Public-Key Cryptography

Lecture 12

CCA Secure PKE

Hybrid Encryption

CCA Secure PKE

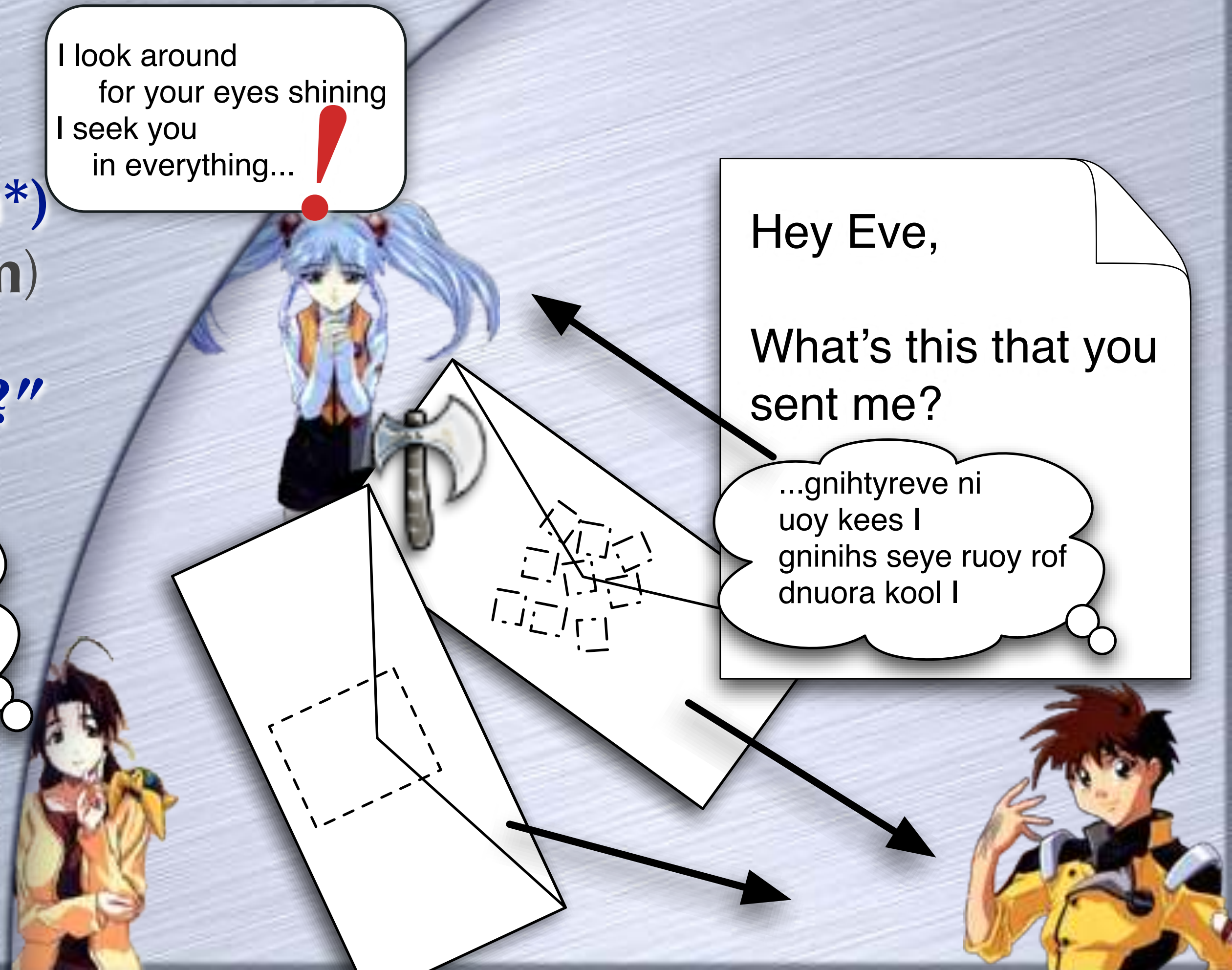
- In SKE, to get CCA security, we used a MAC
  - Bob would accept only messages from Alice
- But in PKE, Bob <u>wants to</u> receive messages from Eve as well!
  - But only if it is indeed Eve's "own message": she should "know" her own message!

Chosen Ciphertext Attack

- Suppose Enc SIM-CPA secure
  - Suppose encrypts a character at a time (still secure)

A subtle e-mail attack

Alice → Bob: Enc(m)
Eve: Hack(Enc(m)) = Enc(m*)
(where **m*** = Reverse of **m**)
Eve → Bob: Enc(m*)
Bob → Eve: "what's this: m*?"
Eve: Reverse m* to find m!



