Unus pro omnibus

Multi-Client Searchable Encryption via Access Control

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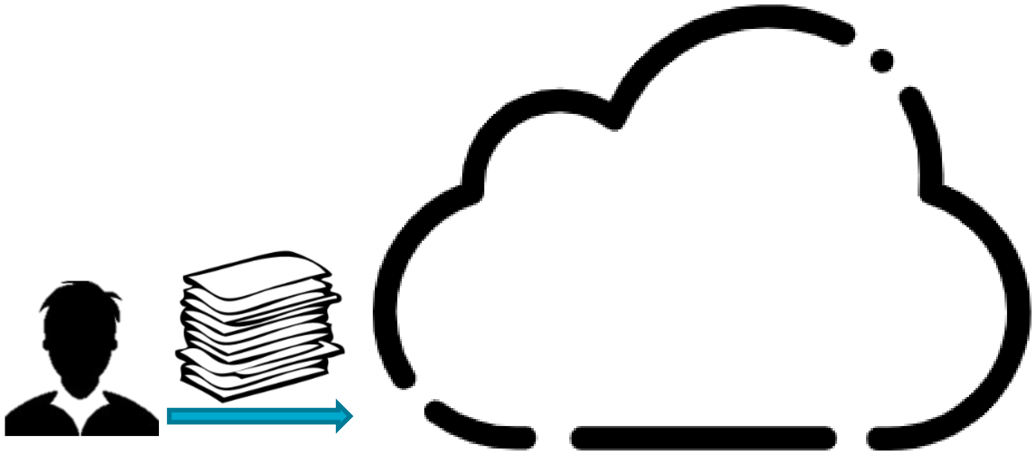
(Secure) Mobile Cloud Applications

- Store ever-growing data from individuals and companies
  - relieve the need for local storage/software



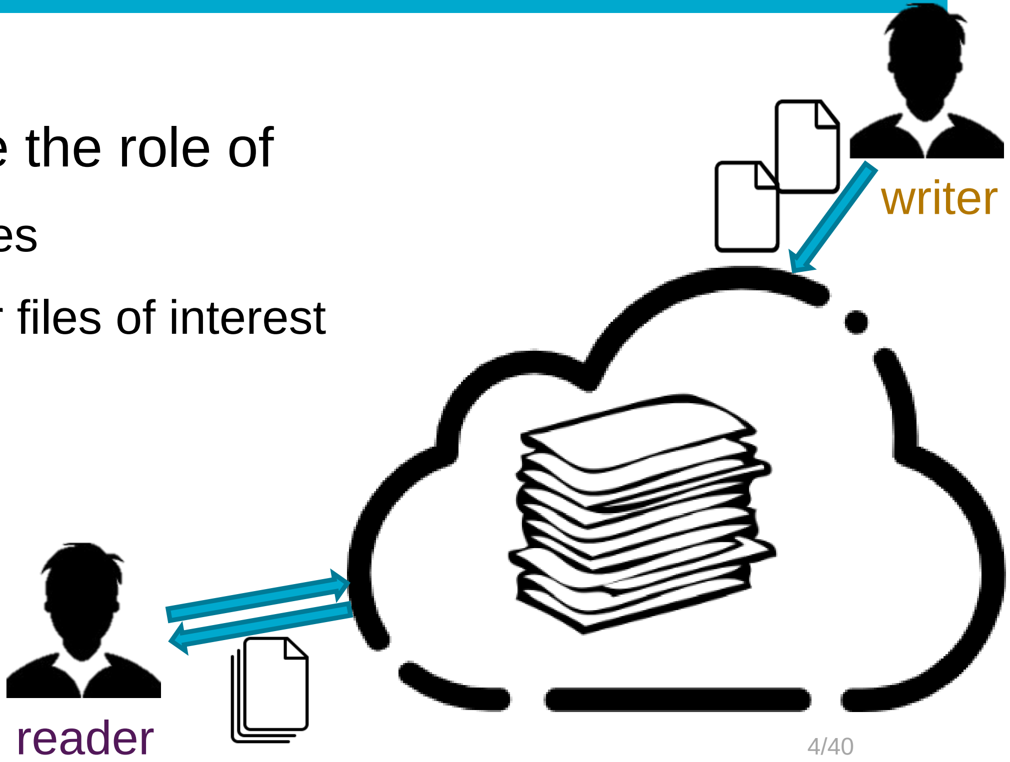
(Secure) Mobile Cloud Applications

- Store ever-growing data from individuals and companies
  - relieve the need for local storage/software
- Manifest as collaborative platforms
- Catalyse novel contributive applications
  - sensor network for crowdsourcing
  - machine learning
  - collective intelligence

from Wikipedia
Google Workspace: 120M education clients by 2021
Microsoft SharePoint: 200M clients by 2020

