Give Me Letters 2, 3 and 6!
Partial Password Implementations and Attacks

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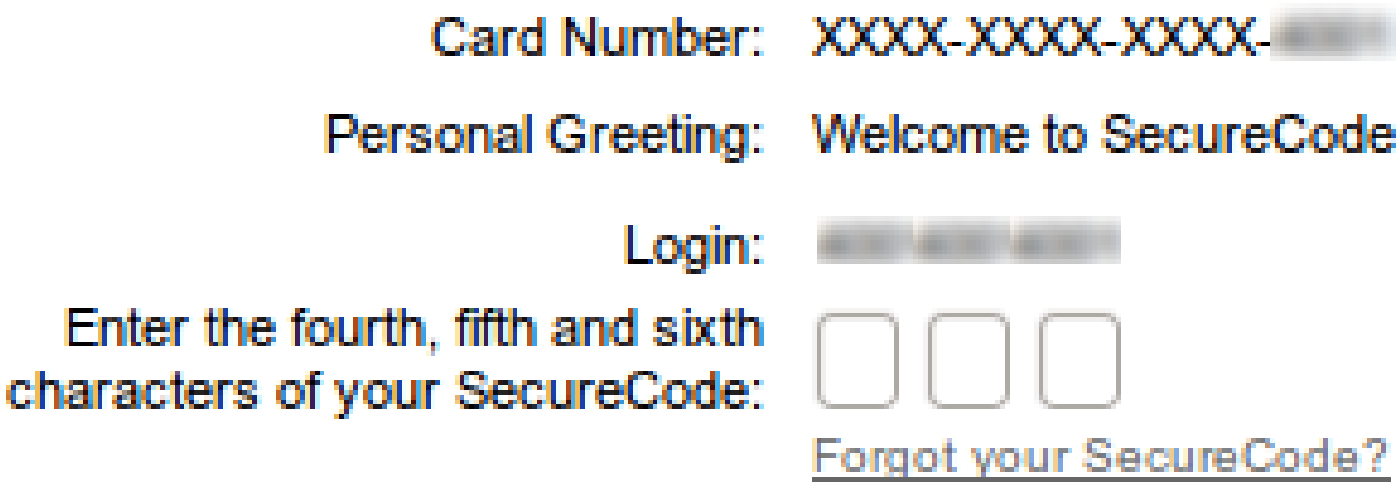
Outline

Partial Passwords

Definitions and examples

A partial password is a challenge on a subset of characters from a full password.

A partial password scheme is an authentication system using partial passwords.



Scheme

Registration User chooses a password of n characters from a set of N

Login Challenge of m positions with response:

Positions:	1	2	3	4	5	6	7
User password:	a	s	h	u	f	1	0
Correct response:		s	h			1	

Retry In case of failure, user challenged again. Number of retries usually limited.

Repeat On next login, challenge changes.

Motivations

Introduced for telephone banking: single observation by operator does not reveal whole secret.

Online, appears to impede several attacks:

- shoulder surfing
- key logging
- man-in-the-browser

Potentially, may also thwart:

- phishing
- offline attacks

Other attractions:

- easy extra authentication step (but not true 2FA)
- cheap (e.g., compared to hardware tokens)

Origins

In UK banking: first introduced for telephone banking.

Matsumoto and Imai, *Human Identification Through Insecure Channel* (Eurocrypt ’91). Related but more elaborate scheme:

- User has a password with known character set
- Challenge: word surrounded by detractor characters
- Response: *substituted* positions and detractors

Repeated several times.

Following work (e.g., Hopper & Bloom 2001): revised schemes and stronger guarantees, but showed required human computation steps are impractical.

So what about schemes actually in use?

Questions

- What are the security assumptions behind current deployment of partial passwords?
- What are good choices for the system parameters: password length, character set size, challenge size?
- How many observations does an attacker need to learn whole password or answer next challenge?
- Are weak passwords such as dictionary words safe?
- Failure mode: should the challenge be changed after failed attempts?
- Are some challenge sequences better than others?
- How usable is the scheme?