Malleability

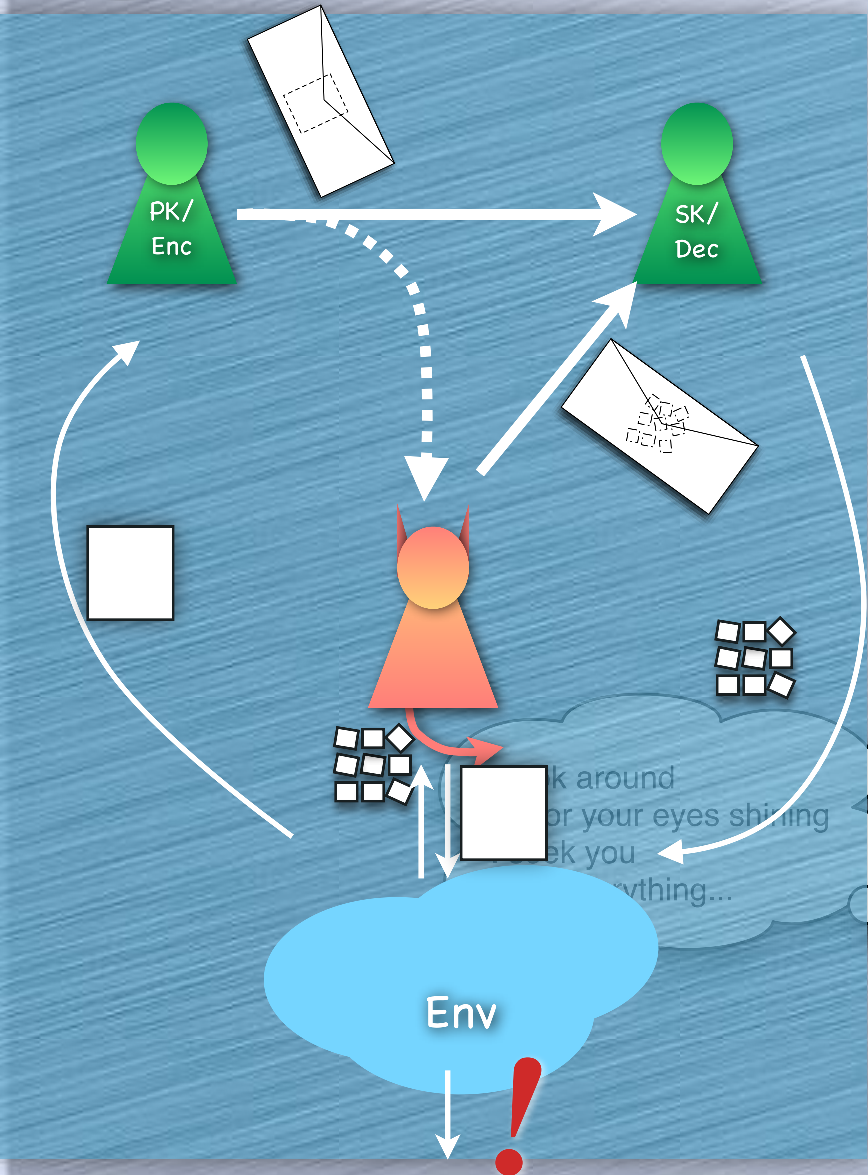
- Malleability: Eve can "malleate" a ciphertext (without having to decrypt it) to produce a new ciphertext that would decrypt to a "related" message

