Anonymous Authentication

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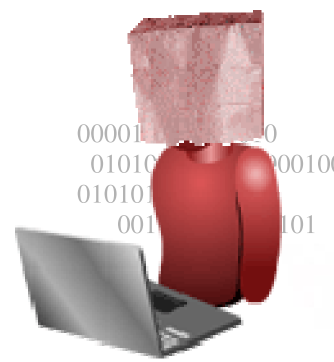

Chat Rooms

- **A huge success for youth and a huge concern for parents**
- **2006 survey (of 1500 US youth) by the Crimes against Children research centre**
  - 13% of youth received unwanted sexual solicitations (down from 19% in 2001)
  - 4% of youth received aggressive solicitations in which solicitors attempted to make offline contact (up from 3% in 2001)

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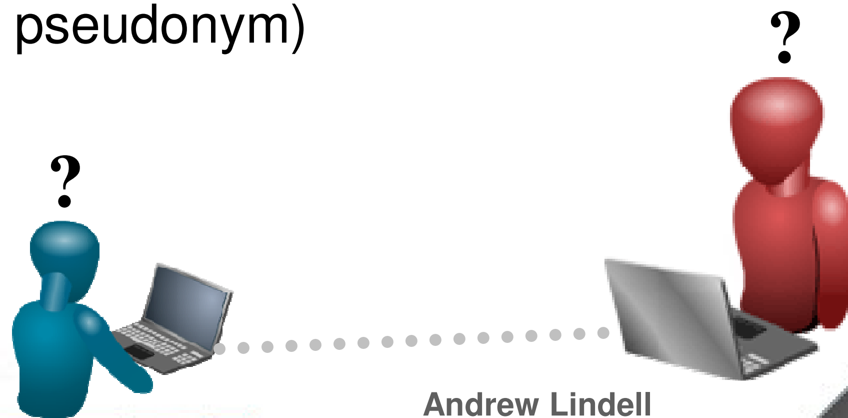
Chat Anonymity

- **Why are online sexual solicitations a concern? Aren't chats anonymous?**
  - **Problem 1:** 34% of children interviewed posted personal information online where anyone could see it
  - **Problem 2:** even when personal information is not explicitly posted, it can be found through multiple sources (e.g., linked by the user's pseudonym)



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Solutions

- **Education**
- **Parental control**
- **Law enforcement**
- **Technology**
  - Set up "safe chat rooms" which deploy strong authentication methods
  - Allow children to access safe chat rooms only
  - This has its own problems…

Authenticated Chat Rooms

- **One of the most attractive aspects of chat rooms is their anonymity**
  - Children can be freed from the bonds of peer pressure and can speak freely
  - Children can ask advice about embarrassing situations, (seemingly) without fear of being traced
- **The use of authentication destroys this aspect of chat rooms**

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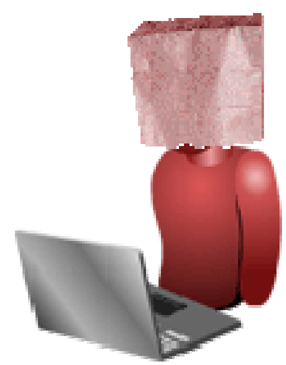
Anonymous Authentication

- **Anonymous authentication – a contradiction in terms**
  - The user authenticates to the server and proves that she is an authorized user
  - The server has no idea which authorized user is authenticating
- **Is this really possible?**
  - **Yes**!



Other Applications

- **Professional forums**
  - Technical papers, technical help, discussion forums
  - These are “great” sources of information for (legal) industrial espionage
  - If authentication is required (to allow only registered or paying users), the problem becomes far more acute
- **Whistle blowing**
  - We want to be sure that the report is really from an employee, but we want to protect them…
- **Social networks**

Another Issue – Revocable Anonymity

- **Assume anonymous authentication is used**
- **Consider the case that one of the users is harassing others (or a pedophile stole someone's authentication device and is using it)**
  - The harasser's account cannot be closed because we don't know who the harasser is
- **Revocable anonymity: when needed, and upon court order, can reveal identity**
  - Without court order cannot reveal ID (provably)

Talk Outline

- **Privacy**
  - It is important – we all know that
  - But, ***why*** is it important?
- **Anonymous web surfing**
  - A very brief mention
- **Anonymous authentication**
  - Definitions
  - Protocols
  - Extensions

