Guesswork and Passwords

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How to Guess a Password?

Passwords are everywhere.
If you don't know the password, can you guess it?

1. Make a list of passwords.

2. Assess the probability that each was used.

3. Guess from most likely to least likely.

A *dictionary attack*, but with optimal ordering.

Want to tell you a bit about the theory of guessing, and what this looks like in practice.

How long will that take?

If we knew probability P_i of ith password.
Rank the passwords from 1 (most likely) to N (least likely).
Average number of guesses is:

$$G = \sum_{i=1}^{N} iP_i.$$

Applies to computers and keys too. `sci.crypt` FAQ:

> *We can measure how bad a key distribution is by calculating its entropy. This number E is the number of "real bits of information" of the key: a cryptanalyst will typically happen across the key within 2^E guesses. E is defined as the sum of $-p_K \log_2 p_K$, where p_K is the probability of key K.*

Relationship to Entropy?

Could guesswork be the same as entropy?

$$G(P) = \sum_{i=1}^{N} iP_i \overset{?}{\approx} 2^{-\sum P_i \log_2 P_i} = 2^{H(P)}$$

The answer is no (Massey '94), Entropy underestimates.

Questions

- Does this P_i really make sense?
- Is there a distribution with which passwords are chosen?
- How would we find out?

(Mainly from Malone and Maher, WWW'12)

Passwords are usually *hashed* and *salted*. (Morris '79)
Storage:

  1. Ask user for password, choose random unique salt.

  2. Calculate hash $= h$(salt.password).

  3. Store username, salt and hash.

Verify

  1. Ask for username and password.

  2. Look up salt and hash for username.

  3. Check if hash $= h$(salt.password).

h maps strings to fixed length.
Preimages should be hard. h should slow, but not too slow[1]

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[1] 25 graphics card cracker does 350,000,000,000 NTLM/s

Getting data

Want a collection of passwords to study distribution.
Asked Yahoo, Google.

- ...

Crackers eventually obliged.

- 2006: flirtlife, 98930 users, 43936 passwords, 0.44.
- 2009: hotmail, 7300 users, 6670 passwords, 0.91.
- 2009: computerbits, 1795 users, 1656 passwords, 0.92.
- 2009: rockyou, 32603043 users, 14344386 passwords, 0.44.
- 2013: adobe, 129576416 users, 55855039 passwords, 0.43.

First four in clear text!
Had to clean up data.

Top Ten

Rank	hotmail	#users	flirtlife	#users	computerbits	#users	rockyou	#users
1	123456	48	123456	1432	password	20	123456	290729
2	123456789	15	ficken	407	computerbits	10	12345	79076
3	111111	10	12345	365	123456	7	123456789	76789
4	12345678	9	hallo	348	dublin	6	password	59462
5	tequiero	8	123456789	258	letmein	5	iloveyou	49952
6	000000	7	schatz	230	qwerty	4	princess	33291
7	alejandro	7	12345678	223	ireland	4	1234567	21725
8	sebastian	6	daniel	185	1234567	3	rockyou	20901
9	estrella	6	1234	175	liverpool	3	12345678	20553
10	1234567	6	askim	171	munster	3	abc123	16648

(c.f. Imperva analysis of Rockyou data, 2010)

Adobe

- Adobe encrypted data instead of hashing.
- 3DES ECB mode.
- Key unknown, but includes password hints.
- No hashing, lots of fun.

Rank	Cyphertext	indicative hint	inferred password	#users
1	EQ7fIpT7i/Q=	0ne to six in numeral form	123456	1905308
2	j9p+HwtWWT86aMjgZFLzYg==	1234567890 ohne 0	123456789	445971
3	L8qbAD3jl3jioxG6CatHBw==	answer is password	password	343956
4	BB4e6X+b2xLioxG6CatHBw==	adbeandonetwothree	adobe123	210932
5	j9p+HwtWWT/ioxG6CatHBw==	123456789 minus last number	12345678	201150
6	5djv7ZCI2ws=	1st 123456 letters	qwerty	130401
7	dQi0asWPYvQ=	1234567 is the password	1234567	124177
8	7LqYzKVeq8I=	6 number 1s	111111	113684
9	PMDTbP0LZxu03SwrFUvYGA==	adobe photo editing software	photoshop	83269
10	e6MPXQ5G6a8=	one two three one two three	123123	82606