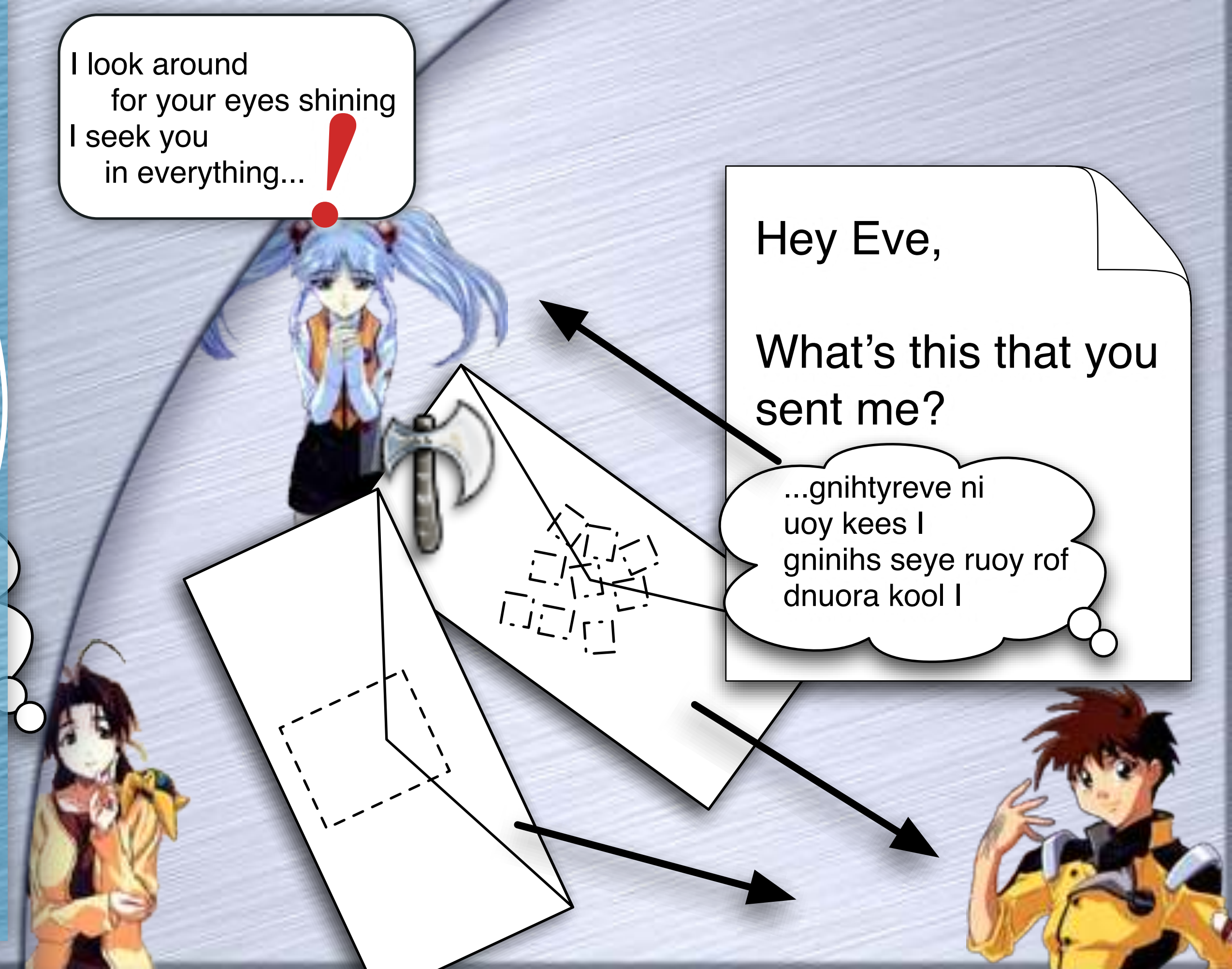
> More subtly, the 1 bit - valid or invalid - may leak information on message or SK

- E.g.: Malleability of El Gamal
  - Recall: $Enc_{(G,g,Y)}(m) = (g^x, M.Y^x)$
  - Given (X,C) change it to (X,TC): will decrypt to TM
  - Or change (X,C) to (X^a, C^a): will decrypt to M^a
- If chosen-ciphertext attack possible
  - i.e., Eve can get a ciphertext of her choice decrypted
  - Then Eve can exploit malleability to learn something "related to" Alice's messages