Privacy

A Concrete Perspective

Privacy

- **Everyone here agrees that privacy is important, but why?**
  - **Typically**
    - The loss of privacy is an invasion into our personal space
    - Warren and Brandeis: privacy is “the right to be let alone”
- **But what concrete damage is incurred?**

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Privacy – A Concrete Perspective

- **We will consider concrete damage that may be incurred due to privacy loss**
  - Understand these concrete damages are crucial for providing secure protocols that actually solve the problem at hand

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Privacy and Self Censorship

- **Storing user online information (emails, web and chat history and more), will likely result in self-censorship and inhibition**
  – Highly likely if linked to real identity (and otherwise possible due to fear of later linkage)
- **Think of the following uses of the Internet**
  – Teenagers on chat sites
  – University forums where students comment on lecturers and courses
  – Web sites that provide information on sensitive medical issues, sexual health and practice, and psychological first aid

Privacy – A Naïve Perspective

- **The above is usually only considered a problem if the user's online identity is linked to her real-world identity**
- **Business Week/Harris Poll in 2000**
  - 35% "not at all comfortable" with profiling online actions without linking to real identity
  - 81% "not at all comfortable" when this profiling **is** linked to real identity
  - (My guess: 35% also concerned that link may happen)
- **No identifier means no invasion of space**

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Information Without Identification

- **If it is 100% guaranteed that a user's profile can never be connected to their identity, then self censorship is unlikely to occur**
- **Example – online newspaper**
  - Newspaper records history of all articles read and all comments posted
  - Information used to construct a newspaper tailored to your interests
  - If identity never provided, this seems fine

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Basic Pseudonyms

- **Based on this, a basic pseudonym that cannot be linked to the user's real-world identity solves the problem!**
- **This is false!**
  - And not only because it is **impossible** to guarantee that a link will never be made

Privacy Loss Without Identification

- **Consider the newspaper example**
  – A user's profile reveals much about their political beliefs, financial status and so on
  – A newspaper with strong interests can tailor the content to influence the user
  – Since the newspaper has a lot of information about the user, and the user is not aware of this (or that it is getting tailored content), the user can be unfairly manipulated
- **This infringes on the user's personal autonomy**

Pseudonyms?

- **A pseudonym that cannot be linked to a user's true identity does not solve the problem at all**
  - In order to manipulate the user, the newspaper only needs to be able to link their history to their current actions

Industrial Espionage

- If a user's real identity is not known, then the information gathered from a professional forum cannot be used to identify what company the user works for
- However, it can be enough to just know that some competitor is researching and developing some product

Price Discrimination

- **Consider an online mall that tracks a buyer's prior purchases and shopping habits**
- **If a seller knows that a buyer does not "shop around", then they may charge higher prices**
  - The seller has more information about what the buyer is willing to pay than what the buyer has about the price for which the seller is willing to sell
  - The buyer is not aware of this asymmetry

Conclusions

- **Privacy is much more than being "let alone"**
- **Naïve solutions that rely on pseudonyms do not suffice**
- **We need *unlinkability* between transactions**
  - This is not easy even when no registration or payment, and so no authentication, is required
  - This is very difficult if **authentication is required** (registering from scratch or paying again each time is unrealistic)