Survey

Online banking survey: results

- Used widely in banks, online and telephone
- Elsewhere: credit cards, utilities, outside UK,. . .
- Usually part of a multi-stage authentication, alongside: names, user ids, account details, personal knowledge questions.
- Challenge sizes fixed, vary from 2-3 positions
- Challenge sequences appear random
- Mostly: ascending position challenges, no repeats
- Most repeat same challenge on retry
- Policies generally weaker than for full passwords

Parameters

	character set size, N	password length, n	challenge size, m	second credential
Cooperative	10	4	2	question
ING DiBa (DE)	10	6	2	PIN
Tesco	10	6	2	password
Smile	10	6	2	question
Nationwide	10	6	3	password
AIB	10	5	3	question
B. of Ireland (IE)	10	6	3	date of birth
Nat West, step 1	10	4	2	pp, step 2
Nat West, step 2	36	6–20	3	pp, step 1
HBoS	36	6–15	3	password
3DSecure, BoI	36	8–15	3	credit card #
Standard Life	36	8–10	3	none
Skipton	36	8–30	3	question
First Direct	36	6–30	3	question
Barclays	52	6–8	2	PIN
HSBC (CA)	62	8	3	question

NB: snapshot from Sept. 2012. Thanks to Atif Hussain for help with survey.

Guessing Attacks

Mode of attack for guessing

- online attack against each account
- suppose a fixed number of attempts allowed: β
- some background (e.g., dictionary), ideally limited
- no use of previous observations
- "trawling": use best strategy on many accounts

Two typical instances of scheme:

6 digit ***PIN***

- $N=10$, $n=6$ $m=2$, $\beta=6$

8 character ***alphanumeric***

- $N=36$, $n=8$, $m=3$, $\beta=10$

Guessing methods

1. brute-force (sample from uniform distribution)
2. position-letter frequency (ranked list per position)
3. **projection dictionary** (ranked list per challenge)
4. dependent projection (tree per challenge) *[later]*

Generate background tables by computation on:

- ordinary dictionary, e.g., `/usr/share/dict/words`
- dictionary with frequencies, e.g., RockYou

We calculate β-success rate: proportion of answers covered by the top β guesses.

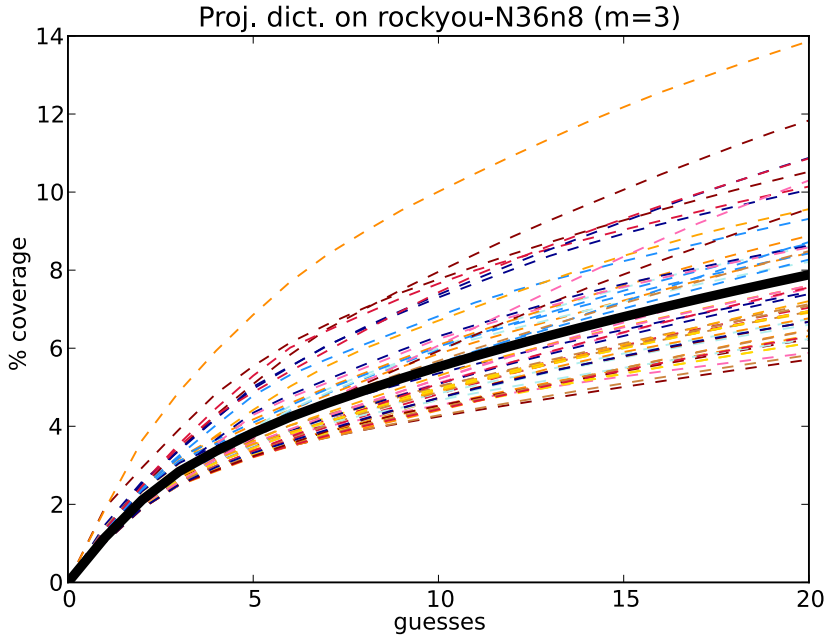
Example projection dictionary attack

Challenge 2 3 6:				*Cum.%*
1.	*a*	*s*	*o*	*1.10*
2.	*l*	*o*	*y*	*1.98*
3.	*r*	*i*	*e*	*2.79*
4.	*2*	*3*	*6*	*3.21*
5.	*a*	*r*	*e*	*3.56*

Challenge 1 2 3:				*Cum.%*
1.	*i*	*l*	*o*	*1.29*
2.	*p*	*a*	*s*	*2.42*
3.	*m*	*a*	*r*	*3.40*
4.	*b*	*a*	*b*	*4.30*
5.	*p*	*r*	*i*	*5.08*

