

6.1800 Spring 2024

Lecture #21: Authentication

authenticating users through the magic of (salted) hash functions

6.1800 in the news

NASA's Voyager 1 Resumes Sending Engineering Updates to Earth

April 22, 2024



NASA's Voyager 1 spacecraft is depicted in this artist's concept traveling through interstellar space, or the space between stars, which it entered in 2012. Credit: NASA/JPL-Caltech

6.1800 in the news

fight data subsystem



The team discovered that a single chip responsible for storing a portion of the FDS memory — including some of the FDS computer's software code — isn't working. The loss of that code rendered the science and engineering data unusable. Unable to repair the chip, the team decided to place the affected code elsewhere in the FDS memory. But no single location is large enough to hold the section of code in its entirety.

So they devised a plan to divide the affected code into sections and store those sections in different places in the FDS. To make this plan work, they also needed to adjust those code sections to ensure, for example, that they all still function as a whole. Any references to the location of that code in other parts of the FDS memory needed to be updated as well.

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The team started by singling out the code responsible for packaging the spacecraft's engineering data. They sent it to its new location in the FDS memory on April 18. A radio signal takes about 22 ½ hours to reach Voyager 1, which is over 15 billion miles (24 billion kilometers) from Earth, and another 22 ½ hours for a signal to come back to Earth. When the mission flight team heard back from the spacecraft on April 20, they saw that the modification worked: For the first time in five months, they have been able to check the health and status of the spacecraft.

6.1800 in the news



steps towards building a more secure system

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1. be clear about goals (**policy**)

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2. be clear about assumptions (**threat model**)

policy: provide **authentication** for users

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threat model: adversary has access to the entire stored table

username	password (plaintext)
user1	fhxiyfioncvgxvrb
user2	pmhdtzyxjpwbsjwv
user3	gxrdqlbxrvhdopjg
user4	hncobhdvimrtbpmy
user5	jprfyxpznunmbabp
user6	abbsocpnkpnqirmf
user7	ybtstxthnpunjrep
user8	eauohxeagxkejbyk
user9	viyigjfdtllgdgd
user10	mwccvpbesqqkuwsu
user11	jpzxomdscorejjcb
user12	aqpyiegxyiftfpaa
user13	qopgbawviyrdzjhz
user14	ordkyoqkugmrzudj
user15	ygeblazpolvfufox
user16	bslrsuhqmsgfvfjx
user17	pwcdmcpucurnzmjy
user18	vlcfilrfcdjgtvqn
user19	jfkwdbgdprxnotuz
user20	cmhuaajeqecvbdlyn
user21	tnfdfjiytbsomleb
user22	abpuvcbxqaoeaujq
user23	ykzpwiijhishbqlpw
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user6	abbsocpnkpnqirmf
user7	ybtstxthnpunjrep
user8	eauohxeagxkejbyk
user9	viyigjfdtllgdgd
user10	mwccvpbesqqkuwsu
user11	jpzxomdscorejjcb
user12	aqpyiegxyiftfpaa
user13	qopgbawviyrdzjhz
user14	ordkyoqkugmrzudj
user15	ygeblazpolvfufox
user16	bslrsuhqmsgfvfjx
user17	pwcdmcpucurnzmjy
user18	vlcfilrfcdjgtvqn
user19	jfkwdbgdprxnotuz
user20	cmhuaajeqecvbdlyn
user21	tnfdfjiytbsomleb
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    stored_password = accounts_table[username]  
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user6	abbsocpnkpnqirmf
user7	ybtstxthnpunjrep
user8	eauohxeagxkejbyk
user9	viyigjfdtllgdgd
user10	mwccvpbesqqkuwsu
user11	jpzxomdscorejjcb
user12	aqpyiegxyiftfpaa
user13	qopgbawviyrdzjhz
user14	ordkyoqkugmrzudj
user15	ygeblazpolvfufox
user16	bslrsuhqmsgfvfjx
user17	pwcdmcpucurnzmjy
user18	vlcfilrfcdjgtvqn
user19	jfkwdbgdprxnotuz
user20	cmhuaajeqecvbdlyn
user21	tnfdfjiytbsomleb
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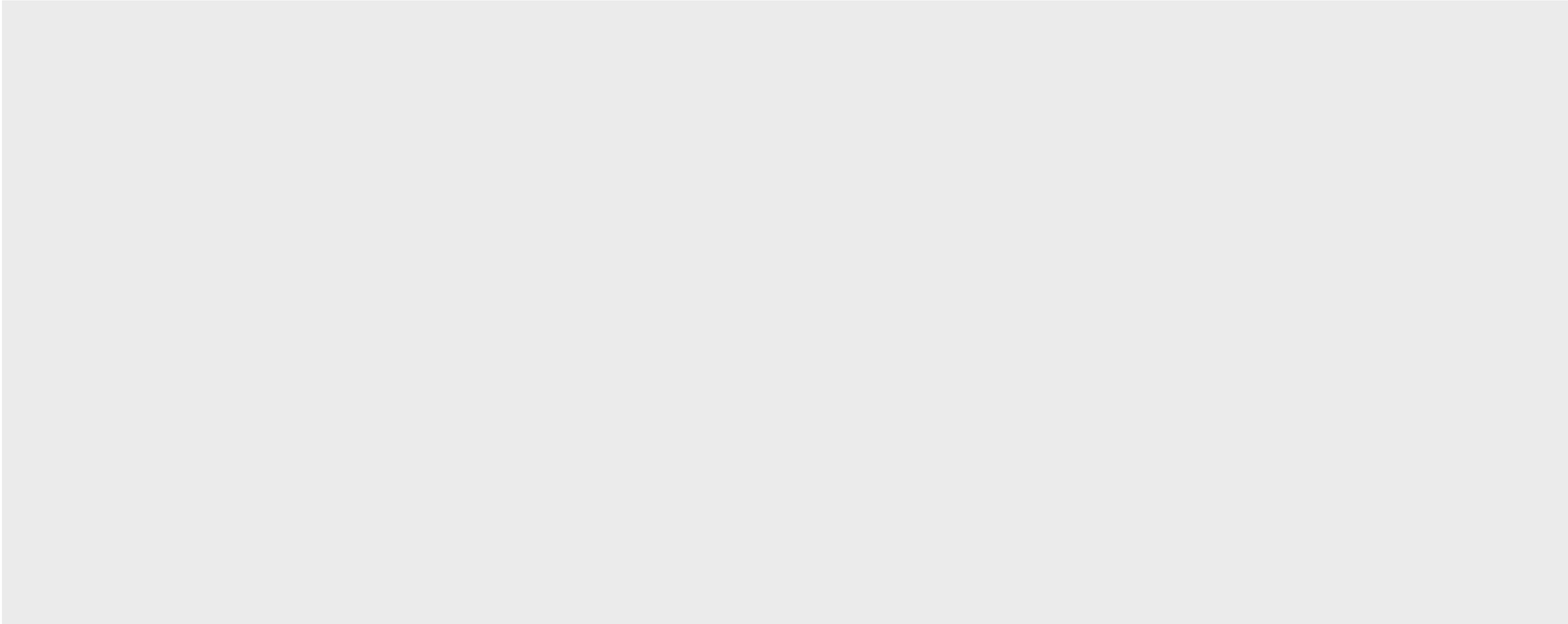
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problem: the adversary (with access to the stored table) can just read the passwords directly

interlude: hash functions

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in the context of our quest for authentication, this means that we cannot rely on a “secret” hash function; there is no such thing

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we are going to use hash functions to (attempt to) solve our authentication problem

username	password (plaintext)
user1	fhxiyfioncvgxvrb
user2	pmhdtzyxjpwbsjwv
user3	gxrdqlbxrvhdopjg
user4	hncobhdvimrtbpmy
user5	jprfyxpznunmbabp
user6	abbsocpnkpnqirmf
user7	ybtstxthnpunjrep
user8	eauohxeagxkejbyk
user9	viyigjfdtllgdgd
user10	mwccvpbesqqkuwsu
user11	jpzxomdscorejjcb
user12	aqpyiegxyiftfpaa
user13	qopgbawviyrdzjhz
user14	ordkyoqkugmrzudj
user15	ygeblazpolvfufox
user16	bslrsuhqmsgfvfjx
user17	pwcdmcpucurnzmjy
user18	vlcfilrfcdjgtvqn
user19	jfkwdbgdprxnotuz
user20	cmhuaajeqecvbdlyn
user21	tnfdfjiytbsomleb
user22	abpuvcbxqaoeaujq
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user1	14cdac7adb383312176cf4376d6bd594d4823e675567a545a0e13ada7f89c995
user2	adab20bca80250418a02196ca80d01d85456675b29816a40212eaa8d4c56ad22
user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc9879789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57d27d29648e770deb91dadb4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6a029316de6da4c2976cba547b2efdb46
user17	6efa1445959a560e0148464ff4d316e94ae5d8f1948f6de483801fa12ed4056b

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user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc9879789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57d27d29648e770deb91dad4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6a029316de6da4c2976cba547b2efdb46
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user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
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user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
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now the adversary cannot just read passwords directly from the table

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user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
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user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
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there are **very few** such functions, and the ones that exist are well-known

question: suppose an adversary reads the hash of user3's password. can the adversary figure out what the password was with that information alone?

username	hash(password)
user1	14cdac7adb383312176cf4376d6bd594d4823e675567a545a0e13ada7f89c995
user2	adab20bca80250418a02196ca80d01d85456675b29816a40212eaa8d4c56ad22
user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
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user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
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user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
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user17	6efa1445959a560e0148464ff4d316e94ae5d8f1948f6de483801fa12ed4056b

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to authenticate users:

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check_password(username, inputted_password):
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user1	14cdac7adb383312176cf4376d6bd594d4823e675567a545a0e13ada7f89c995
user2	adab20bca80250418a02196ca80d01d85456675b29816a40212eaa8d4c56ad22
user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc9879789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57d27d29648e770deb91dadb4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6a029316de6da4c2976cba547b2efdb46
user17	6efa1445959a560e0148464ff4d316e94ae5d8f1948f6de483801fa12ed4056b

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user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc9879789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57d27d29648e770deb91dadb4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6a029316de6da4c2976cba547b2efdb46
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user3	02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb4157c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc9879789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57d27d29648e770deb91dad4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f712d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6a029316de6da4c2976cba547b2efdb46
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. . .	
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adab20bca80250418a02196ca80d01d85456675b29816a40212eaa8d4c56ad22	pmhdtzyxjpwbsjwv
02c0d53273d41d74221c69c5393157965182254904aa0653aa43f3a206e6eaa1	gxrdqlbxrvhdopjg
21f110ed053c24004463526b3ba06999c52580abeff8a85e89f7d9af966446e3	hncobhdvimrtbpmy
2fae96a772f8e7c1bc5ae87ba291e4671b66792a024b324e87305ca551c34a80	jprfyxpznunmbabp
e5034d3265313a5b4fbac596b1e3f954805c0662c2f9cca6ca3efaa8282080cf	abbsocpnkpnqirmf
. . .	

it takes so little time to calculate a hash that it's feasible for the attacker to have the hash of *many* of our passwords

(it took my laptop 8 seconds to compute 10 million hashes)

an adversary can quickly make a table ahead of time, mapping passwords to their hashes, and use that to determine the user passwords

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user3	02c0d53273d41d74221c69c539315796 5182254904aa0653aa43f3a206e6eaa1
user4	21f110ed053c24004463526b3ba06999 c52580abeff8a85e89f7d9af966446e3
user5	2fae96a772f8e7c1bc5ae87ba291e467 1b66792a024b324e87305ca551c34a80
user6	e5034d3265313a5b4fbac596b1e3f954 805c0662c2f9cca6ca3efaa8282080cf
user7	5de31d1e08319d086c7fee8de384eb41 57c6b02a6e575b7c49a6a9d8c7388836
user8	b8cd12c77b504b4e103dcc12cce948b2 d737638d80c4e8c221cbbe13d1776bb7
user9	bbd108d7967db8489432dc3d1899d4d9 c5d2f8d39ff106035d74757c140b527d
user10	1f7dbe35470e3f7364736afb9a02787c 832ea8b5cdd958d53d27aa69c834e63b
user11	062f82f9ef701cfa2573aa40f2e7cc98 79789512d55bafb2b72486ba262612d0
user12	224c37554776a15372b768a2c9232a57 d27d29648e770deb91dad4b6ddd5f3a
user13	92df155300535fa28fefe4a65f2059fb 3bedfe6409d01cbf29dd45b1163234b4
user14	964205c227974d9048fe67a485f73f71 2d950dea64bf3c94cbf93fadec91d657
user15	907c14aae02712091b9682e5e08b997c 69094d15b92e55b1463d247e10c9c235
user16	e30cff73a266cda4e41ad3e28d7770c6 a029316de6da4c2976cba547b2efdb46
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hash(password)	password
. . .	
14cdac7adb383312176cf4376d6bd594 d4823e675567a545a0e13ada7f89c995	fhxiyfioncvgxvrb
adab20bca80250418a02196ca80d01d8 5456675b29816a40212eaa8d4c56ad22	pmhdtzyxjpwbsjwv
02c0d53273d41d74221c69c539315796 5182254904aa0653aa43f3a206e6eaa1	gxrdqlbxrvhdopjg
21f110ed053c24004463526b3ba06999 c52580abeff8a85e89f7d9af966446e3	hncobhdvimrtbpmy
2fae96a772f8e7c1bc5ae87ba291e467 1b66792a024b324e87305ca551c34a80	jprfyxpznunmbabp
e5034d3265313a5b4fbac596b1e3f954 805c0662c2f9cca6ca3efaa8282080cf	abbsocpnkpnqirmf
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there are **very few** such functions, and the ones that exist are **well-known**

interlude: hash functions

hash functions are not normal functions! they have a number of exciting properties

a **hash function H** takes an input string of arbitrary size and outputs a fixed-length string

H is **deterministic**: if $x_1 = x_2$, then $H(x_1) = H(x_2)$

H is **collision-resistant**: if $x_1 \neq x_2$, then the probability that $H(x_1) = H(x_2)$ is virtually zero

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in the context of our quest for authentication, this means that we cannot rely on a “secret” hash function; there is no such thing

current problem: an adversary can easily pre-compute hashes for *a lot* of passwords

interlude: **slow** hash functions

hash functions are not normal functions! they have a number of exciting properties

a **slow hash function** H takes an input string of arbitrary size and outputs a fixed-length string

H is **deterministic**: if $x_1 = x_2$, then $H(x_1) = H(x_2)$

H is **collision-resistant**: if $x_1 \neq x_2$, then the probability that $H(x_1) = H(x_2)$ is virtually zero

H is **one-way**: given x , it is easy — **but slow** — to compute $H(x)$.
given $H(x)$ (without x), it is virtually impossible to determine x

there are **very few** such functions, and the ones that exist are well-known

in the context of our quest for authentication, this means that we cannot rely on a “secret” hash function; there is no such thing

these slow hash functions are technically called “key derivation functions”, but we want to emphasize the relationship between them and the hash functions you’re already familiar with

they also have some additional properties, but not ones that we’re concerned with for this lecture

username	slow_hash(password)
user1	Vu7yYhTYngJSsXQARH/t0ExTjzMAvxm
user2	zg1MEP8gq.wSEEBs77IKSKp0fcPyVHi
user3	Q4echHF0G36Hwz1r2PMBwD0mSBAnhF6
user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIktSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

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user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSppryJeAfq74AmFYk32
user9	NrYewdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
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user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYewdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
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```

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user3	Q4echHF0G36Hwz1r2PMBwD0mSBAnhF6
user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYewdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbcz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

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slow_hash(password)	password
...	
	fhxyfioncvngxvrb
	pmhdtzyxjpwbsjwv
	gxrdqlbxrvhdopjg
	hncobhdvimrtbpmy
	jprfyxpznunmbabp
	abbsocpnkpnqirmf
...	

is it feasible for an adversary to make the same table as before?

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user1	Vu7yYhTYngJSsXQARH/t0ExTjzMAvxm
user2	zg1MEP8gq.wSEEBs77IKSKp0fcPyVHi
user3	Q4echHF0G36HWz1r2PMBwD0mSBAnhF6
user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSprryJeAfq74AmFYk32
user9	NrYewdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfEef1abf

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

slow_hash(password)	password
...	
	fhxyfioncvngxvrb
	pmhdtzyxjpwbsjwv
	gxrdqlbxrvhdopjg
	hncobhdvimrtbpmy
	jprfyxpznunmbabp
	abbsocpnkpnqirmf
...	

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6.1800 in the news

<u>RANK</u>	<u>PASSWORD</u>	<u>TIME TO CRACK IT</u>	<u>COUNT</u>
1	123456	< 1 Second	4,524,867
2	admin	< 1 Second	4,008,850
3	12345678	< 1 Second	1,371,152
4	123456789	< 1 Second	1,213,047
5	1234	< 1 Second	969,811
6	12345	< 1 Second	728,414
7	password	< 1 Second	710,321
8	123	< 1 Second	528,086
9	Aa123456	< 1 Second	319,725
10	1234567890	< 1 Second	302,709

username	slow_hash(password)
user1	Vu7yYhTYngJSsXQARH/t0ExTjzMAvxm
user2	zg1MEP8gq.wSEEBs77IKSKp0fcPyVHi
user3	Q4echHF0G36HWz1r2PMBwD0mSBAnhF6
user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xciYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbcz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

slow_hash(password)	password
. . .	
50TqbEyfwG1I95NA9zQFTrqte6c1y5q	111111
n3CrTA6Tk5a0F/oHioWesdj1Zeirh1a	password
T7bMFpBeUq0M09QRbYE611hA0QcvVXY	123456
K.V00Ucnrb1jbF1RsQksDzrXHrNkwYG	asdfasdf
P8.czpjwjtTR5aLdN71hP17mbOZ.He2	123123
sEh47bf/w44wPdoHp5y0qWNabaVfa.G	qwerty
. . .	

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user2	zg1MEP8gq.wSEEBs77IKSKp0fcPyVHi
user3	Q4echHF0G36Hwz1r2PMBwD0mSBAnhF6
user4	1ea8JUL1BbtIR01hKWnTj2m1CHuGvi6
user5	Dfhb01Yy2HSXsjbQ0tIT3FavbR5A3Sm
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	thVVCSZCcZB3IbP.tRupSLKfseoSHKa
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	4AP5KW7YJS2HV699oDXKwz3nX1nAAK.
user14	7xhtnhapBhUEeG9HdJm1Ef5M1A9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbcz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	dINFGeda4wyIdtCqoGt7sI45Pd1rpY0
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYI0rIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	A9CYWLRBPWcnguZt7wtBT0cunnrG1Ym
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

slow_hash(password)	password
...	
50TqbEyfwG1I95NA9zQFTrqte6c1y5q	111111
n3CrTA6Tk5a0F/oHioWesdj1Zeirh1a	password
T7bMFpBeUq0M09QRbYE611hA0QcvVXy	123456
K.V00Ucnrb1jbF1RsQksDzrXhrNkwYG	asdfasdf
P8.czpjwtTR5aLdN71hP17mbOZ.He2	123123
sEh47bf/w44wPdoHp5y0qWNabaVfa.G	qwerty
...	