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Anonymous Web Surfing

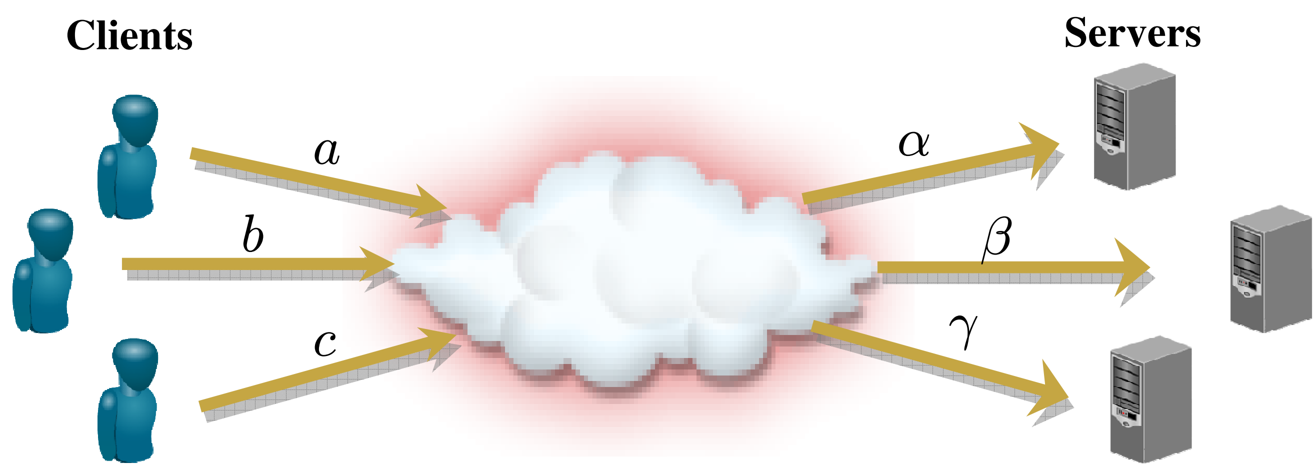
A Brief Survey

Anonymous Routing

- **Necessary infrastructure for anonymous authentication**
- **Two security goals**
  - **User anonymity:** modify packets so that user requests contain no identifying information
  - **Unlinkability:** ensure that an attacker who views Internet traffic (and possibly controls some routers) cannot know which client is interacting with which server
- **Achieving the goals**
  - **User anonymity:** not too difficult
  - **Unlinkability:** very difficult, depends on traffic

An Abstraction

- We assume that we have a magical mechanism that receives messages from all clients and sends them to their designated servers (without revealing the contents to an eavesdropper)



How is Anonymous Routing Achieved

- **There are numerous methods**
  - Mix-Nets
  - Onion routing
  - Dining cryptographers
  - Crowds
- **See the paper for references**

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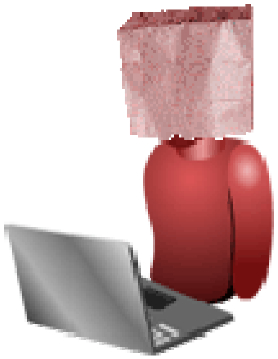
Anonymous Authentication

What it is, and how it can be achieved



The High-Level Idea

- **It is impossible to authenticate a user without knowing something**
- **Anonymous authentication protocols have the following properties**
  - The authenticating server **knows** that the user belongs to a given set of (authorized) users
  - The authenticating server has **no idea** which member of the set has just authenticated
- **Of course, such a protocol must run on top of an anonymous routing mechanism**

Defining Security

- **Secure authentication**
  - No unauthorized user should be able to fool the server into granting it access (except with very small probability)
  - We mainly consider a public-key infrastructure model
- **Full (perfect) anonymity**
  - Let ℓ be the size of the set of users being considered
  - The protocol provides *perfect anonymity* if after authentication, the server can guess which user authenticated with probability at most $\frac{1}{\ell}$

Another Definition

- **It is sometimes useful to consider a more relaxed definition (that suffices for most applications)**
- **Verifiable (perfect) anonymity**
  - The user may receive a special **`cheat`** message as output
  - The guarantee is that **if** the user does not receive **`cheat`**, **then** the server can guess which user authenticated with probability at most $\frac{1}{\ell}$
- **This suffices in many cases, because the user has not yet done anything**

Solving the Mystery

- **How is it possible to achieve anonymity?**
- **A naïve idea**
  – Issue all users with the same password/secret key
  – This achieves perfect anonymity
- **The problem**
  – Cannot revoke a user's account without changing everyone's key!

Another Approach – Background

- **Let $U_1, \ldots, U_n$ be the users and let user U_i have a key-pair (sk_i, pk_i) for some public-key encryption scheme (say, RSA)**
  - The server has the record (U_i, pk_i) for every user (realistically, this can use a PKI and certificates)
  - A user's account can be cancelled by removing its record
  - We assume that each user knows all of the other users' public keys

The Protocol – First Attempt

- **User U_i sends first message**
  - Anonymous request to connect
- **Server first message**
  - The server chooses a long random string w
  - The server computes $c_i = E_{pk_i}(w)$ for every i
  - The server sends $c_1, \ldots, c_\ell$ to the user
- **User second message**
  - Upon receiving $c_1, \ldots, c_\ell$ the user U_i computes $w = D_{sk_i}(c_i)$ and sends w to the server
- **Server provides access if the user reply is w**