THE GREATEST CROSSWORD PUZZLE
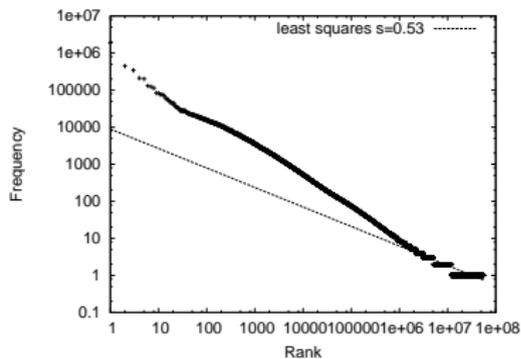IN THE HISTORY OF THE WORLD

Questions for Data

- Is there password distribution?
  Is knowing it better than a crude guess?

- Are there any general features?
  Do different user groups behave in a similar way?

- Some distributions better than others.
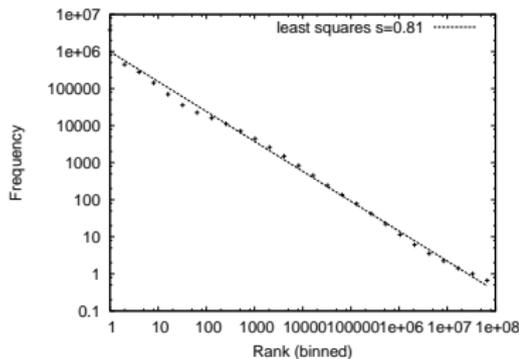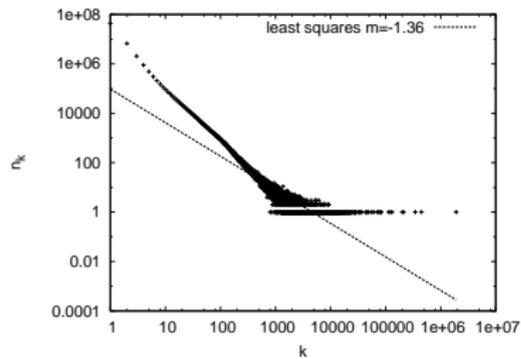 Can we help users make better decisions?
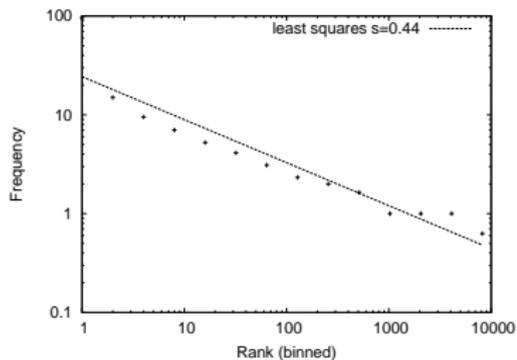
Distribution?

f vs. rank

log f vs. log rank
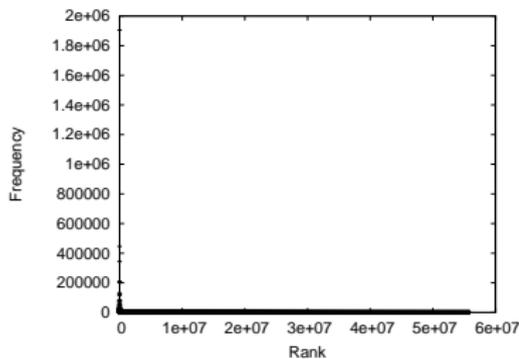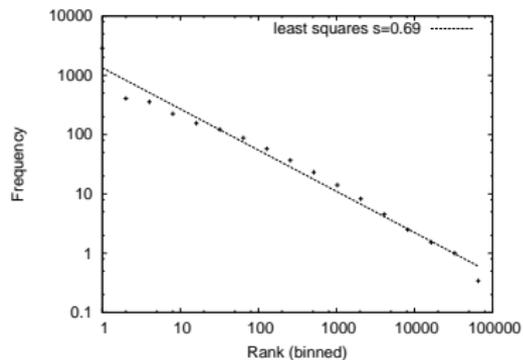
binned log f vs. log rank

