Network Security: Public Key Infrastructure

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Slides adapted from Radia Perlman's slides

Key Distribution - Secret Keys

- What if there are millions of users and thousands of servers?
- Could configure n^2 keys
- Better is to use a Key Distribution Center
  - Everyone has one key
  - The KDC knows them all
  - The KDC assigns a key to any pair who need to talk

Key Distribution - Secret Keys

Alice KDC Bob

A wants to talk to B

Randomly choose K_{ab}

$\{\text{"B"}, K_{ab}\}_{Ka}$ $\{\text{"A"}, K_{ab}\}_{Kb}$

$\{\text{Message}\}_{Kab}$

A Common Variant

Alice KDC Bob

A wants to talk to B

Randomly choose K_{ab}

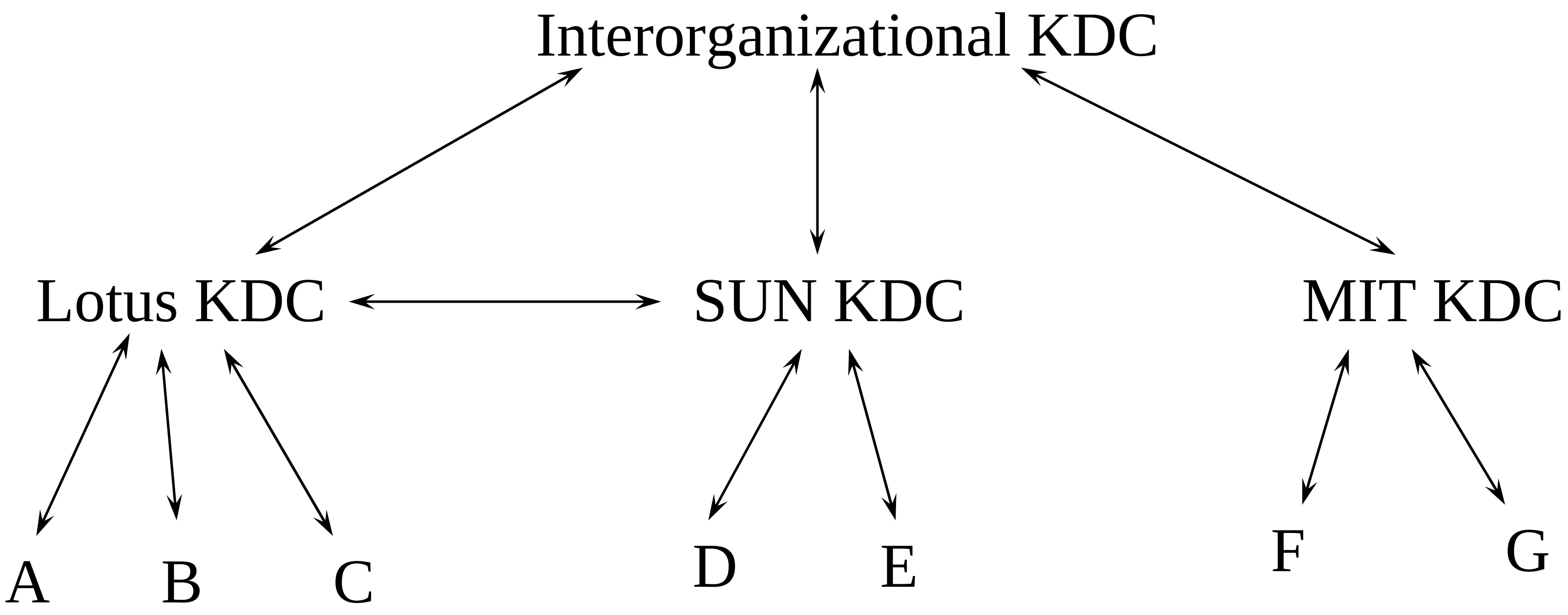
$\{“B”, K_{ab}\}_{Ka}, \{“A”, K_{ab}\}_{Kb}$

$\{“A”, K_{ab}\}_{Kb}, \{Message\}_{Kab}$

KDC Realms

- KDCs scale up to hundreds of clients, but not millions
- There's no one who everyone in the world is willing to trust with their secrets
- KDCs can be arranged in a hierarchy so that trust is more local

KDC Realms



KDC Hierarchies

- In hierarchy, what can each compromised KDC do?
- What would happen if root was compromised?
- If it's not a name-based hierarchy, how do you find a path?