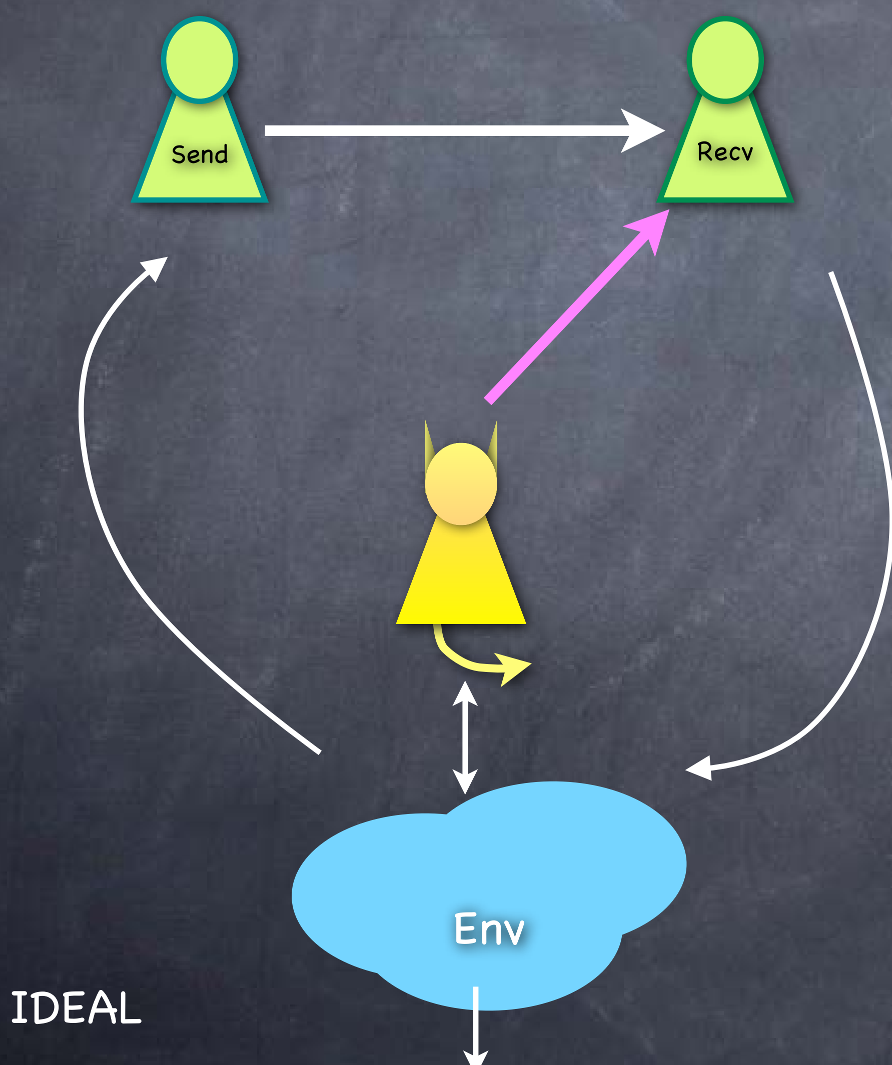
Chosen Ciphertext Attack

- SIM-CCA: does capture this attack





SIM-CCA Security (PKE)



Secure (and correct) if:

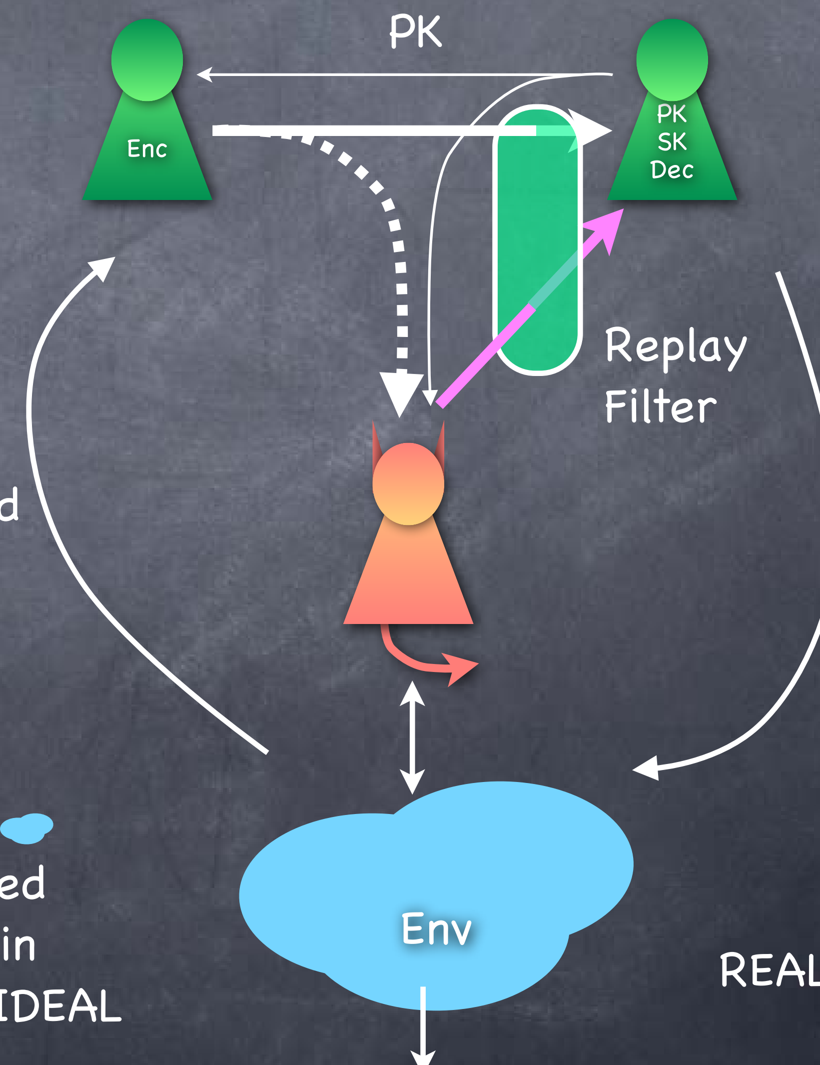
∀

∃ s.t.

∀

output of

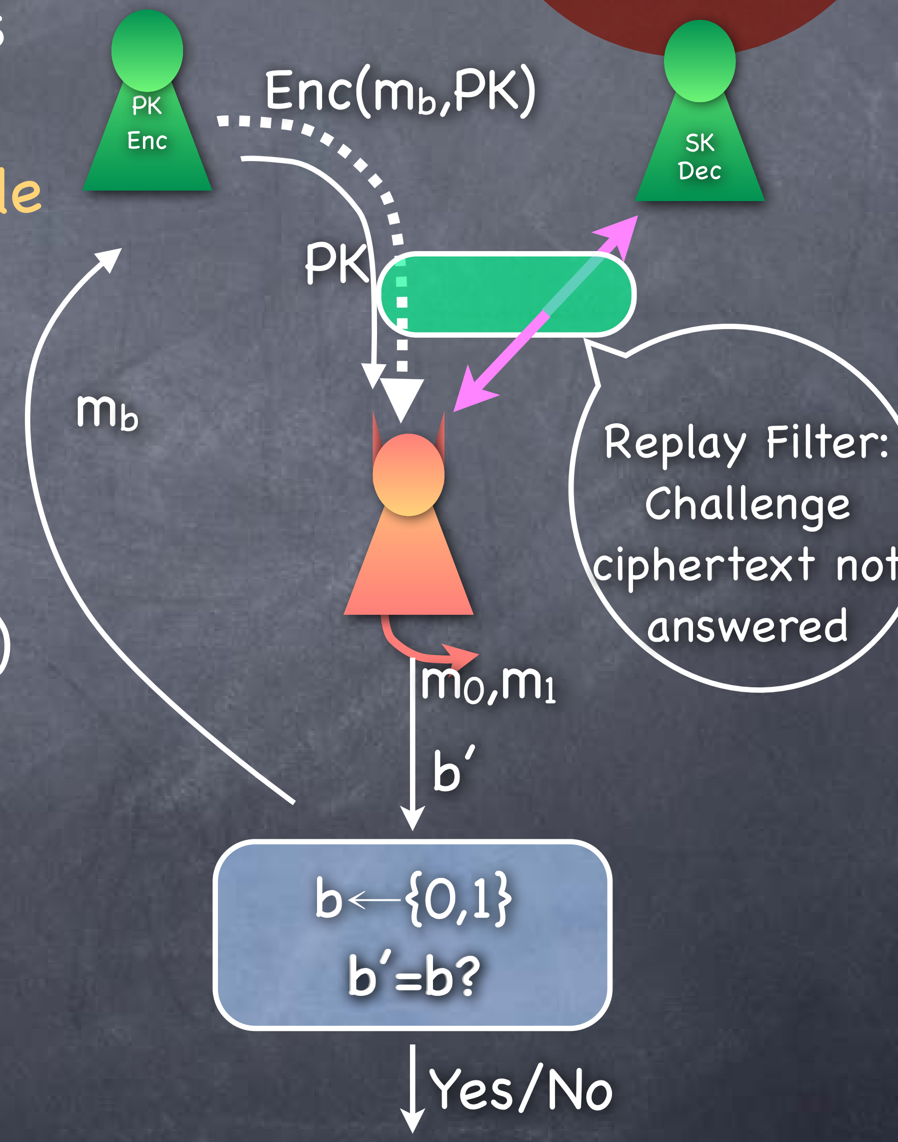
is distributed identically in REAL and IDEAL



IND-CCA (PKE version)