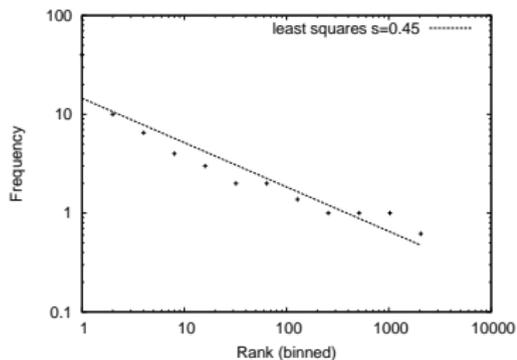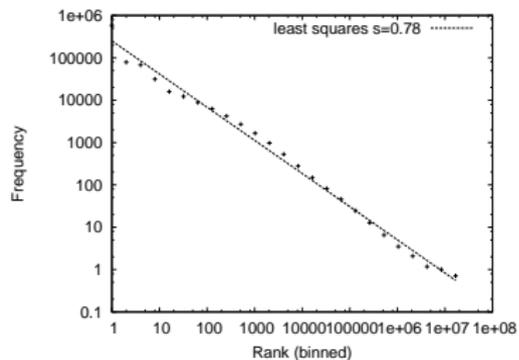$\log n_k$ vs. $\log k$

Others?

hotmail

flirtlife

computerbits

rockyou

Zipf?

- A straight line on a log-log plot points towards heavy tail.
- Zipf?

$$P_r \propto \frac{1}{r^s}$$

- Slope gives s.
- Alternatively fit to n_k number of passwords used by k users. (Adamic '00)

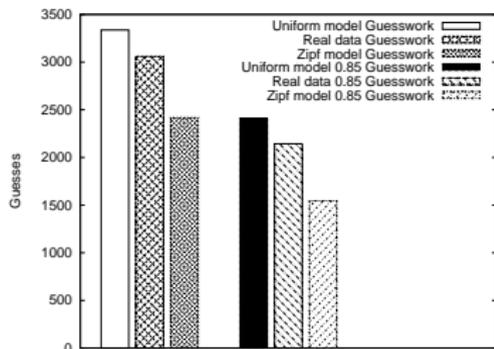|	hotmail	flirtlife	c-bits	rockyou	adobe
s raw	0.16	0.64	0.15	0.51	0.53
s binned	0.44	0.69	0.45	0.78	0.81
$-m$ raw	2.46	1.72	2.56	1.37	1.36
$-m$ binned	3.07	2.32	3.10	2.23	2.22
$1 + 1/s$ binned	3.27	2.45	3.22	2.28	2.23

Zipf

- Can also do MLE and check p-values (Clauset '09).
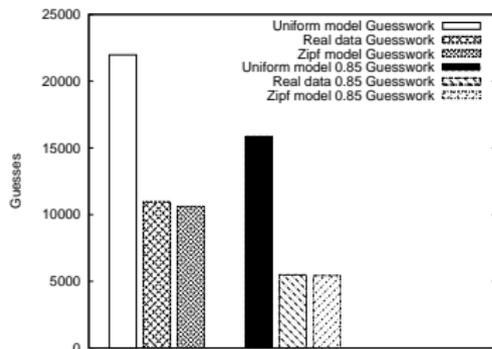- s is small, less than 1.
- Can get p-values[2]

	hotmail	flirtlife	c-bits	rockyou	adobe
s MLE	0.246	0.695	0.23	0.7878	0.7927
s stderr	0.009	0.001	0.02	< 0.0001	< 0.0001
p-value	< 0.01	0.57	< 0.01	< 0.01	< 0.01