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user2	50TqbEyfWGlI95NA9zQFTTrqte6c1y5q
user3	T7bMFpBeUqOM09QRbYE6l1hA0QcvVXY
user4	1ea8JULlBbtIR01hKWnTj2m1CHuGvi6
user5	50TqbEyfWGlI95NA9zQFTTrqte6c1y5q
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcIYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user14	7xhtnhapBhUEeG9HdJm1Ef5MlA9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	P8.czpjwjtTR5aLdN7lhP17mbOZ.He2
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYIOrIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	sEh47bf/w44wPdoHp5y0qWNabaVfa.G
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

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threat model: adversary has access to the entire stored table

slow_hash(password)	password
...	
50TqbEyfWGlI95NA9zQFTTrqte6c1y5q	111111
n3CrTA6Tk5a0F/oHioWesdj1Zeirhla	password
T7bMFpBeUqOM09QRbYE6l1hA0QcvVXY	123456
K.V00Ucnrb1jbF1RsQksDzrXhrNkwYG	asdfasdf
P8.czpjwjtTR5aLdN7lhP17mbOZ.He2	123123
sEh47bf/w44wPdoHp5y0qWNabaVfa.G	qwerty
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user4	1ea8JULlBbtIR01hKWnTj2m1CHuGvi6
user5	50TqbEyfWGlI95NA9zQFTTrqte6c1y5q
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xciYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user14	7xhtnhapBhUEeG9HdJm1Ef5MlA9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	P8.czpjwjtTR5aLdN7lhP17mb0Z.He2
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYIOrIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	sEh47bf/w44wPdoHp5y0qWNabaVfa.G
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
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...	
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T7bMFpBeUq0M09QRbYE6l1hA0QcvVXy	123456
K.V00Ucnrb1jbF1RsQksDzrXHrNkwYG	asdfasdf
P8.czpjwjtTR5aLdN7lhP17mb0Z.He2	123123
sEh47bf/w44wPdoHp5y0qWNabaVfa.G	qwerty
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user4	1ea8JULlBbtIR01hKWnTj2m1CHuGvi6
user5	50TqbEyfWGLI95NA9zQFTTrqte6c1y5q
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcIYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSppryJeAfq74AmFYk32
user9	NrYewdAW641dHnWwagPG9FnzvyXkFQm
user10	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
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user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	P8.czpjwjtTR5aLdN7lhP17mb0Z.He2
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYIOrIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	sEh47bf/w44wPdoHp5y0qWNabaVfa.G
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
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user4	1ea8JULlBbtIR01hKWnTj2m1CHuGvi6
user5	50TqbEyfWGLI95NA9zQFTTrqte6c1y5q
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcIYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBRSprryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user14	7xhtnhapBhUEeG9HdJm1Ef5MlA9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	P8.czpjwjtTR5aLdN7lhP17mb0Z.He2
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYIOrIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	sEh47bf/w44wPdoHp5y0qWNabaVfa.G
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
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we would like to make it more difficult for adversaries to pre-compute hashes, even for common passwords

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

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user3	T7bMFpBeUq0M09QRbYE6l1hA0QcvVXY
user4	1ea8JULlBbtIR01hKWnTj2m1CHuGvi6
user5	50TqbEyfWGLI95NA9zQFTTrqte6c1y5q
user6	EbsIBgo/bir0FcP7sRpCXQGfxSfqX/G
user7	6KfAluC3xcIYx/2McraVURKume2PSLG
user8	PW3jcT9uQEBSppryJeAfq74AmFYk32
user9	NrYeWdAW641dHnWwagPG9FnzvyXkFQm
user10	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user11	dZTHFkjpzV29FcNDqmmwdhoF4exaKr.
user12	f90PAGN1e0h/neXJ9R71rj0saTGkFb2
user13	n3CrTA6Tk5a0F/oHioWesdj1Zeirhla
user14	7xhtnhapBhUEeG9HdJm1Ef5MlA9f/Nm
user15	dsgI4qRw98MQI1AbvVZZUynnQ/cs5Te
user16	D7LI3Qzct7fyBzvuXAXjbCz9a6UMYpm
user17	JMzSCQjujmgxXSg9.xFqC65Wz3C6RH6
user18	P8.czpjwjtTR5aLdN7lhP17mb0Z.He2
user19	UCshY6u.q83PKggZ5JuoaFHqHyb9R92
user20	KBvqt5KUmmmAHuZ525sw5ziYIOrIQ7q
user21	pIzJp/ypb1vsGEGRjUIcZBCYYGN1wcy
user22	sEh47bf/w44wPdoHp5y0qWNabaVfa.G
user23	Hm0noE1AIkTSEKm6t4sXmIKYU2xdAwS
	2b8216082174E14e222a624cfE5f1abf

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

we would like to make it more difficult for adversaries to pre-compute hashes, even for common passwords

idea: add randomness

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

highlighted users are using common passwords

username	salt
user1	TU6kbcuPm7jA./IQYZG.80
user2	y7oSC2QsrrvXTzEZ1DZFdwu
user3	4ncYRSB5v3rWiU1nPpA0iu
user4	SK9H4x4Ha00wz4N0Twj20.
user5	j8YyeDX.9GnsT5Hu94z7t0
user6	CIqY72CGM8KNQId1CqXY7.
user7	OGtMXrEZEx0L5440dvrhbe
user8	RFET9TVo18cmpQdhqMCV5.
user9	rDAhDK5V6n3TUS3ahf2Z9e
user10	nv0YvT0/ocz0W51mbVZSU0
user11	yNL/e3PpBsfBYgwi0Ai/gu
user12	1zroU10scwDzgG3GY86pF0
user13	TAkV7nBQ5amY4V.aIjez0u
user14	1J796dTzufUC8ItVIKIy0u
user15	/x.Vk/XhUILbk3XjgyVyf0
user16	hyg8T0JPDX3dCf92Zkx4Yu
user17	YbaY0SdkA01IF.drWa6CX0
user18	yaE.gULeQg.K2Se1X191Q.
user19	NLt0SA/QPo2IIbtb7G5610
user20	RFFSWUGGFEX5XNyW8rLToe
user21	YWEgwinWuKrNUFvgzQKUNe
user22	ukqUgo0ZWCqIQjH3DwC4xe
user23	sPRFpmFnu5G41APUkV0wr0
	KDh8kxp2T3uyfYnan00070

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

we're going to associate a random value — a *salt* — with each user. these salts are stored in plaintext; they are not a secret

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrLPLjFDKu
user11	yNL/e3PpBsfBYgwi0Ai/gu	bbT5sTcmsk1syXVILfVdJ/HAI Eonb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxv3T3vYfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

we're going to associate a random value — a *salt* — with each user. these salts are stored in plaintext; they are not a secret

instead of storing a hash of the password, we will concatenate the password and the salt, and store the hash of that string

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMcv5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIeOnb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	e0X2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

question: how do we authenticate users in this system? I.e., how does the below code need to change?

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

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user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMcv5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrLPLjFDKu
user11	yNL/e3PpBsfBYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIe0nb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkV7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

question: how do we authenticate users in this system? I.e., how does the below code need to change?

```
check_password(username, inputted_password):
    stored_hash = accounts_table[username]
    inputted_hash = slow_hash(inputted_password)
    return stored_hash == inputted_hash
```

this is our previous check_password function

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFET9TVo18cmpQdhqMcv5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsk1syXVILfVdJ/HAIEonb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAKv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFEX5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

to authenticate users:

```

check_password(username, inputted_password)
    stored_hash = accounts_table[username].hash
    salt = accounts_table[username].salt
    inputted_hash = slow_hash(inputted_password | salt)
    return stored_hash == inputted_hash

```

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

username	salt	slow_hash(password salt)
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user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrrLPLjFDKu
user11	yNL/e3PpBsfBYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIeOnb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkV7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPDU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

slow_hash(password salt)	password
...	
?	111111
?	123456
?	password
...	

is it feasible for an adversary to make the same table as before?

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

username	salt	slow_hash(password salt)
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user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrrLPLjFDKu
user11	yNL/e3PpBsfBYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIe0nb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkV7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaY0Sdka01IF.drWa6CX0	ZKbZQtEh4UNoTf1WsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	e0X2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

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slow_hash(password salt)	password
...	
?	111111
?	123456
?	password
...	

is it feasible for an adversary to make the same table as before?

to pre-compute the table, even for just the most common passwords, the adversary would need a separate table for every possible salt; this is infeasible

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

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user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIe0nb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkV7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaY0Sdka01IF.drWa6CX0	ZKbZQtEh4UNoTf1WsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxp2T3vYfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

slow_hash(password salt)	password
...	
?	111111
?	123456
?	password
...	

is it feasible for an adversary to make the same table as before?

to pre-compute the table, even for just the most common passwords, the adversary would need a separate table for *every possible salt*; this is infeasible

to target a specific user — say user1 — an adversary could read user1's salt and make a table using that salt. the more common user1's password, the more likely it would be revealed, but it's unlikely an adversary would pre-compute this table since they would not know the salt ahead of time.

given x , it is easy **but slow** to compute $H(x)$; given $H(x)$, it is virtually impossible to determine x . there are **very few** such functions, and the ones that exist are well-known

limiting transmission of passwords

we want users to transmit passwords infrequently, because transmitting a password repeatedly can open a user up to other attacks outside of our current threat model

limiting transmission of passwords

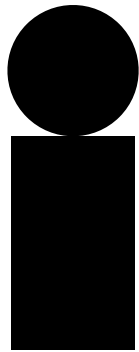
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cookies allow users to authenticate themselves from some period of time, without repeatedly retransmitting their passwords