IND-CCA + ~correctness equivalent to SIM-CCA

- Expt picks a random bit b. It also runs KeyGen to get a key (PK,SK). Adv gets PK and (guarded) access to Dec_{SK} oracle
  - Adv sends two messages m_0, m_1 to Expt
  - Expt returns $Enc(m_b,K)$ to the adversary (and installs replay filter)
  - Adversary returns a guess b'
  - Experiment outputs 1 iff b'=b
- IND-CCA secure if for all PPT adversaries $Pr[b'=b] - 1/2 \leq \nu(k)$



CCA Secure PKE Schemes

- Several schemes in the heuristic "Random Oracle Model"
  - RSA-OAEP
  - Fujisaki-Okamoto
  - DHIES (doesn't need the full power of ROM)
- Cramer-Shoup Encryption: Provably secure CCA scheme, under DDH assumption (next time)
- Hybrid Encryption schemes: Improving the efficiency of PKE

Random Oracle Model

- Random Oracle: a mythical oracle that, when initialized, picks a random function $R:\{0,1\}^* \rightarrow \{0,1\}^{n(k)}$ and when queried with x, returns R(x)
  - All parties have access to the same RO
- In ROM, evaluating some "hash function" H would be modeled as accessing an RO
  - Hope: the code for H has "no simple structure" and only way to get anything useful from it is to evaluate it on an input
- Sometimes security definitions need to be adapted for ROM
- Rigorous proofs of security, after moving to the ROM

Random Oracle Model

- **There is no Pseudo-RO**
  - Unlike PRF, RO must be locally evaluable for all parties. (think: giving out the seed of a PRF)
- There are schemes secure in ROM, such that for any instantiation of the RO, the scheme is insecure!
  - Also natural <u>constructs/primitives</u> which are realizable in ROM, but not in the standard model!
- What does a proof in ROM tell us?
  - Secure against attacks that treat H as a blackbox (and for which H is pseudorandom)

RSA-OAEP

- RSA-OAEP
  - "Text-book RSA encryption" (i.e., f_{RSA}, the Trapdoor OWP candidate) applied to an "encoding" of the message
    - Encoding is randomized
    - Encoding uses a hash function modeled as a Random Oracle
    - Security in the RO Model, assuming f_{RSA} a OWP
  - Part of RSA Cryptography Standard (PKCS#1 Ver 2.1). Commonly used in SSL/TLS implementations

Hybrid Encryption

- PKE is far less efficient compared to SKE (even in ROM)
  - SKE using Block Ciphers (e.g. AES) and MAC is very fast
  - RSA-OAEP uses modular exponentiations (Cramer-Shoup even more)
- Hybrid encryption: Use (CCA secure) PKE to transfer a key for the (CCA secure) SKE. Use SKE with this key for sending data
  - Hopefully the combination remains CCA secure
  - Note: PKE used to encrypt only a (short) key for the SKE
    - Relatively low overhead on top of the (fast) SKE encryption

Hybrid Encryption

Or to generate a key

- Hybrid Encryption: KEM/DEM paradigm
  - Key Encapsulation Method: a public-key scheme to transfer a key
  - Data Encapsulation Method: a symmetric-key scheme (using the key transferred using KEM)
- For what KEM/DEM is a hybrid encryption scheme CCA secure?
  - Works if KEM is a SIM-CCA secure PKE scheme and DEM is a SIM-CCA secure SKE scheme
    - Easy to prove using "composition" properties of the SIM definition
  - Less security sufficient: KEM used to transfer a random key; DEM uses a new key every time.

Another PKE Scheme: CCA Secure in RO Model

- Fujisaki-Okamoto Hybrid scheme
  - KEM "encrypts" random x, using random coins derived as H(m,x), where m is the message and H a random oracle
  - DEM "encrypts" m with key K = G(x), where G is another random oracle
  - Decryption decrypts x, then m, and then checks if KEM was correct
  - Very weak security sufficient for encryptions used in KEM and DEM (but only with H, G modelled as random oracles)

Another CCA Secure PKE: DHIES

- Diffie-Hellman Integrated Encryption Scheme
  - Part of some standards
- Essentially a hybrid scheme
  - Data Encapsulation: CPA secure SKE, and MAC
  - Key Encapsulation: $X=g^x$. Let $K=Y^x$, where Y is the PK (as in El Gamal), and (K_{SKE},K_{MAC}) = Hash(K) (where $K=Y^x=X^y$)
- CCA secure if Hash is modelled as a Random Oracle
  - Alternately, in the standard model, can be based on a complex (non-standard) assumption involving Hash and the group: "Oracle Diffie-Hellman Assumption"