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[2]Generate with given parameters, compare Anderson-Darling, look at fraction exceeding original.
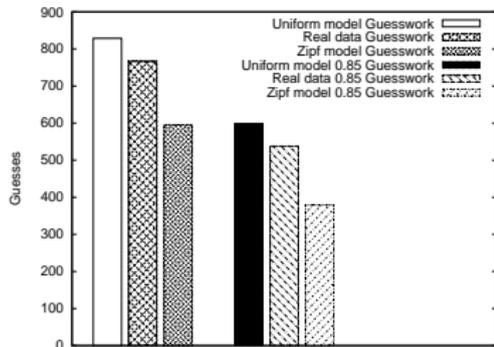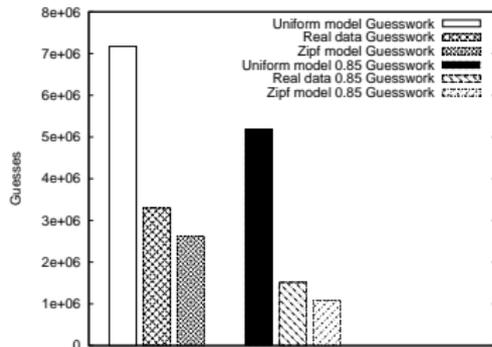
Guesswork Predictions

hotmail

flirtlife

computerbits

rockyou

Conclusions

- Idea of distribution of password choices seems useful.
- Zipf is OK, but not perfect match.
- Worth trying other distributions?
- Different user groups have a lot in common (not peak).
- Dictionaries not great for dictionary attacks.
- Treat users as random password generators?
- Banned lists are not optimal[3].
- Future: Generalise beyond web passwords?
- Future: How do you evaluate password advice?

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[3]Also not even unimodal!
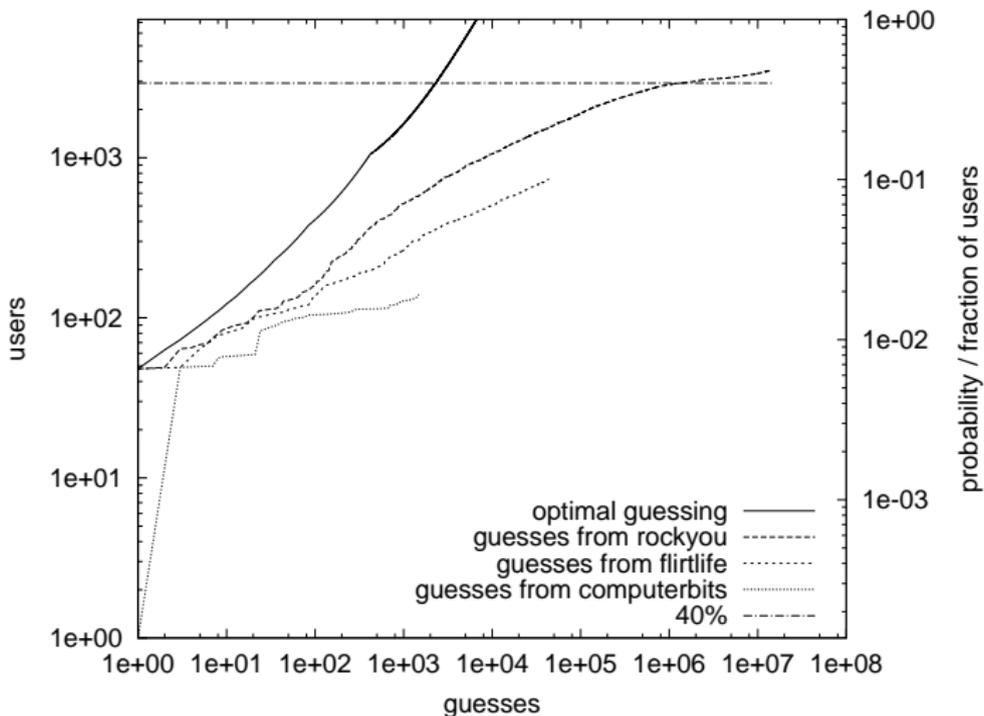
Who cares?

1. Algorithm Design — exploit heavy tail?
2. Can we get close to optimal dictionary attack?
3. Can we make dictionary attack less effective?