Key Distribution - Public Keys

- Certification Authority (CA) signs “Certificates”
- Certificate = a signed message saying “I, the CA, vouch that 489024729 is Radia’s public key”
- If everyone has a certificate, a private key, and the CA’s public key, they can authenticate

KDC vs CA Tradeoffs

- Impact of theft of KDC database vs CA private key
- What needs to be done if CA compromised vs. if KDC compromised?
- What if KDC vs CA down temporarily?
- What’s more likely to work behind firewalls?

Strategies for CA Hierarchies

- One universally trusted organization
- Top-Down, starting from a universally trusted organization's well-known key
- No rules (PGP, SDSI, SPKI).
  - Anyone signs anything. End users decide who to trust
- Many independent CA's.
  - Configure which ones to trust

One CA

- Choose one universally trusted organization
- Embed their public key in everything
- Give them universal monopoly to issue certificates
- Make everyone get certificates from them
- Simple to understand and implement

One CA: What's wrong with this model?

- Monopoly pricing
- Getting certificate from remote organization will be insecure or expensive (or both)
- That key can never be changed
- Security of the world depends on honesty and competence of the one organization, forever

One CA Plus RAs

- RA (registration authority), is someone trusted by the CA, but unknown to the rest of the world (verifiers).
- You can request a certificate from the RA
- It asks the CA to issue you a certificate
- The CA will issue a certificate if an RA it trusts requests it
- Advantage: RA can be conveniently located

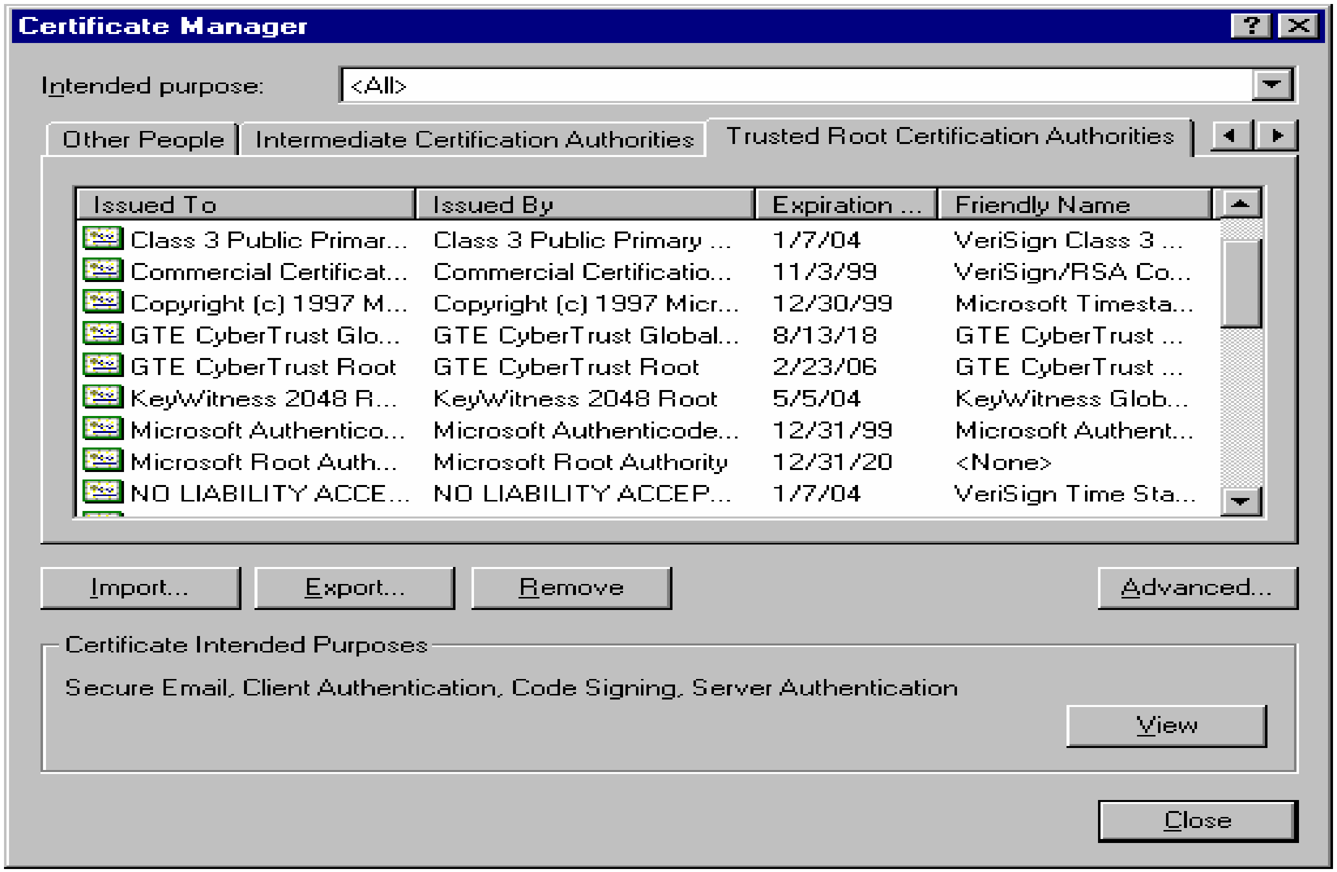
What’s wrong with one CA plus RAs?

