6.857 Computer and Network Security
Lecture 5

Admin:
- Problem Set #1 due in Lecture 6
- Problem Set #2 out Lecture 6
- Next lecture by TA (secret sharing and bitcoin)
- Submit passwords (not real ones) for problem set #2

Project Ideas:
- "Format-Transforming Encryption"
- Shrimpton 2014 Real-World Crypto talk
- Also see https://fteproxy.org/

Today:
- Crypto hash functions: applications and constructions
- Applications:
  - Signatures
  - Commitments
  - Merkle trees
  - Payword
  - Hash-cash
- Construction:
  - Merkle-Damgard
  - Sponge function

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③ Digital signatures ("hash & sign")

PK_A = Alice's public key (for signature verification)

SK_A = Alice's secret key (for signing)

Signing: $\sigma = \text{sign}(SK_A, M)$ [Alice's sig on M]

Verify: $\text{Verify}(M, \sigma, PK_A) \in \{\text{True}, \text{False}\}$

Adversary wants to forge a signature that verifies.

- For large M, easier to sign h(M):

  $\sigma = \text{sign}(SK_A, h(M))$ ["hash & sign"]

Verifier recomputes h(M) from M, then verifies σ.

In essence, h(M) is a "proxy" for M.

- Need CR (Else Alice gets Bob to sign x, where $h(x)=h(x')$, then claims Bob really signed x', not x.)
- Don't need OW (e.g. h=identity is OK here.)

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④ Commitments

- Alice has value x (e.g. auction bid)
- Alice computes $C(x)$ ("commitment to x") & submits $C(x)$ as her "sealed bid"
- When bidding has closed, Alice should be able to "open" $C(x)$ to reveal x
- Binding property: Alice should not be able to open $C(x)$ in more than one way! (She is committed to just one x.)
- Secrecy (hiding): Auctioneer (or anyone else) seeing $C(x)$ should not learn anything about x.
- Non-malleability: Given $C(x)$, it shouldn't be possible to produce $C(x+1)$, say...
- How:

$$C(x) = h(r\|x) \qquad r \in_R \{0,1\}^{256}$$

To open: reveal r & x

- Note that this method is randomized (as it must be for secrecy.
- Need: OW, CR, NM

(really need more, for secrecy, as $C(x)$ should not reveal partial information about x, even.)

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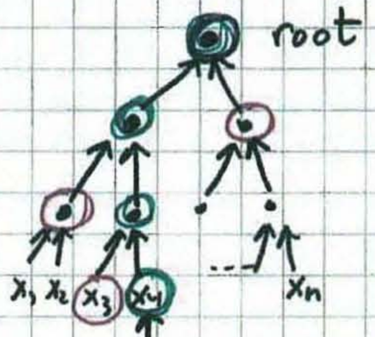
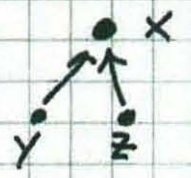
⑤ <u>To authenticate a collection of n objects</u>:

Build a tree with n leaves $x_1, x_2, \ldots, x_n$

& compute authenticator for node as fn of values

at children... This is a "Merkle tree":





Value at x

$= h(\text{value at } y \,\|\, \text{value at } z)$

Root is authenticator for all n values $x_1, x_2, \ldots, x_n$

To authenticate x_i, give sibling of x_i &

sibling of all his ancestors up to root

Apply to: time-stamping data

authenticating whole file system

<u>Need:</u> <u>CR</u>

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Hash-cash (by Adam Back)

- "Proof of work" by email sender

- Intent: reduce spam by making email "expensive" (computational)

- Sender must solve puzzle:

  find r s.t.

  h(sender, recipient, date, time, r)

  ends in 20 zeros

- include r in header as "proof of work/payment"

- each for recipient to verify

- takes about 2^{20} trials to solve for r

- doesn't work against bot-nets

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Hash function construction ("Merkle-Damgard" style)

- Choose output size d (e.g. $d = 256$ bits)
- Choose "chaining variable" size c (e.g. $c = 512$ bits)

  [Must have $c \geq d$; better if $c \geq 2 \cdot d$ ...]
- Choose "message block size" b (e.g. $b = 512$ bits)
- Design "compression function" f

  $$f : \{0,1\}^c \times \{0,1\}^b \rightarrow \{0,1\}^c$$

  [f should be OW, CR, PR, NM, TCR, ...]
- Merkle-Damgard is essentially a "mode of operation" allowing for variable-length inputs:

  * Choose a c-bit initialization vector IV, c_0

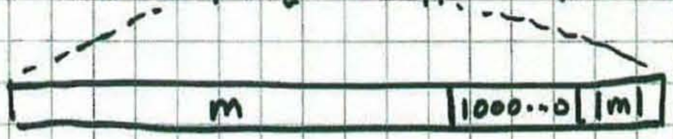
  [Note that c_0 is fixed & public.]