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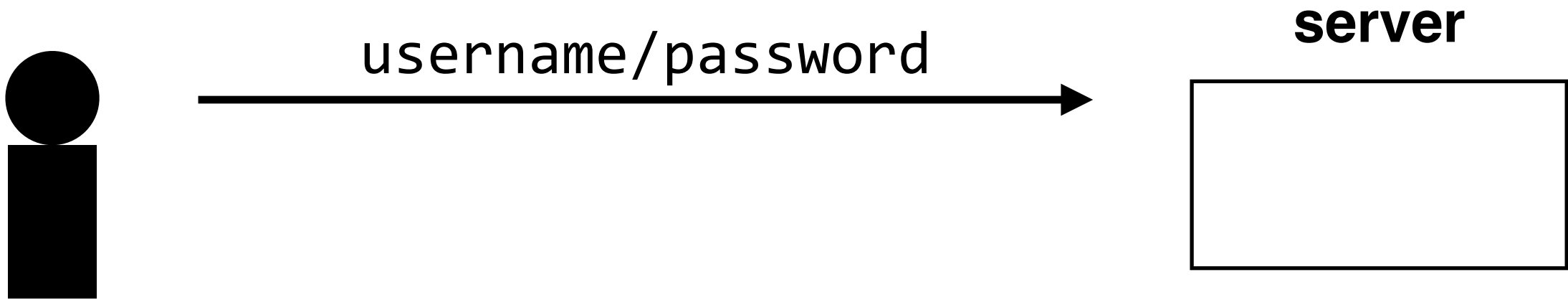
server



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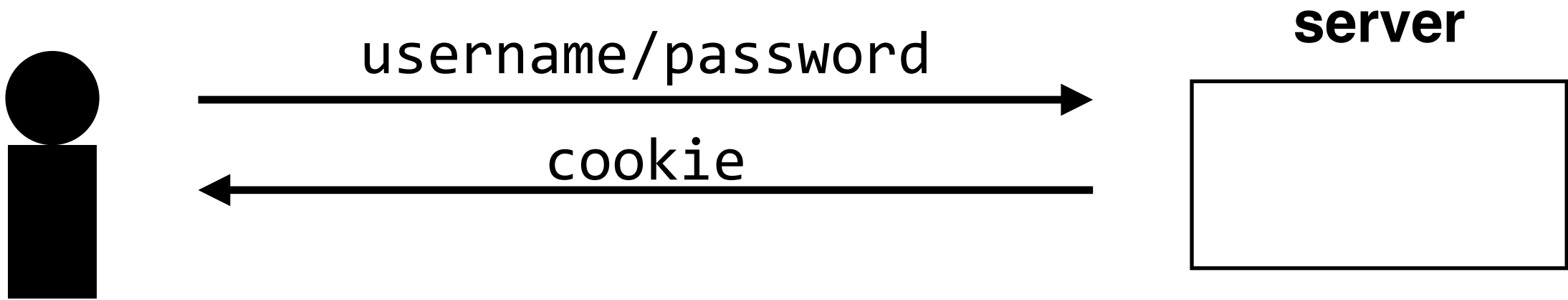
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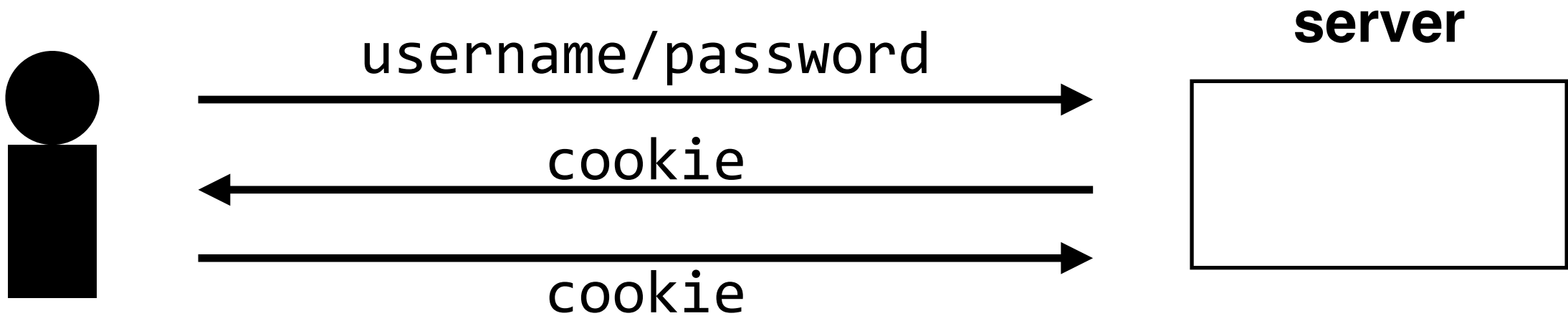
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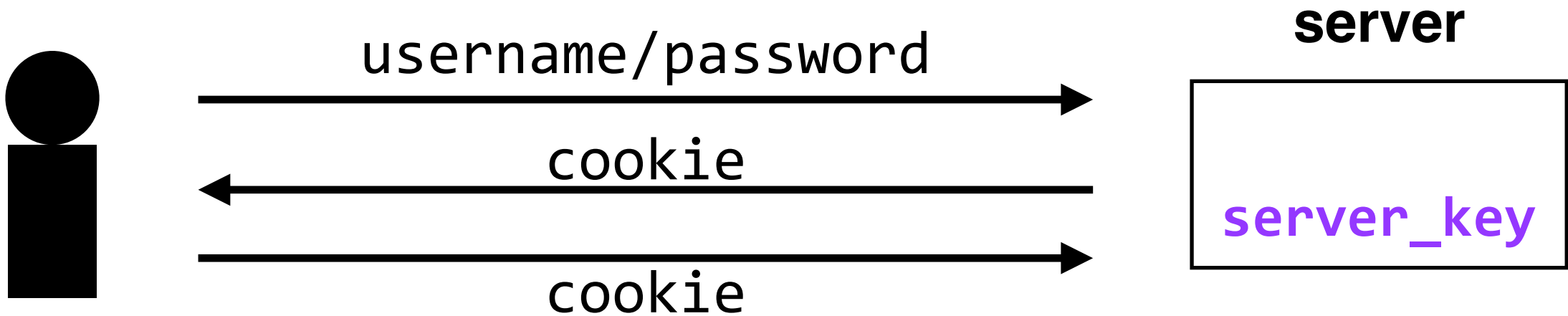
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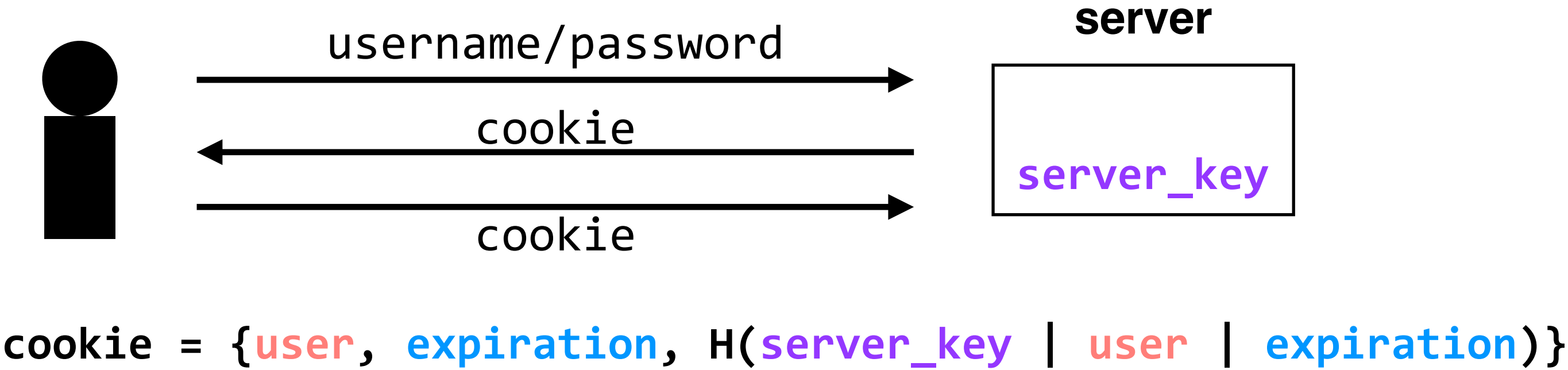
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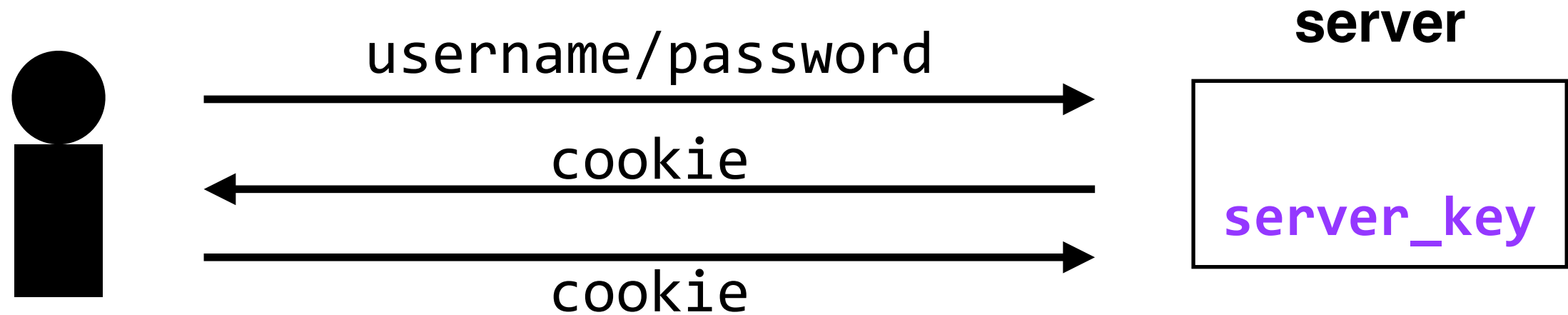
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`cookie = {user, expiration, H(server_key | user | expiration)}`