- Still monopoly pricing
- Still can’t ever change CA key
- Still world’s security depends on that one CA key never being compromised (or dishonest employee at that organization granting bogus certificates)

Oligarchy of CAs

- Come configured with 50 or so trusted CA public keys
- Usually, can add or delete from that set
- Eliminates monopoly pricing

Default Trusted Roots in IE



What's wrong with oligarchy?

- Less secure!
  - security depends on ALL configured keys
  - Naïve users can be tricked into using platform with bogus keys, or adding bogus ones (easier to do this than install malicious software)

- Although not monopoly, still favor certain organizations

CA Chains

- Allow configured CAs to issue certs for other public keys to be trusted CAs
- Similar to CAs plus RAs, but
  - Less efficient than RAs for verifier (multiple certs to verify)
  - Less delay than RA for getting usable cert

Anarchy

- Anyone signs certificate for anyone else
- Like configured+delegated, but users consciously configure starting keys
- Problems
  - Does not scale (too many certs, computationally too difficult to find path)
  - No practical way to tell if a path should be trusted
  - Too much work and too many decisions for user

Name Constraints

- Trustworthiness of a CA is not binary
  - Complete trust or no trust
- CA should be trusted for certifying a subset of the users
- Example:
  - Northeastern University CCS should (only) be trusted to certify users with name x@y.ccs.neu.edu
- If users have multiple names, each name should be trusted by the “name authority”