The Protocol – First Attempt

Server | User U_i

Request authentication $\longleftarrow$

Choose random w

$\forall j,\ c_j = E_{pk_j}(w)$

$\xrightarrow{c_1, \ldots, c_\ell}$

$w = D_{sk_i}(c_i)$

$\xleftarrow{w}$

Accept w

- **Security…**

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Problem – Cheating Server

- **A cheating server may encrypt a different w_i for every user U_i**
  - The user cannot tell the difference (it can only decrypt c_i)
  - The server can know exactly which user is authenticating by the value w_i that it returns
- **Solution**
  - Have the server “prove” that it encrypted the same value under all public keys

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Proof of Encryption Equality

- **One possibility**
  - The server sends all ciphertexts and proves that they encrypt the same value using a **zero-knowledge proof**
  - Very expensive!
- **Note**
  - The server cannot decrypt the ciphertexts for the user in order to check, because neither the user nor the server know the **private keys**

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Proof of Encryption Equality

- **Background:**
  - All secure encryption is probabilistic
- **RSA PKCS1#1 v1.5 encryption:**
  - First pad as below, then compute x^e **mod** N

RSA PKCS#1 v1.5 padding:

0002	random	00	the message **m**

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A Proof of Encryption Equality

- **The server needs to prove that all ciphertexts encrypt the same w**
- **The server cannot decrypt the ciphertexts, but can show how it encrypted them!**
  - The server sends the random padding that it used to encrypt each ciphertext
  - The user can then **re-encrypt** under each key and check that all ciphertexts encrypt the same value

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A Proof of Encryption Equality

- **In more detail**
  - Denote an encryption of w with public-key pk and random padding r (as in PKCS#1) by $c = E_{pk}(w;r)$
  - Given a public-key pk, a ciphertext c, a plaintext w, and random padding r, check:
    - If $E_{pk}(w;r) = c$ then c is an encryption of w
  - By **unambiguity** of decryption, c is not an encryption of any value $\tilde{w} \neq w$

Proof of Encryption Equality

- **Using the proof of equality**
  - The server cannot send this proof **before** the user replies, because then the user knows w and can get unauthorized access
  - If the server sends the proof **after** the user replies, then by sending a different w_i to every U_i, it already knows the user's identity
- **Verifiable anonymity**
  - The server sends it after, but if it learns the user's identity, the user will know for sure that it **cheated**

The Full Protocol

Server		User U_i
	$\xleftarrow{\text{Request authentication}}$	
Choose random w $\forall j,\ c_j = E_{pk_j}(w; r_j)$	$\xrightarrow{c_1, \ldots, c_\ell}$	
		$w = D_{sk_i}(c_i)$
	$\xleftarrow{w}$	
Accept w	$\xrightarrow{r_1, \ldots, r_\ell}$	
		Verify: $\forall j,\ c_j = E_{pk_j}(w; r_j)$

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Security Analysis

- **Theorem**
  - If the encryption scheme is secure against chosen-plaintext attacks, then the above is a secure authentication protocol that achieves verifiable anonymity
- **Proof**
  - **Secure authentication:** only an owner of one of the secret keys can find w
  - **Anonymity:** if server doesn't cheat, all users return the same value w
- **Formal proof (and definitions) in paper**

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Efficiency

- **Server overhead**
  - Compute one encryption per user (with RSA and small public exponent, not too expensive)
- **Client overhead**
  - Compute one encryption per user
  - Compute one decryption (on smartcard)
- **Important!**
  - Only one decryption on the smartcard
  - Any encryption scheme can be used and so standard smartcards and PKI can be utilized

Scalability

- **What about very large sets of users?**
  - Infeasible to carry out thousands of public-key operations to authenticate a single user
- ***k*-anonymity: user is guaranteed to be hidden amongst *k* other users**
  - We guarantee this, relative to **random** users
  - User chooses a random subset including itself and this is the set that is used

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Implementation Issue

- **The protocol assumes that all users know all of the public keys**
- **How is this accomplished?**
  - If the server posts a set of public-keys (certificates), then how does the user know that they are real?
  - If 90% are fake, then a user choosing a subset of 100 random users, will actually only be hiding amongst about 10 real users
  - Conclusion: if the server is not trusted (even at this level), users must share public keys amongst each other