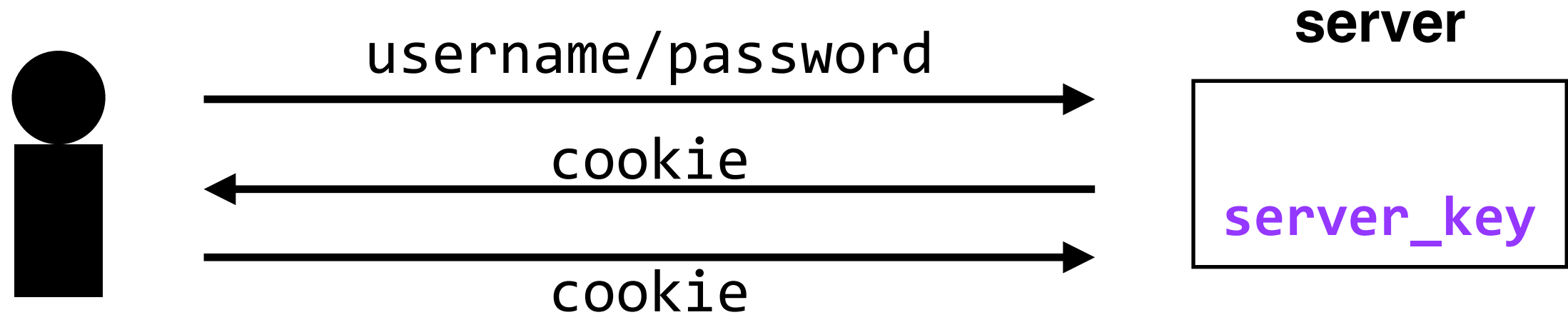
`user` here is more than just a username; it also contains information about the user's browser

limiting transmission of passwords

we want users to transmit passwords infrequently, because transmitting a password repeatedly can open a user up to other attacks outside of our current threat model

cookies allow users to authenticate themselves from some period of time, without repeatedly retransmitting their passwords

threat model: adversary can observe the cookie and is trying to learn the user's password, or to learn enough information such that it could create cookies that were valid for a long period of time



cookie = {**user**, **expiration**, H(**server_key** | **user** | **expiration**)}

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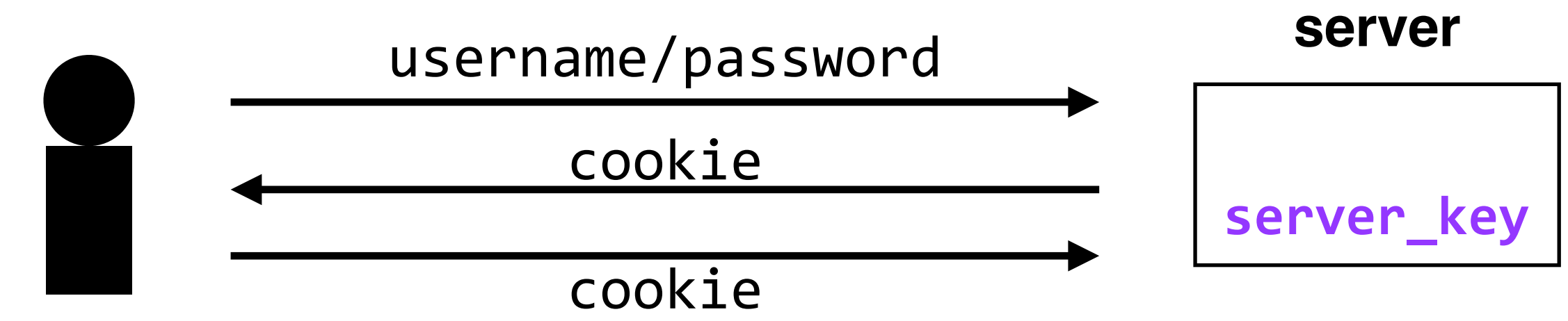
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challenge-response protocols

authenticate users without ever transmitting the password, and can help combat phishing attacks



$$\text{cookie} = \{\text{user}, \text{expiration}, \text{H}(\text{server_key} \mid \text{user} \mid \text{expiration})\}$$

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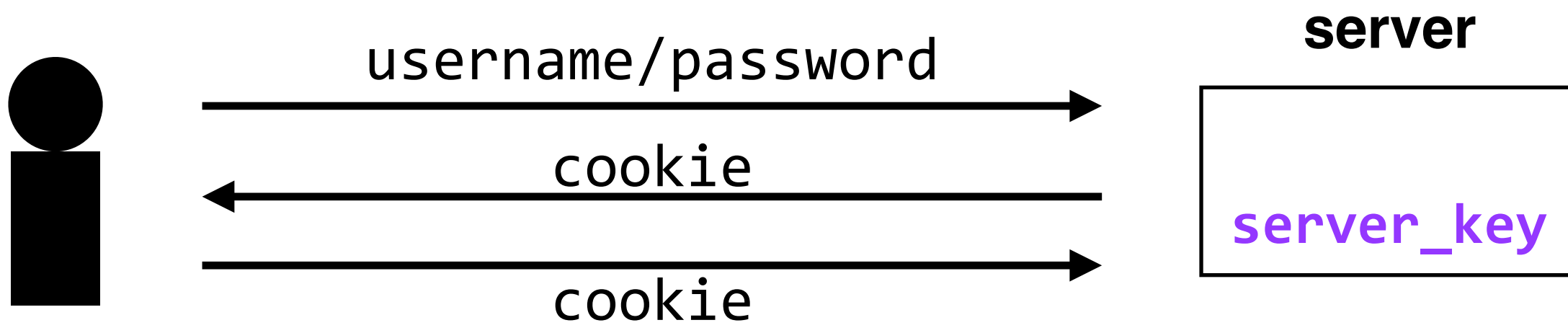
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valid server

username	password
user1	fhxiyfioncvngxvrb

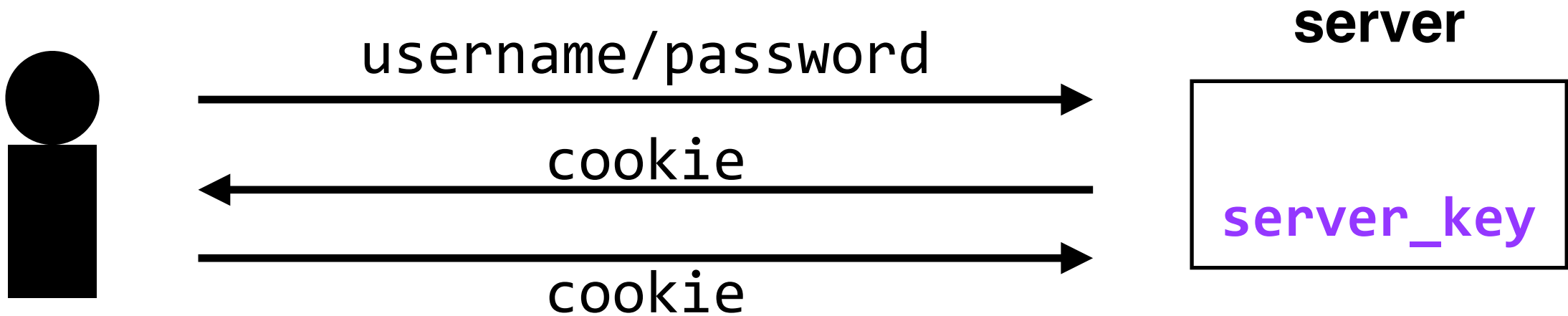
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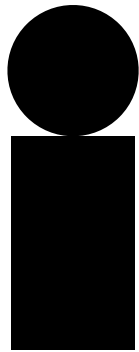
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valid server