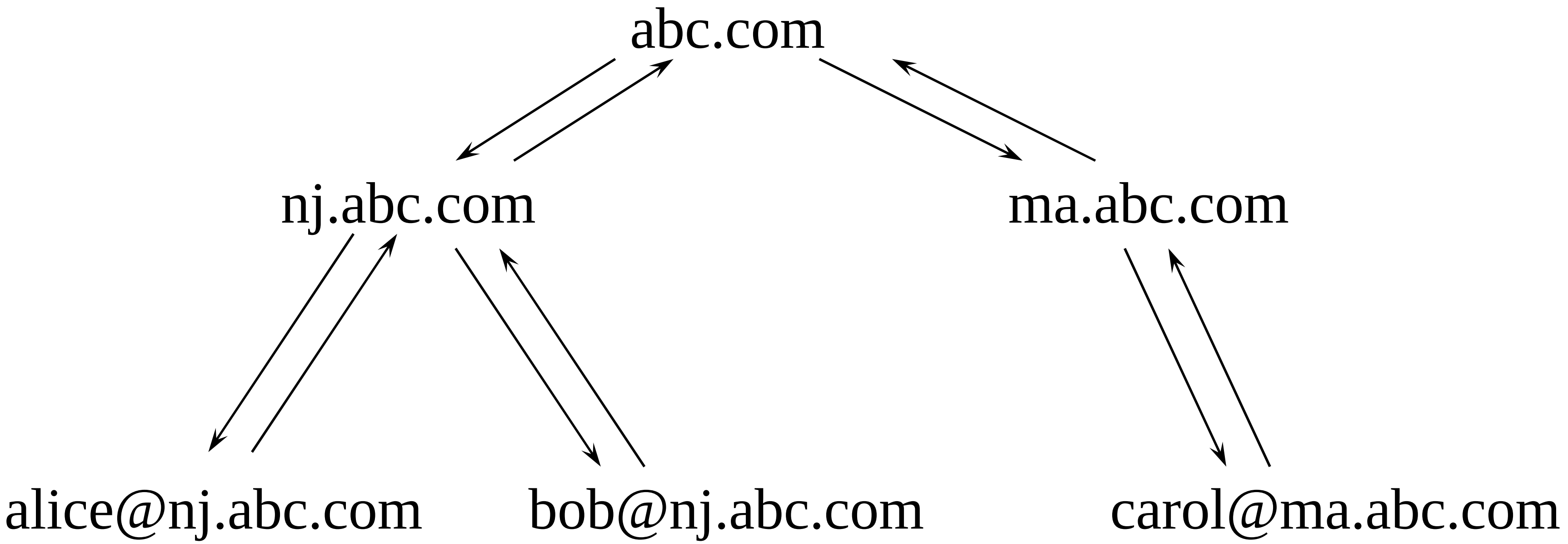
Top Down with Name Subordination

- Assumes hierarchical names
- Similar to monopoly: everyone configured with root key
- Each CA only trusted for the part of the namespace rooted at its name
- Can apply to delegated CAs or RAs
- Easier to find appropriate chain
- More secure in practice
  - This is a sensible policy that users don't have to think about)

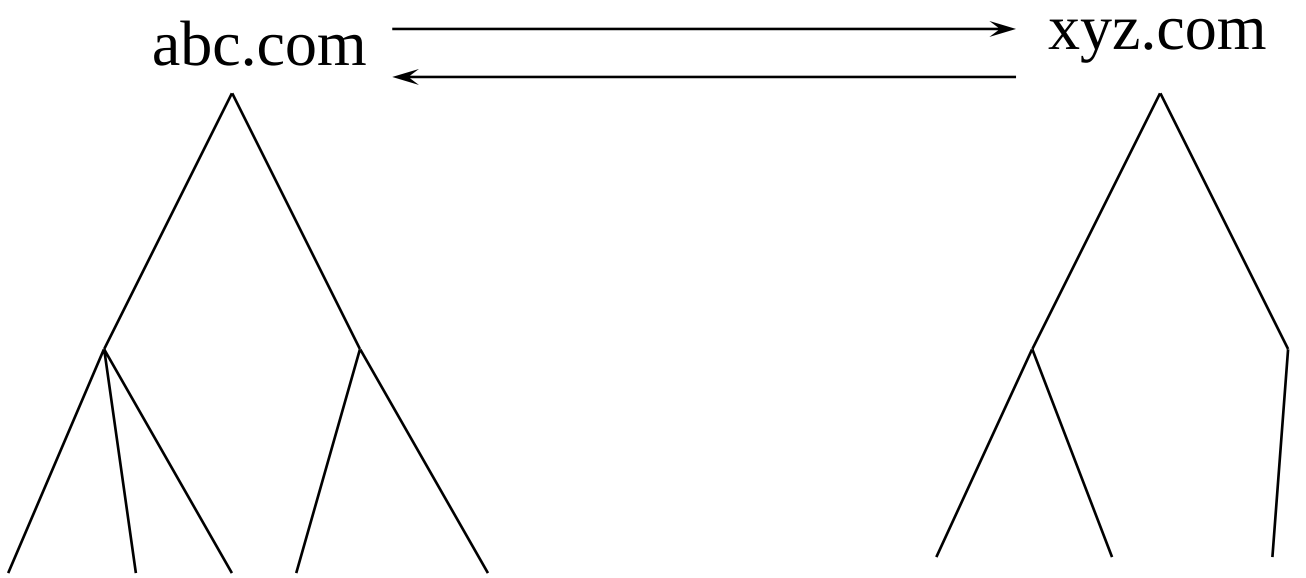
Bottom-Up Model

- Each arc in name tree has parent certificate (up) and child certificate (down)
- Name space has CA for each node in the tree
  - E.g., a certificate for .edu, neu.edu, and ccs.neu.edu
- “Name Subordination” means CA trusted only for a portion of the namespace
- Cross Links to connect Intranets, or to increase security
- Start with your public key, navigate up, cross, and down

