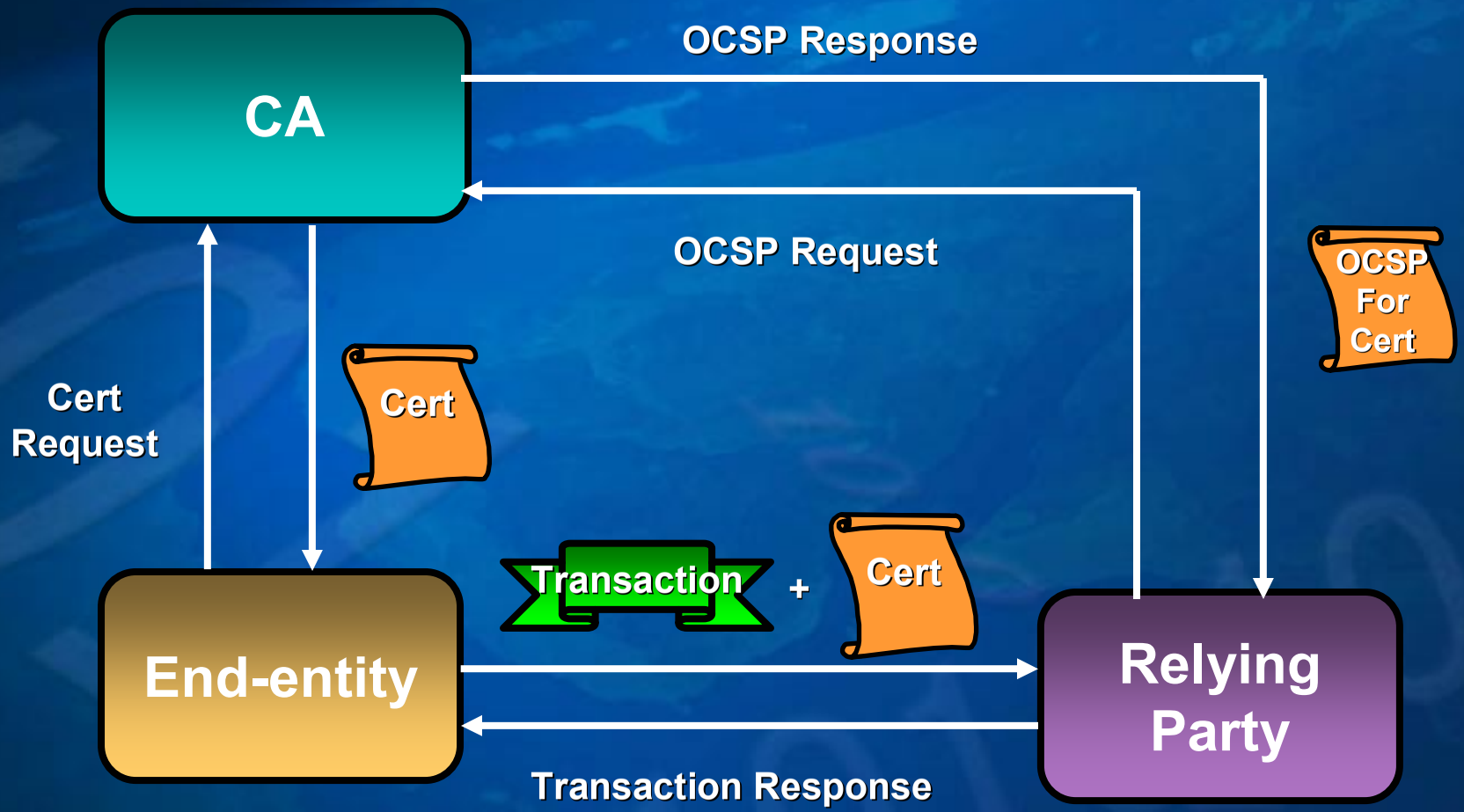
CRLs vs. OCSP Responses

- Aggregation vs. Freshness
  - CRLs combine revocation information for many certs into one long-lived object
  - OCSP Responses designed for real-time responses to queries about the status of a single certificate
- Both CRLs & OCSP Responses are generated by the issuing CA or its designate. (Generally this is *not* the relying party.)

Online Status Checking

- OCSP: Online Certificate Status Protocol
  - A way to ask "is this certificate good right now?
  - Get back a signed response from the OCSP server saying, "Yes, cert C is good at time t"
    - Response is like a "freshness certificate"
- OCSP response is like a selective CRL
  - Client indicates the certs for which he wants status information
  - OCSP responder dynamically creates a lightweight CRL-like response for those certs

OCSP in Action



Final thoughts on Revocation

- From a financial standpoint, it's the revocation data that is valuable, not the issued certificate itself
  - For high-valued financial transactions, seller wants to know your cert is good right now
  - Same situation as with credit cards, where the merchant wants the card authorized right now at the point-of-sale
- Card authorizations transfer risk from merchant to bank – thus they're worth $$$
  - Same with cert status checks

Using Certificates

- Most certificate uses do not require any sort of directory
  - Only needed to locate someone else's certificate for encryption
- Authentication protocols have the client present their certificate (or chain) to the server
  - Ex: SSL, TLS, Smart card logon
  - Rules for mapping a certificate to user account vary widely
    - Cert fields, name forms, binary compare
- Signing operations embed the certificates with the signature
  - How else would you know who signed it?

Using Certificates (2)

- X.509 and PKIX define the basic structure of certificates
  - If you understand X.509, you can parse any certificate you're presented
- However, every protocol defines a certificate profile for certificate use in that particular protocol
  - Ex: TLS, S/MIME, IPSEC, WPA/WPA2
- CAs/organizations define profiles too
  - Ex: US DoD Common Access Card certs

Additional Implementation Considerations

- Publishing certificates
  - How? Where? What format?
- Key escrow / data recovery for encryption keys/certs
- Auto-enrollment (users & machines)
- Establishing trusts / hierarchies
- Protecting private keys
- Disseminating root certificates