Achieving Full Anonymity

- **What if full anonymity is desired?**
- **Background – ring signatures** [RST]
  – A way of signing a message so that only someone from the "ring" could have signed, but it's impossible to know who actually did
    - *Unforgeability and anonymity*

  – Rings can be formed by anyone, on their own
  – Initial application: "how to leak a secret"
  – Construction of [RST]: uses regular RSA, requires one decryption and an additional encryption for every user in the ring

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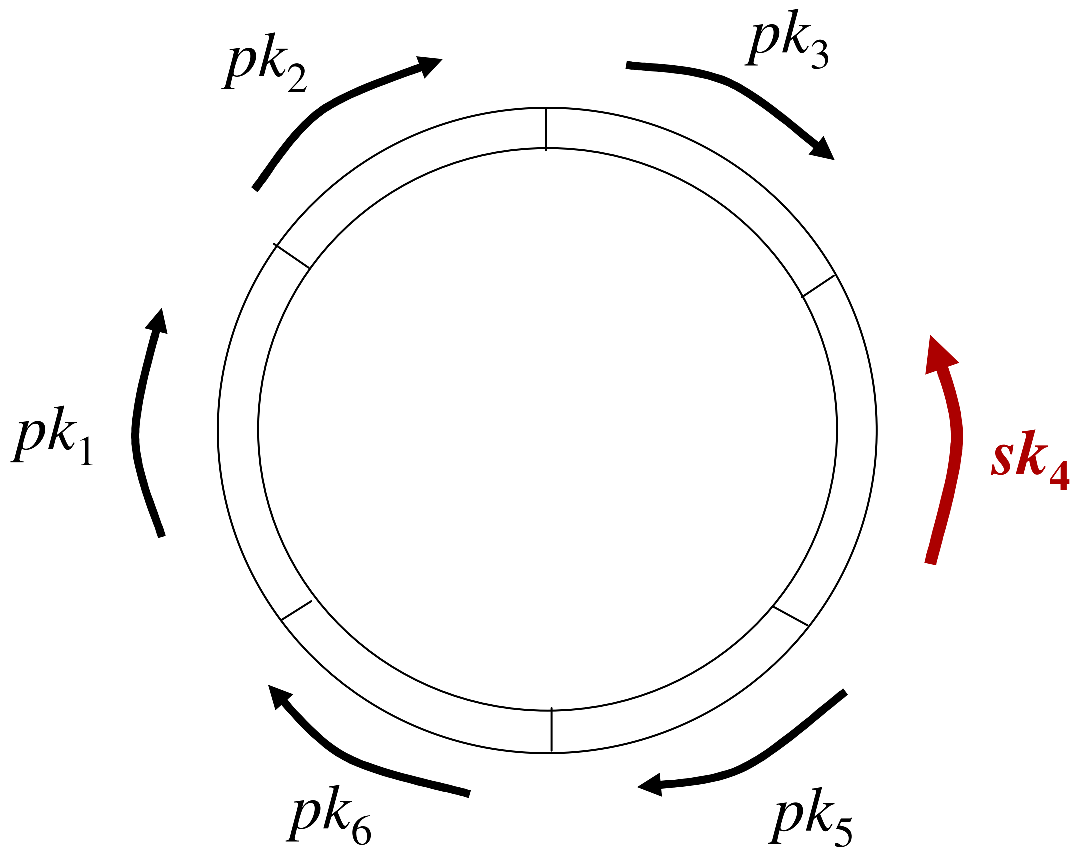
Ring Signatures



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Anonymous Authentication with Ring Signatures

- **Incorporate ring signatures into SSL**
  - Use SSL with server and **client** authentication
  - In SSL, the client authentication is achieved by the client **signing** on the handshake messages
  - Use a **ring signature** instead of a normal one
- **Security**
  - **Secure authentication:** from unforgeability of ring signatures
  - **Anonymity:** from anonymity of ring signatures

Protocol Comparisons

- **Protocol based on encryption**
  - Seemingly higher bandwidth (but user needs to identify subset anyway)
  - Can use any secure encryption scheme (low requirements)
- **Protocol based on ring signatures**
  - Lower bandwidth (apart from identifying subset, requires same bandwidth as SSL with regular client authentication)
  - Assumes strong assumptions: **ideal cipher**