2 and 3 are questions about common behavior and helping users.
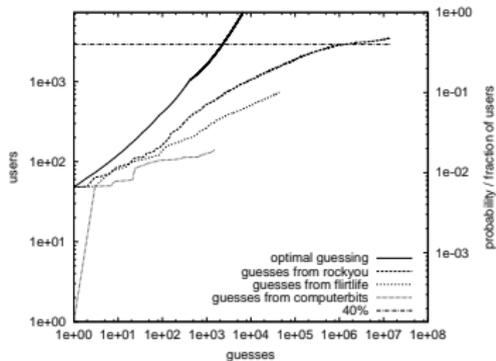
Can use the clear text data to study.

Dictionary Attack
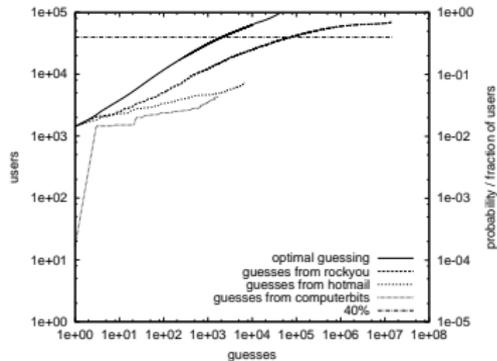
Suppose we use one dataset as a dictionary to attack another.
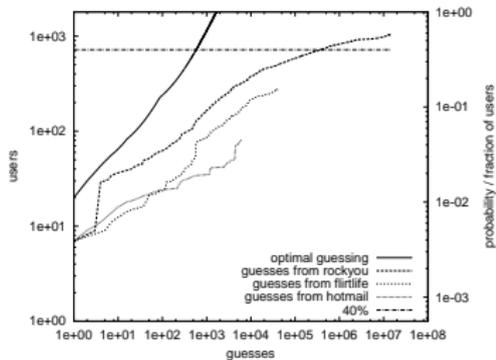

hotmail

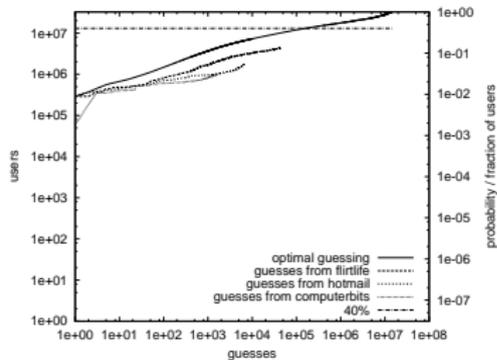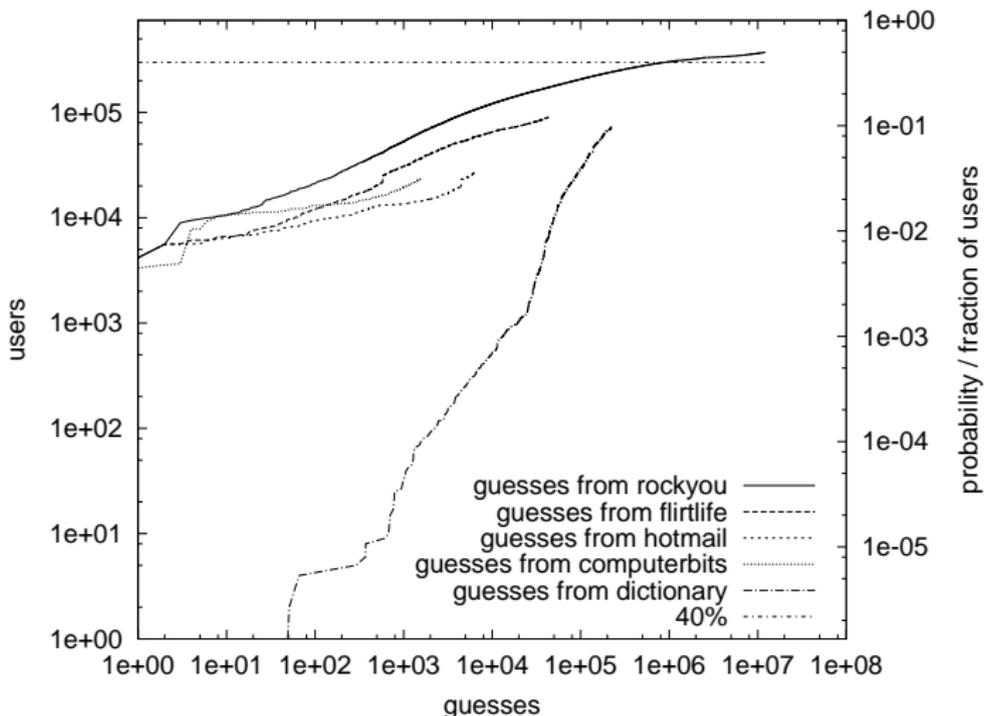# Dictionary Attack — Same Story