username	password
user1	fhxiyfioncvgxvrb

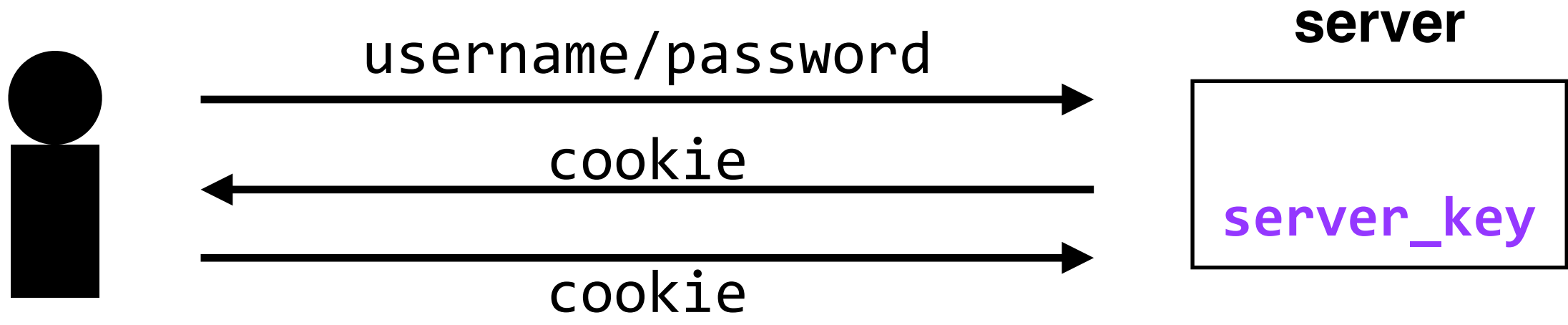
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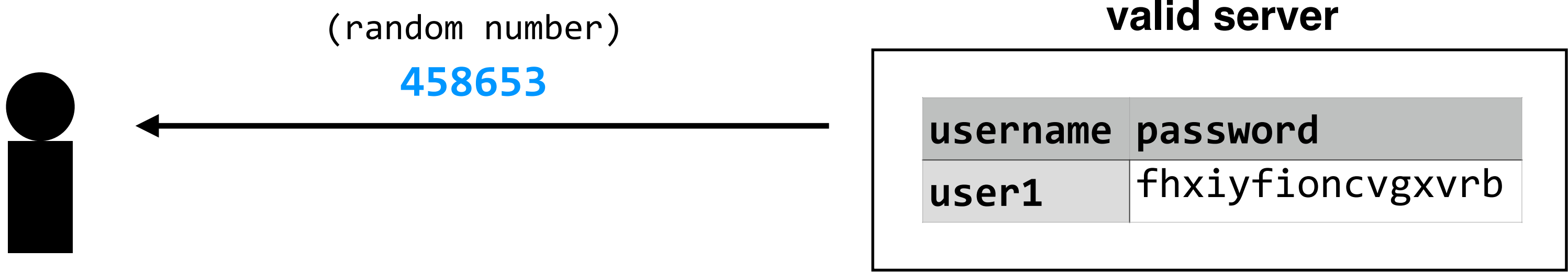
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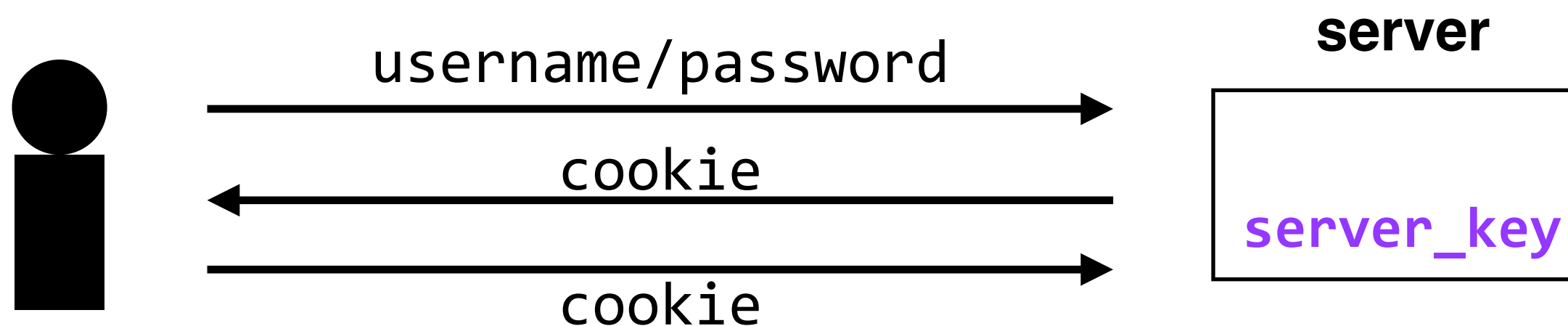
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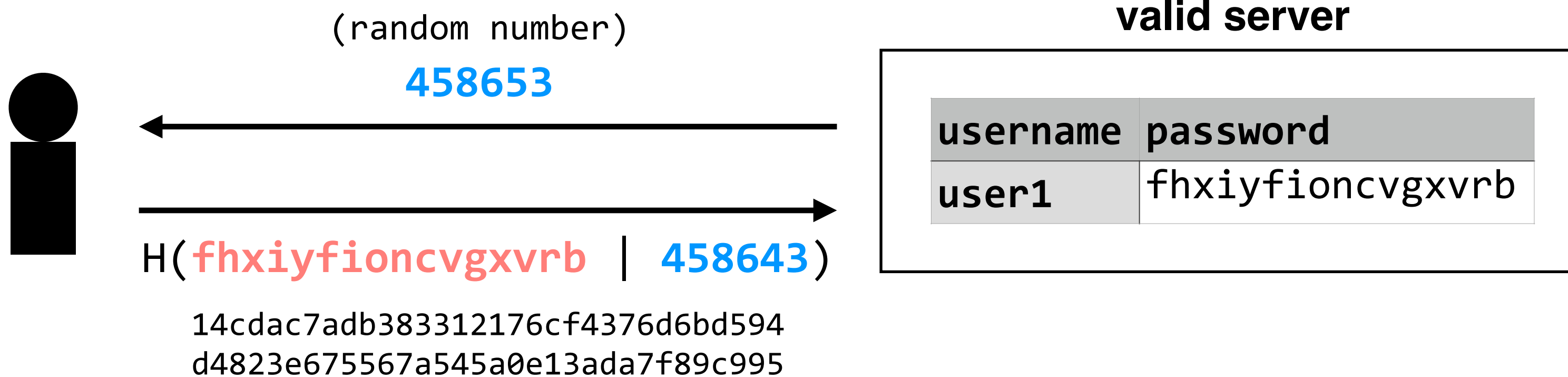
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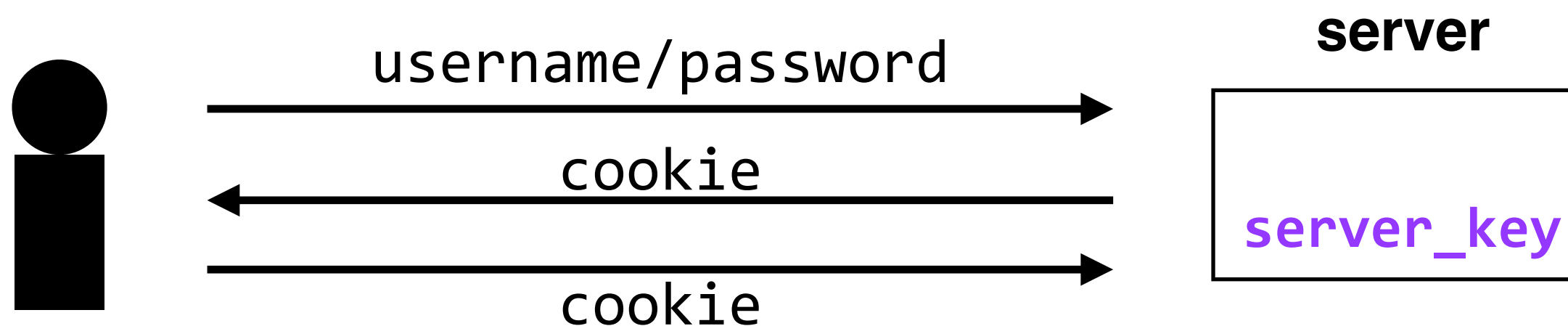
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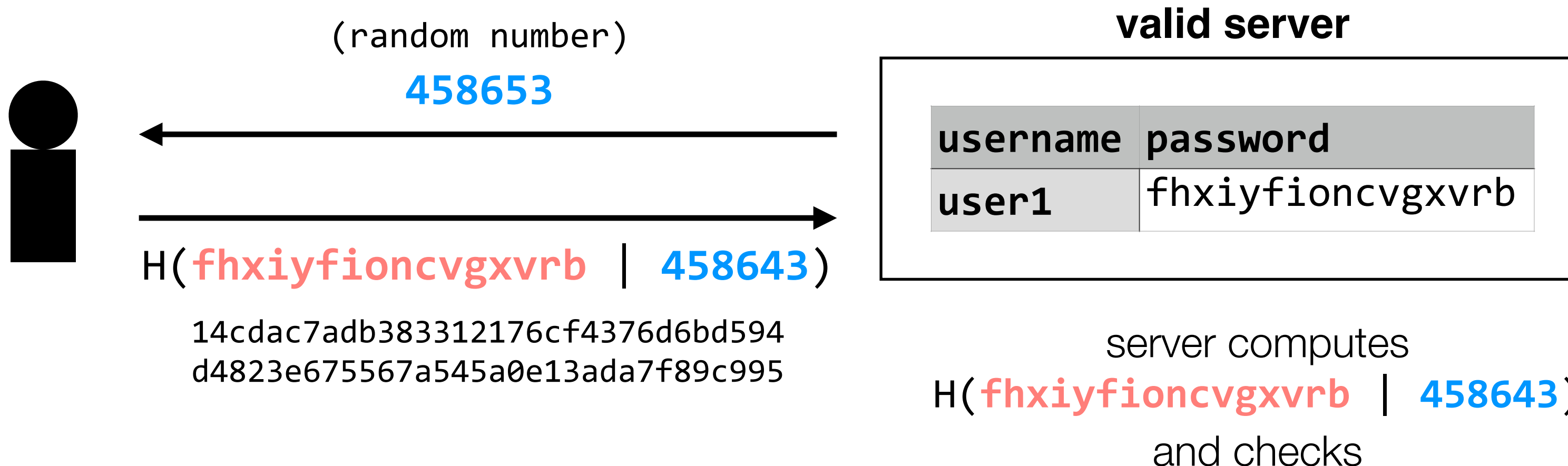
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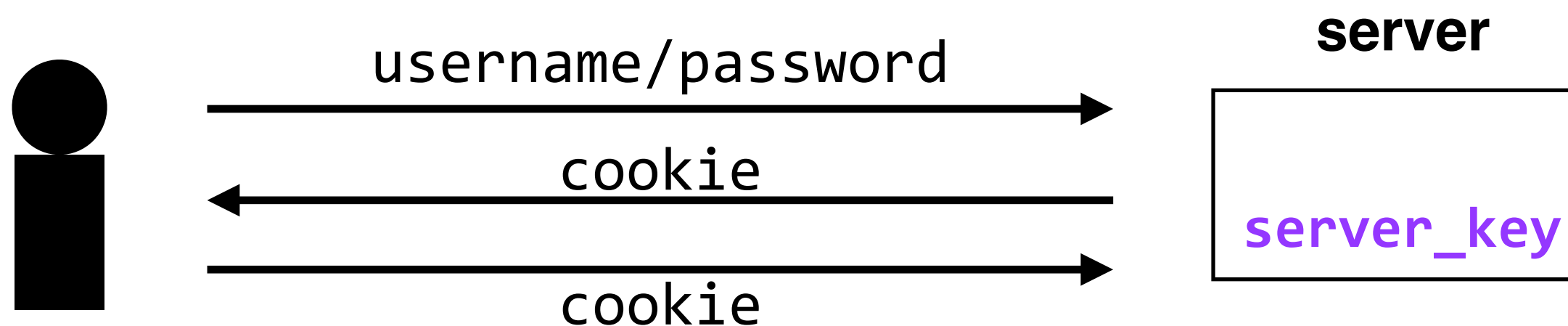