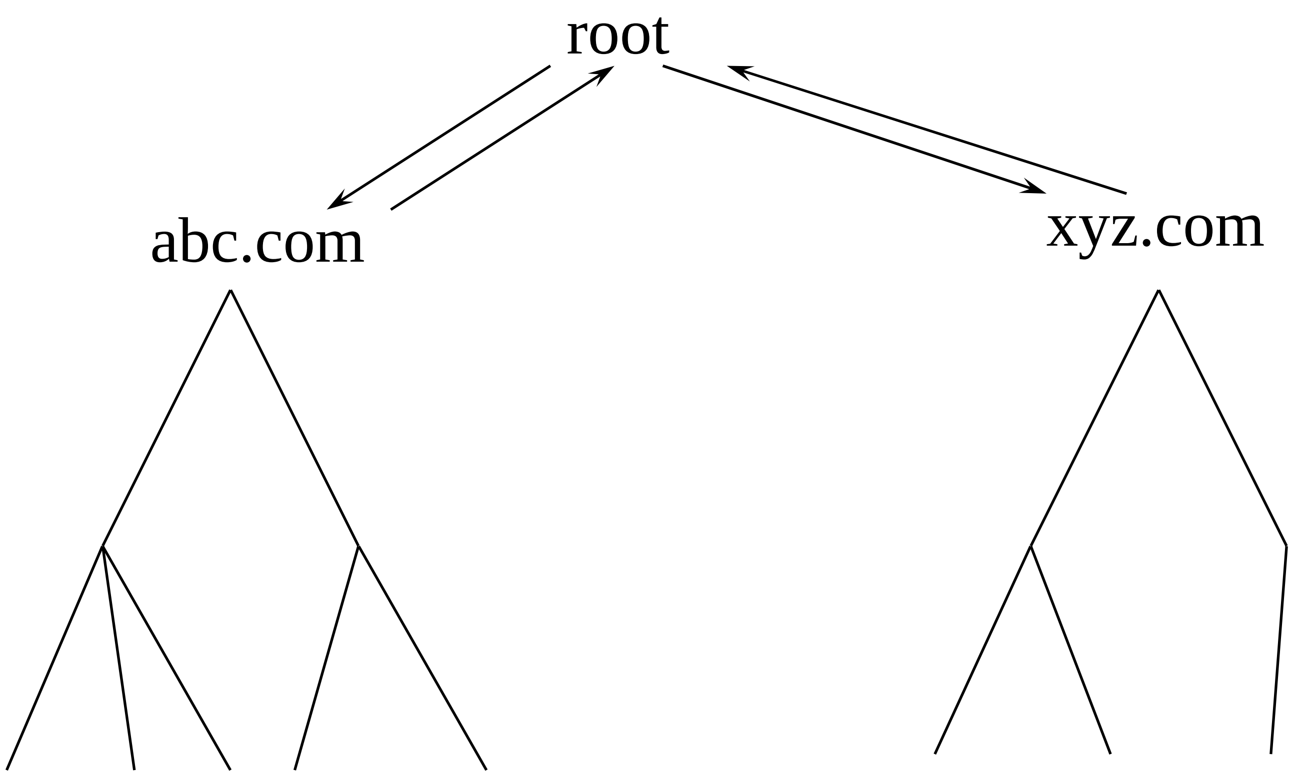
Intranet


abc.com
nj.abc.com
ma.abc.com
alice@nj.abc.com
bob@nj.abc.com
carol@ma.abc.com

Extranets: Crosslinks



Extranets: Adding Roots



Advantages of Bottom-Up

- For intranet, no need for outside organization
- Security within your organization is controlled by your organization
- No single compromised key requires massive reconfiguration
- Easy configuration:
  - you start with is your own public key

Bridge CA Model

- Similar to bottom-up, in that each organization controls its destiny, but top-down within organization
- Trust anchor is the root CA for your org
- Your org's root points to the bridge CA, which points to other orgs' roots

Chain Building

- Call building from target “forward”, and from trust anchor “reverse”
  - With the reverse approach it can be easier to find a path from the anchor to *A* by looking at the path
  - With the forward approach “going up” we don’t know if a link/path starting at *A* leads to a trust anchor known by *B*

- Where should cert be stored?
  - With subject: harder to build chains from trust anchors
  - With issuer: it may become impractical if large fanout at root

X.509

- An authentication framework defined by ITU
- A clumsy syntax for certificates
  - No rules specified for hierarchies
  - X.509 v1 and v2 allowed only X.500 names and public keys in a certificate
  - X.509 v3 allows arbitrary extensions
- A dominant standard
  - Because it is flexible, everyone willing to use it
  - Because it is flexible, all hard questions remain
- C: country, CN: common name, O: organization, etc.