Collecting & Utilizing Data with the Cloud

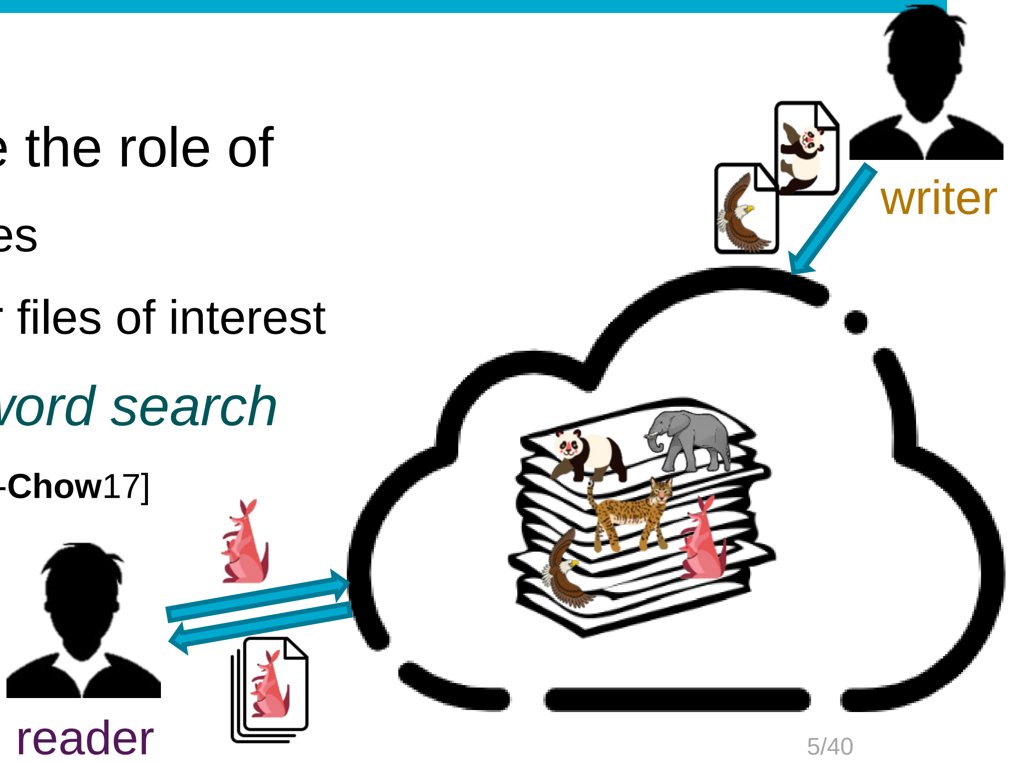
- Each of **many clients** can take the role of
  - *writer* who contributes/updates files
  - *reader* who retrieves/searches for files of interest



Collecting & Utilizing Data with the Cloud

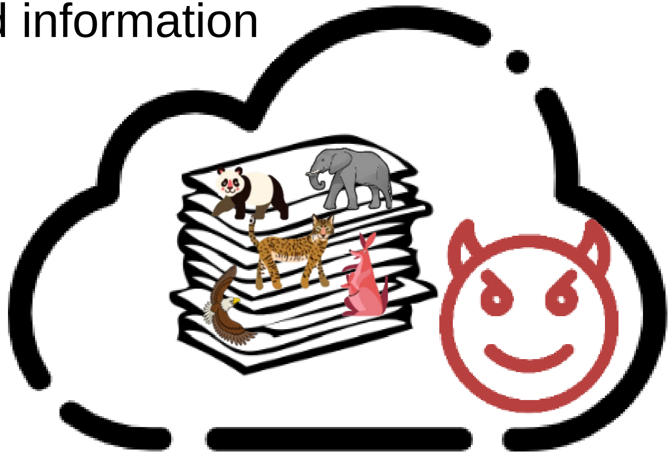
- Each of **many clients** can take the role of
  - *writer* who contributes/updates files
  - *reader* who retrieves/searches for files of interest
- We focus on *fundamental keyword search*
  - cover general query-response [Lai-**Chow**17]
  - each file has a set of keywords
  - "files of interest"