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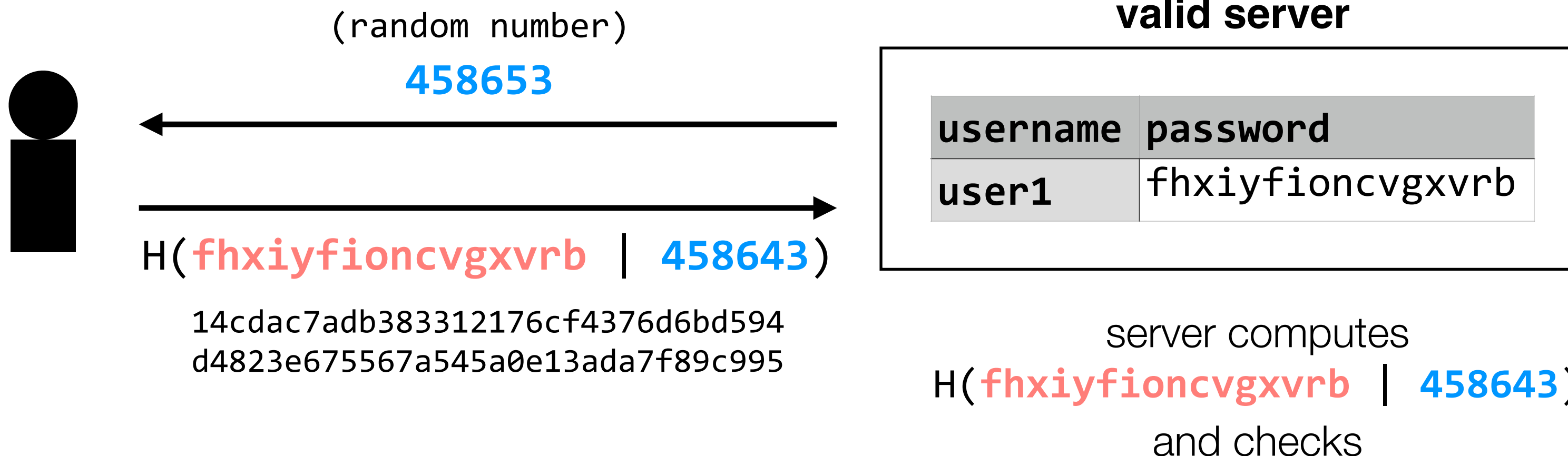
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threat model: adversary owns a server, and is trying to convince the user to send their password directly to the adversary



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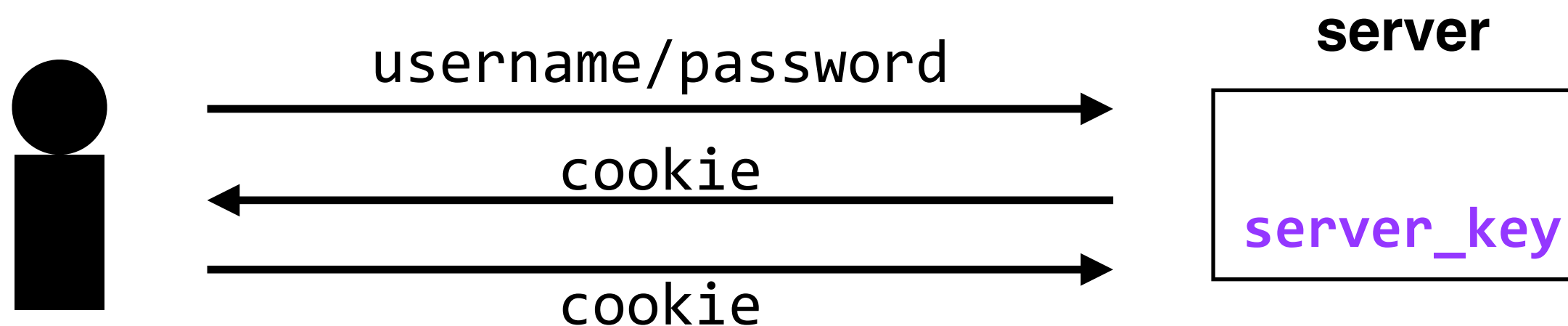
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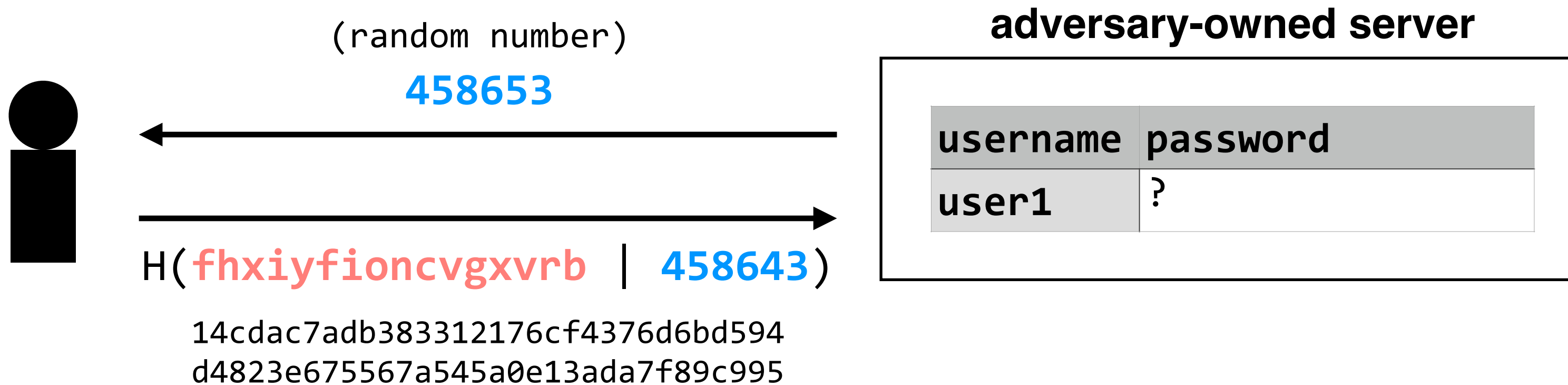
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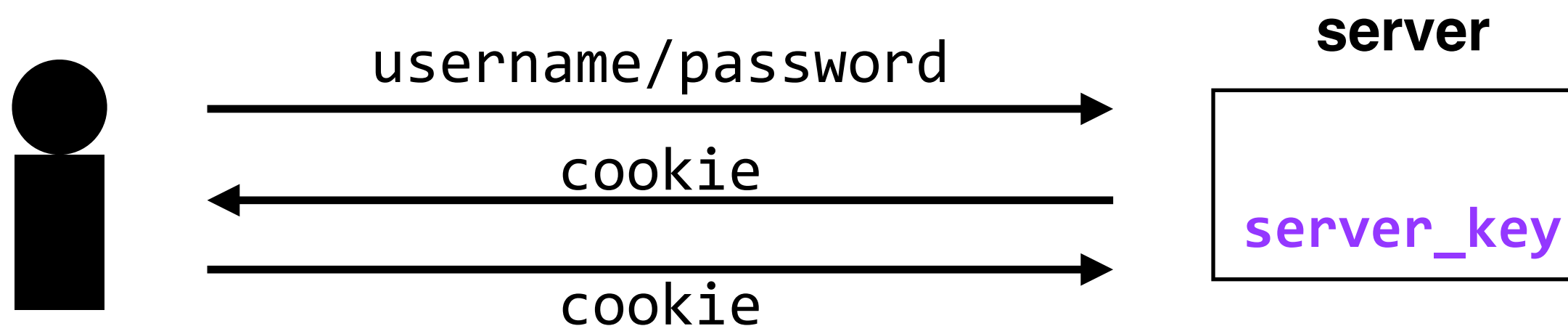
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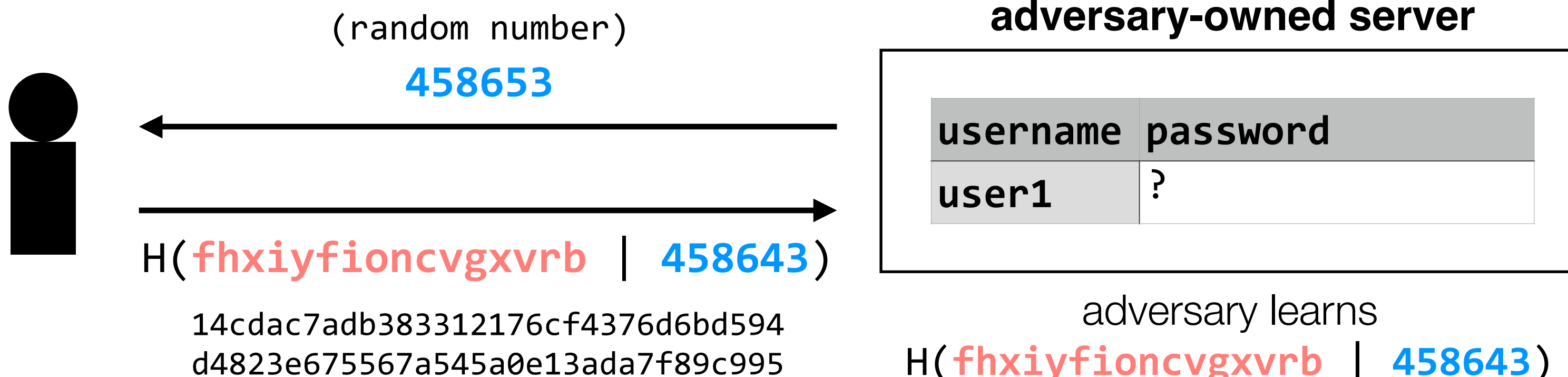
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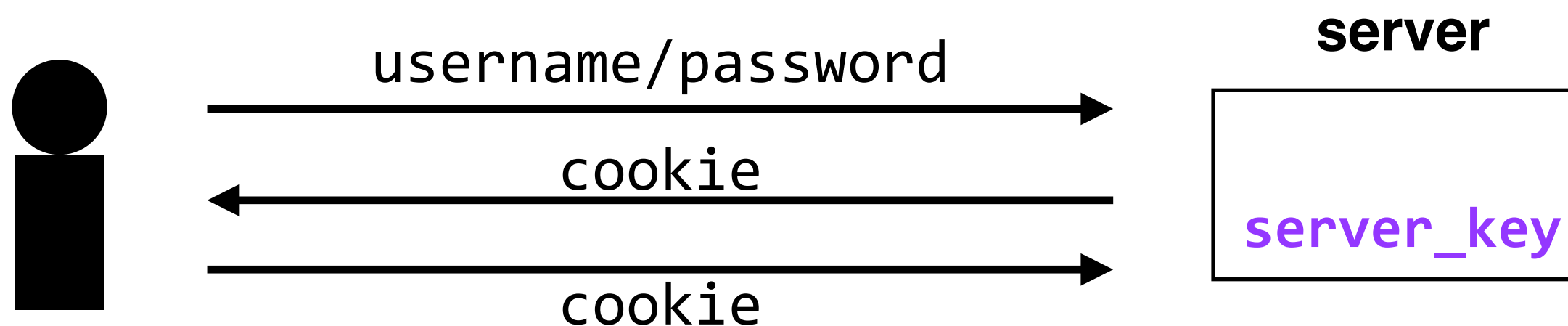
adversary learns
H('fhxiyfioncvgxvrb' | 458643)
but can't reverse-engineer the password
(hashes are one-way)