- The top 5 choices for two of the $\binom{n}{m} = 56$ challenges
- Dictionary is RockYou (8-char alphanumeric) with frequencies
- 5.3m total, top 5 words in ranked dictionary covers 3.02%
- Top 5 full words:
  `password`, `iloveyou`, `princess`, 12345678, `babygirl`

Example projection dictionary attack



- This shows the coverage of guesses for increasing β
- Each line is a different challenge, bold is average
- Success rate for β=10 is 5.5% versus 3.9% without projection

Recording Attacks

Mode of attack for recording

- online, β attempts per challenge, as before
- allow recording previous k challenge-response pairs

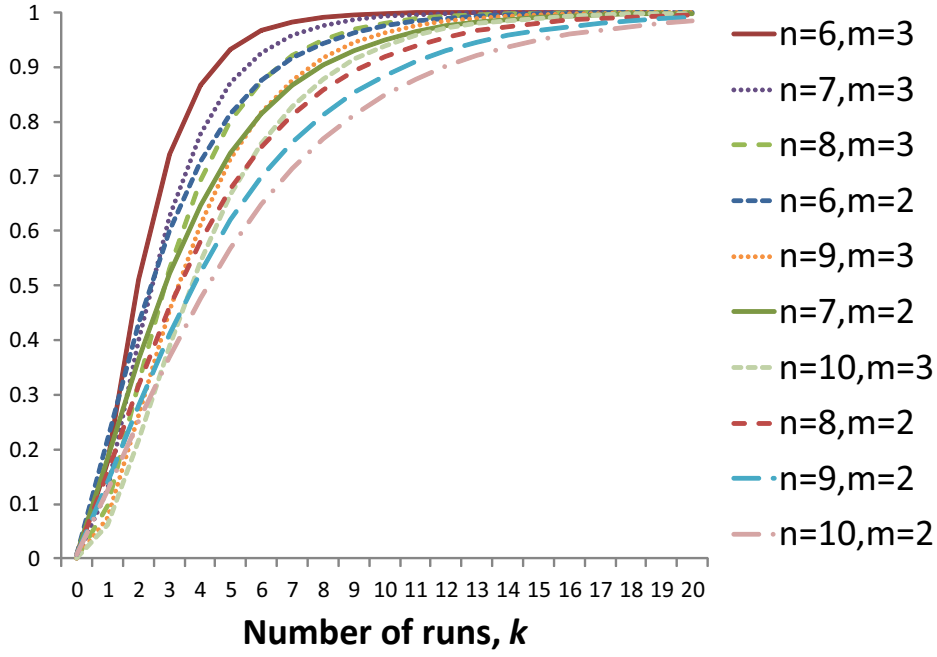
Recording methods

1. Pure recording: only answer when positions known
2. Recording+guessing: guess remainder of positions

Combinatorics: we find equations for two different success rates for increasing k. They are probabilities of:

- answering the next challenge, or
- learning the whole password.

Success rates for answering next challenge



This is a plot of

$$\sum_{j=0}^{m} \overline{s_n^m}(k,j) w_j$$

where $0 \leq j \leq m$ positions are known in a challenge after k runs.

- $\overline{s_n^m}(k,j)$: fraction of challenges with j known positions
- w_j: the β-success rate for a particular guessing method

Summary

Results for typical parameters

Attack type	**parameters**	**% success rate**	
		PINs	alphanumeric
Brute force		6	0.002
Letter position	RockYou	17.2	0.3
Dictionary	RockYou	15.3	3.9
Proj. dictionary	RockYou	30.6	5.5
Recording	k=1 (k=4)	6.7 (63.1)	1.8 (59.0)
Recording + BF Guess	k=1 (k=4)	41.1 (83.8)	9.6 (69.1)
Recording + Best Dict	k=1 (k=4)	60.2 (90.4)	25.2 (81.2)

Summary

- survey of partial password implementations
- model of partial password authentication scheme
- several attack methods, guessing and recording
- theoretical success rates measured analytically (pure recording) and empirically (using a dictionary)

Future/ongoing work:

- Better attacks (dependent case)
- Unseen challenge (Goring et al, 2007)
- Failure modes, challenge schedule and format
- General study of multi-stage authentication
- Discuss more with banks. . .