hotmail

flirtlife

computerbits

rockyou

Dictionary Attack Gawker

December 2010, Gawker, 748090 Unix `crypt` Hashes, well salted.

Dell'Amico'10 review smart generators. This looks ×10!

Helping Users

User is biased 'random' password generator.
Can we make them a better generator?

- Banned list (e.g. twitter),
- Password rules (e.g. numbers and letters).
- Act like a cracker (e.g. cracklib),
- Cap peak of password distribution (e.g. Schechter'10),
- Aim for uniform?

In WWW'12 paper, looked at Metropolis-Hastings algorithm.
We'll look at rejection sampling here.

Helping with Rejection

If we know P_i, then we could use rejection sampling.

1. Have a probability r_i for each password that it is chosen.
2. Ask user for a new password x'.
3. With probability $r_{x'}$ accept the password, otherwise go to 2.

If users choices are i.i.d with distribution P_i:

- Resulting distribution is proportional to $q_i = r_i P_i$.
- $r_i = C/P_i$ results in a uniform distribution.
- Take $C = P_N$ to give least number of rejections.

How does this do?

- Generate 1000000 users.
- Rockyou-based i.i.d password choices.
- Learns $F(x)$ as it goes, uses $1/F(x)$.
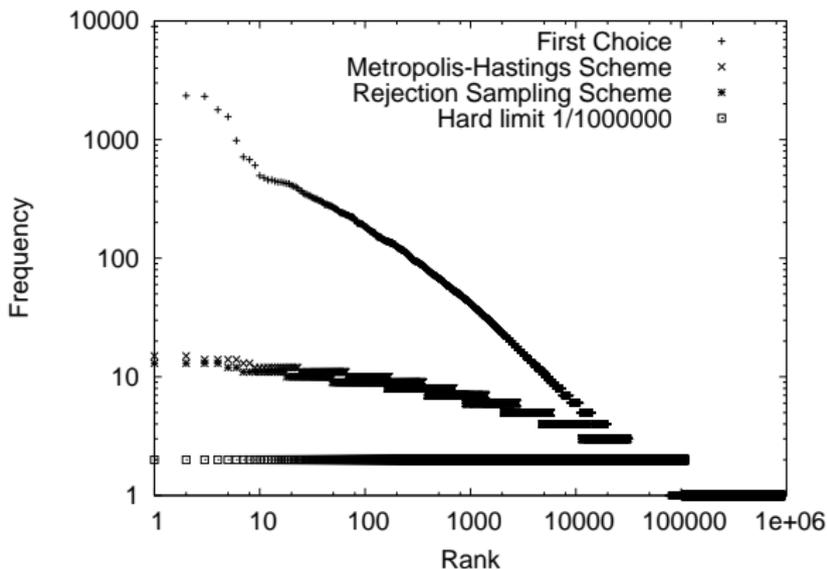
How annoying? Mean tries 1.29, variance 0.63.

(More) Conclusions

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- Worth trying other distributions?
- Different user groups have a lot in common (not peak).
- Dictionaries not great for dictionary attacks.
- Treat users as random password generators?
- Future: Generalise beyond web passwords?
- Future: Field test Rejection Sampling system?