X.509 Certificate Contents

- version # (1, 2, or 3)
- Serial Number
- Effective Date
- Expiration Date
- Issuer Name
- Issuer UID (not in V1)
  - Unique ID
- Subject Name
- Subject UID (not in V1)
- Subject Public Key Algorithm
- Subject Public Key
- Signature Algorithm
- Signature
- Extensions (V3 only)

Some X.509 V3 Extensions

- Public Key Usage
  - Encryption
  - Signing
  - Key Exchange
  - Non-repudiation
- Subject Alternate Names
- Issuer Alternate Names
- Key Identifiers
- Where to find CRL information
- Certificate Policies
- “Is a CA” flag
  - path length constraints
  - name constraints
- Extended key usage
  - specific applications

Policies

- A policy is an OID:
  - Code Signing (1.3.6.1.5.5.7.3.3),
  - Windows Hardware Driver Verification (1.3.6.1.4.1.311.10.3.5)
- Verifier specifies required OIDs

Policies (as envisioned by X.509/PKIX)

- Policy is an OID (Object Identifier) e.g., *top-secret, or secret*
- Verifier says what policy OID(s) it wants
- Every link must have same policy in chain, so if verifier wants A *or* B *or* C, and chain has A, AC, ABC, B: not OK
- Policy mapping: A=X; “want A” AB, A, A=X, X, X…
- “Policy constraints” things like:
  - policies must appear, but it doesn’t matter what they are
  - “any policy” policy not allowed
  - any of these, but specified as taking effect n hops down chain

Other Certificate Standards

- PKIX: http://www.ietf.org/html.charters/pkix-charter.html
  - An IETF effort to standardize extensions to X.509 certificates
  - PKIX is a profile of X.509
  - Still avoids hard decisions, anything possible with PKIX
- SPKI: http://www.ietf.org/html.charters/spki-charter.html
  - Simple Public Key Infrastructure
  - A competing IETF effort rejecting X.509 syntax
- SDSI: http://theory.lcs.mit.edu/~cis/sdsi.html
  - Simple Distributed Security Infrastructure
  - A proposal within SPKI for certificates with relative names only

Revocation Problem

- Suppose a bad guy learns your password or steals your smart card...
- Notify your KDC and it will stop issuing "tickets"
- Notify your CA and it will give you a new certificate
- How do you revoke your old certificate?

Revocation Problem

- Tickets can have short lifetimes; they can even be “one-use” with nonces

- Certificates have expiration dates, but it is inconvenient to renew them frequently
  - If sufficiently frequent and automated, CA can no longer be off-line

- Supplement certificate expirations with Certificate Revocation Lists (CRLs) or a blacklist server (On-Line Revocation Server: OLRS)

Why not put CA on-line?

- On-line revocation server is less security sensitive than an on-line CA
- The worst it can do is fail to report a revoked certificate
- Damage is more contained
- Requires a double failure
- With CRLs, limits OLRS damage

Revocation Ideas

- Incremental (delta) CRLs
- Micali's hashing scheme
- Kaufman-Perlman "first valid cert"
- Good lists vs bad lists

Micali's Hashing

- Components:
  - CA: generates/revokes certificates
  - Directory:
    - Gets daily updates from the CA and gets requests from users
    - It is not trusted
  - Users
- Technique for efficient revocation:
  - CA generates:
    - Certificate = signature of traditional info (e.g., public key, issue date, etc.) and Y_n and N_n: 100 bits messages unique to the certificate. n is the certificate lifetime
    - Computes: $Y_n = \text{Hash}^n(Y_0)$ and $N_n = \text{Hash}^N(N_0)$, where Y_0, and N_0 are secret values
  - Every day i the CA sends the directory:
    - Y_{n-i} or N_{n-i} depending on if the certificate is revoked or not

Authorization

- Access Control Lists (ACL) capabilities:
  - Makes a difference whether you can answer “who has access to that” or “what can he do”
- Groups, nesting, roles
- On-line group servers
- Anonymous groups

Suppose want to move subtrees?

- How would you design certificates if you want to be able to move an entire subtree, for example, *com.sun.east.labs.radia* becomes *com.sun.labs.radia*.

- What would up, down, and cross certs look like? How design cross link if want things not to change if both points move together?