Revocable Anonymity

- **In some cases, anonymity needs to be revoked**
  - Ban access to users who misbehave
    - Hostile users in anonymous chat
    - Criminal activity
- **When anonymous authentication is used, this cannot be done**
- **Revocable anonymity**
  - There exists a **court authority** who can revoke anonymity when required (and only it can revoke)

Achieving Revocable Anonymity

- **There exist solutions, but they are all expensive and require dedicated hardware**
  - They don't use "standard" encryption techniques
- **As of yet, we also don't have a solution that doesn't require a special-purpose smartcard**
  - We do have solutions that are simple extensions of our protocols

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Achieving Revocable Anonymity

- **A first attempt**
  - The court authority has a public encryption-key pk_C
  - The user U_i includes an encryption $E_{pk_C}(ID_i)$ in its authenticating message to the server
- **Revocability**
  - If needed – and under court order – the court authority decrypts the additional ciphertext and finds the user's identity ID_i
- **Problem**
  - A cheating user can encrypt garbage or someone else's ID

Solving the Problem

- **We need to bind the encryption of the user's identity with its authentication message**
- **We assume that the user is given a smartcard by the organization, and cannot modify it**
  - The organization initializes the keys and so the user cannot replace it with a different smartcard
- **The requirement:**
  - If the user succeeds in authenticating, then its encrypted identity must be received by the server
  - We view the user as a man-in-the-middle adversary

Revocable Anonymity with Ring Signatures

- **Additional SSL modification**
  - The court authority has a public encryption-key pk_C
  - The user U_i includes an encryption $E_{pk_C}(ID_i)$ in the handshake messages
  - The handshake messages are all signed by the smartcard
  - Technically:
    - The smartcard receives a hash z of the handshake messages
    - The smartcard signs upon z and the ciphertext c

Revocable Anonymity with Ring Signatures

- **Security**
  - The smartcard operations are atomic
  - If the user modifies the ciphertext (that encrypts its identity), the ring signature generated by the smartcard will fail
  - In this case, the user will **fail** to gain access

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Revocable Anonymity Using Encryption

- **It is also possible to achieve a similar effect using our original protocol**
  - The full description appears in the paper

Password-Based Anonymous Authentication

- **What if we don't have a PKI setup?**
  – We wish to use symmetric keys, or passwords (regular, one-time or whatever)
- **We present a partial solution that can be based on any authentication mechanism (even biometrics)**

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High-Level Protocol

- **Step 1 – standard authentication**
  - The user authenticates using regular, non-anonymous authentication
- **Step 2 – register temporary public key**
  - After authenticating, the user generates a temporary key pair (pk, sk) and sends pk to the server
  - The server registers pk as an authorized public-key
- **Step 3 – disconnect and re-authenticate**
  - The user disconnects and connects again, running an anonymous authentication protocol using pk

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Properties of the Protocol

- **Security**
  - **Authentication:** no problems here
  - **Anonymity:** this is preserved as long as the server cannot link the anonymous authentication request to the user who just disconnected
- **Achieving anonymity**
  - User must either register key well before authenticating, or wait until a number of users join
  - Can use time slots

Properties of the Protocol

- **User keys**
  - This protocol intensifies the problem of how users know other users' public keys
  - Need to use some trusted bulletin board (not run by the same organization and assuming no collusion)

Conclusions

- **Privacy is far more than just the "right to be let alone"**
  - Online entities can learn large amounts of information and use that information against us, giving them an asymmetric advantage
  - We need unlinkability to preserve our privacy
- **Anonymous routing is the basic infrastructure needed for preserving privacy (unlinkability)**
- **The above is fine, as long as authentication is not needed**

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Conclusions

- **If authentication is needed, anonymity can still be preserved**
  - We saw two protocols
  - Implementation has a real cost, but a classic security/efficiency tradeoff makes it realistic (hide inside a not-too-large set of users)
  - Revocable anonymity is possible (but requires dedicated smartcards; not too bad with the invent of JavaCards, but still a disadvantage)
  - Partial solutions based on passwords are also possible

Future Work

- **Revocation**
  – Devise protocols that use only standard smartcard operations
- **Passwords**
  – Provide more satisfactory solutions that have stronger guarantees
- **System**
  – Come up with other methods of sharing public keys of users, so that server cannot introduce fake ones

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