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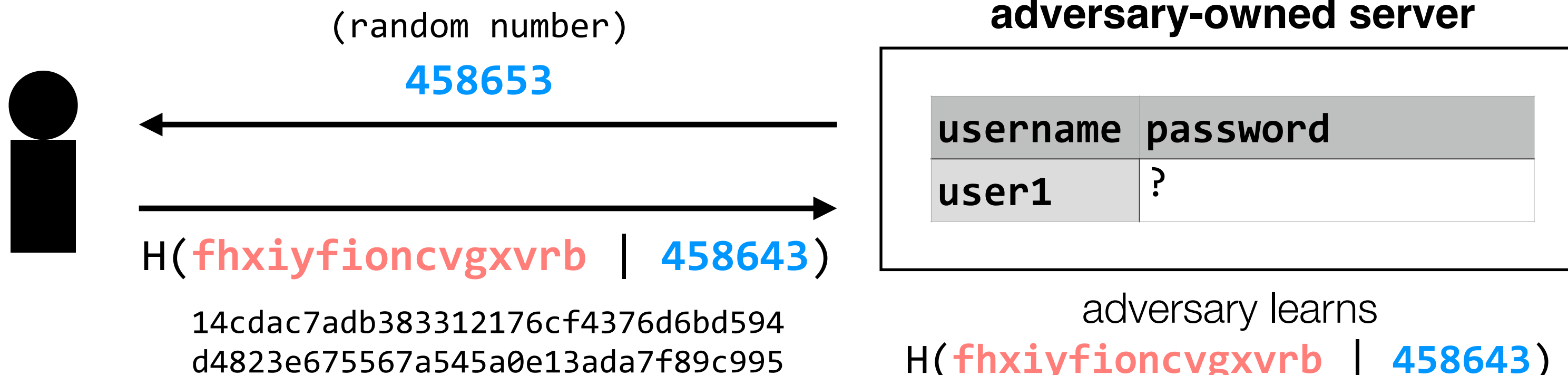
cookie = {**user**, **expiration**, H(**server_key** | **user** | **expiration**)}

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authenticate users without ever transmitting the password, and can help combat phishing attacks

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adversary learns
H(**fhxiyfioncvgxvrb** | **458643**)
but can't reverse-engineer the password
(hashes are one-way)

in this specific setup, problems arise when the valid server is using salted hashes (as it should be), but challenge-response protocols exist to handle that case

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIeOnb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxv3T3uvfYnan00070	ZEmTSuEMiUHNT78Dmka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFeT9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIeOnb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaYOSdkA01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	e0X2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFex5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxv3T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPBU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

are there alternatives to passwords?

username	salt	slow_hash(password salt)
user1	TU6kbcuPm7jA./IQYZG.80	rBda9fbnXhUCWi6c9Mj1UtQF1K1I4Sq
user2	y7oSC2QsrxXTzEZ1DZFdwu	tjFcpSrZN6ry0YueyrAtUfFnFa0ui2C
user3	4ncYRSB5v3rWiU1nPPA0iu	hacrgR1fU44c9XnBckef2fu.ifuB.Ya
user4	SK9H4x4Ha00wz4N0Twj20.	wWk3GjGeMspoqy3VcMghpbkE50jHQXS
user5	j8YyeDX.9GnsT5Hu94z7t0	Vif1hwGH1.5H3j0mawzBPdKTiXf5L6.
user6	CIqY72CGM8KNQId1CqXY7.	stk3mDJDaaH9Nfgf/ePJrkRoK15.Heu
user7	OGtMXrEZEx0L5440dvrhbe	A.7NaJc21Y6I3J6rdJtiIJXVpMvaMgG
user8	RFET9TVo18cmpQdhqMCV5.	yVzcp0jXBoNjcMWHpAxVu1FqdM5W9m
user9	rDAhDK5V6n3TUS3ahf2Z9e	Af4wBH1YqLTvxrhBgVGP85IALXRya3C
user10	nv0YvT0/ocz0W51mbVZSU0	b4miFmYcRy0/TFVhtntbrLPLjFDKu
user11	yNL/e3PpBsfbYgwi0Ai/gu	bbT5sTcmsklSyXVILfVdJ/HAIeOnb..
user12	1zroU10scwDzgG3GY86pF0	MG5LtQ6m/c4gVxbLa1pPIJ403eXFPry
user13	TAkv7nBQ5amY4V.aIjez0u	LHPo8.0XJDG1eWwG87nPvY8/vNPa2G
user14	1J796dTzufUC8ItVIKIy0u	pAI7ZRwvV0hxBVW/sttFquJC1/74LTC
user15	/x.Vk/XhUILbk3XjgyVyf0	zx1P3YgW8d9m1n91Z6GW7jsbBALniWi
user16	hyg8T0JPDX3dCf92Zkx4Yu	50h.8uSUrokBgqnByYYH/mDEH7my98C
user17	YbaY0Sdka01IF.drWa6CX0	ZKbZQtEh4UNoTf1wsXs9hZ7wbnnzgC.
user18	yaE.gULeQg.K2Se1X191Q.	E/syZIC.1.zg5.ZTMZwWX/RmkvpipNu
user19	NLt0SA/QPo2IIbtb7G5610	eOX2p48XcKRXKFY87f56h3W.UEe07Gi
user20	RFFSWUGGFEX5XNyW8rLToe	0W94ciFDN5stVqVzYs1i4t/SNA2pwhS
user21	YWEgwinWuKrNUFvgzQKUNe	yatU0vWN//72U180dxGHnC1TLWdTfXe
user22	ukqUgo0ZWCqIQjH3DwC4xe	jg1.0SatbZooR614taWv3HBpXNN5Xp2
user23	sPRFpmFnu5G41APUkV0wr0	mVpzAYGXEGs583nG894R98k1S3YmP1q
	KDh8kxv2T3uvfYnan00070	ZEmTSuEMiUHNT78Dmaka24RmUW1oPDU

policy: provide **authentication** for users

threat model: adversary has access to the entire stored table

are there alternatives to passwords?

yes, and they have their own trade-offs

using passwords to provide **authentication** takes some effort. storing **salted hashes**, incorporating **session cookies** and **challenge-response protocols** can help mitigate common attacks

passwords provide more **general lessons** about security: consider human factors when designing secure systems, in particular

there are always **trade-offs**. many proposed improvements on passwords do add security, but often add complexity and decrease usability