  * [Padding] Given message, append

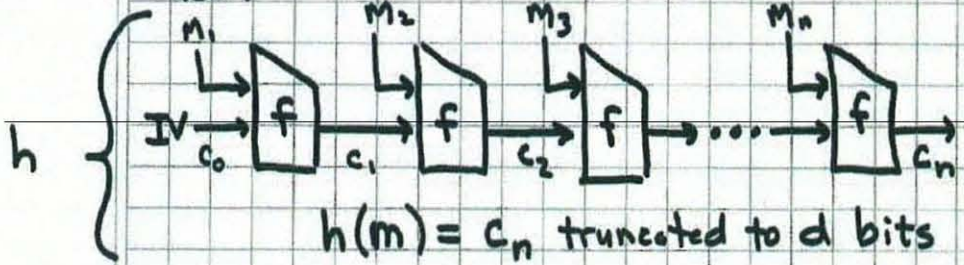
  - 10^* bits
  - fixed-length representation of length of input

  so result is a multiple of b bits in length:

  $$M = M_1 M_2 \cdots M_n \quad (n \text{ b-bit blocks})$$



Then:



$h(m) = c_n$ truncated to d bits

Theorem: If f is CR, then so is h.

Proof: Given collision for h, can find one for f by working backwards through chain. ▨

Thm: Similarly for OW.

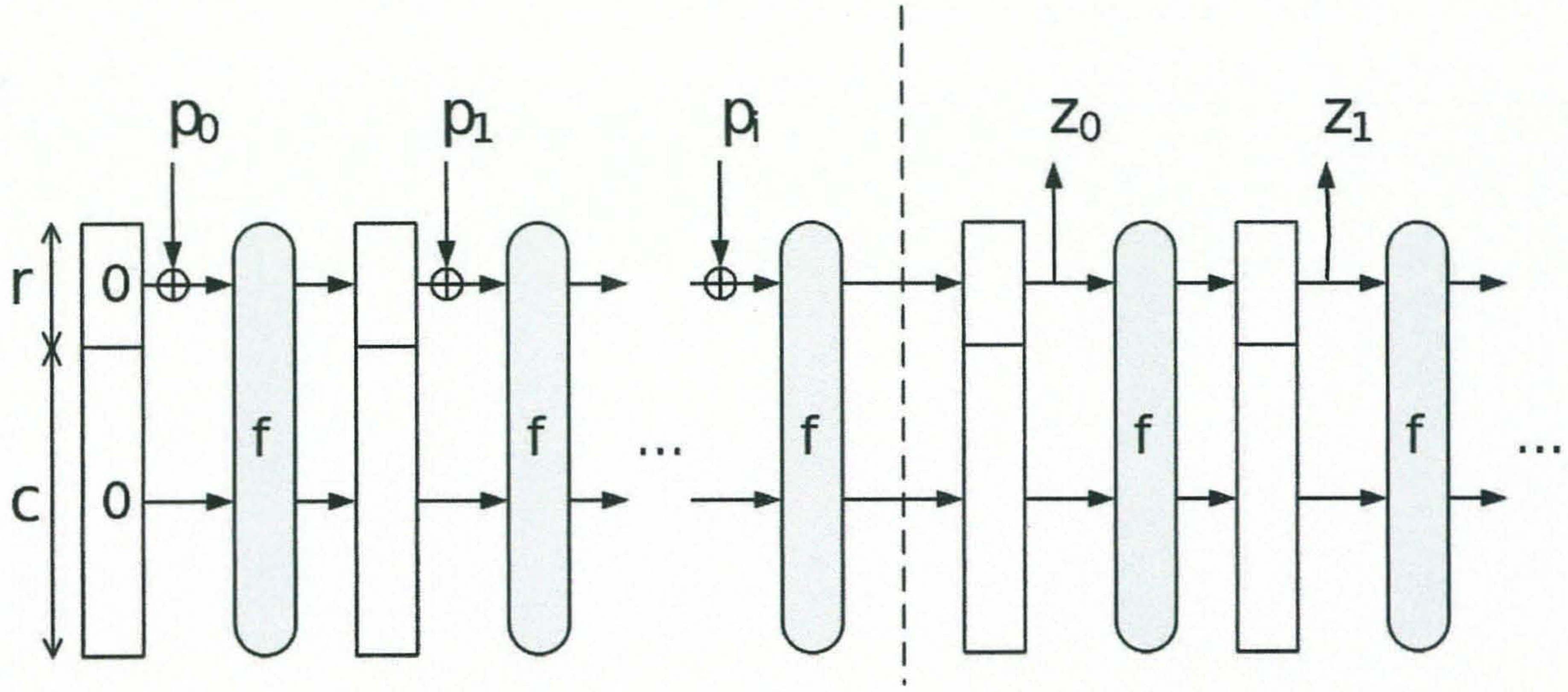
Common design pattern for f:

$$f(c_{i-1}, M_i) = c_{i-1} \oplus E(M_i, c_{i-1})$$

where $E(K, M)$ is an encryption function (block cipher) with b-bit key and c-bit input/output blocks.

(Davies-Meyer construction)

Keccak



Keccak Sponge Construction

d = output hash size in bits $\in \{224, 256, 384, 512\}$

$c = 2d$ bits

state size = $25w$ where w = word size (e.g. $w=64$)

$c + r = 25w$

$r \geq d$ (so hash can be first d bits of z_0)

Input padded with 10^*1 until length is a multiple of r

f has 24 rounds (for $w=64$), not quite identical (round constant)

f is public, efficient, invertible function from $\{0,1\}^{25w}$ to $\{0,1\}^{25w}$

e.g. $d = 256$
$c = 512$
$r = 1088$
$w = 64$