  = those contain a specific keyword



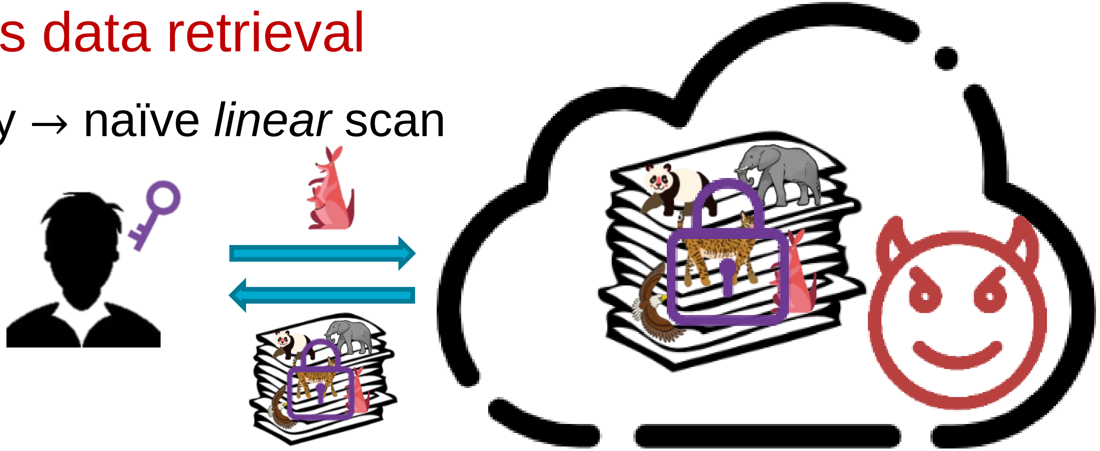
Secure Data Outsourcing

- Cloud servers are untrustworthy
- Outsourced data are sensitive
  - e.g., data breach of medical records or credit card information



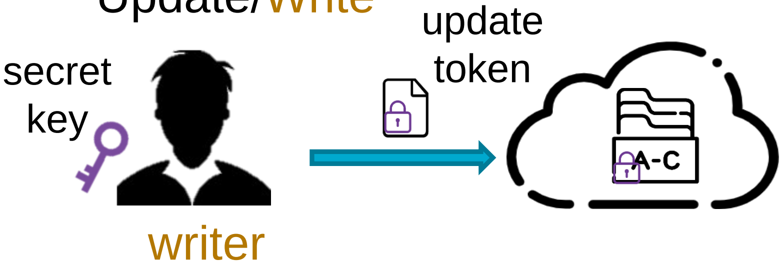
Secure Data Outsourcing

- Cloud servers are untrustworthy
- Outsourced data are sensitive
- Standard encryption hinders data retrieval
  - download all → decrypt locally → naïve *linear* scan
  - no multi-client support

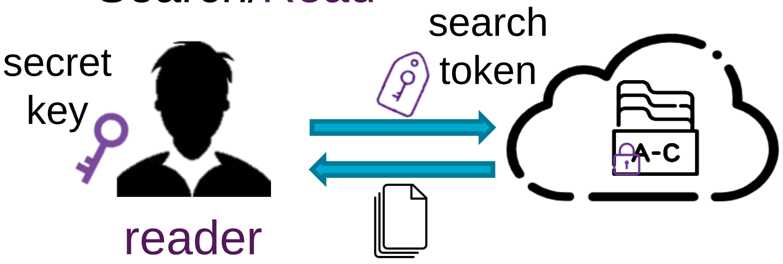


Searching Encrypted Data in the Cloud

- Searchable Symmetric Encryption (SSE) [SWP00, CGKO06, KPR12]
  - Update/Write



  - Search/Read



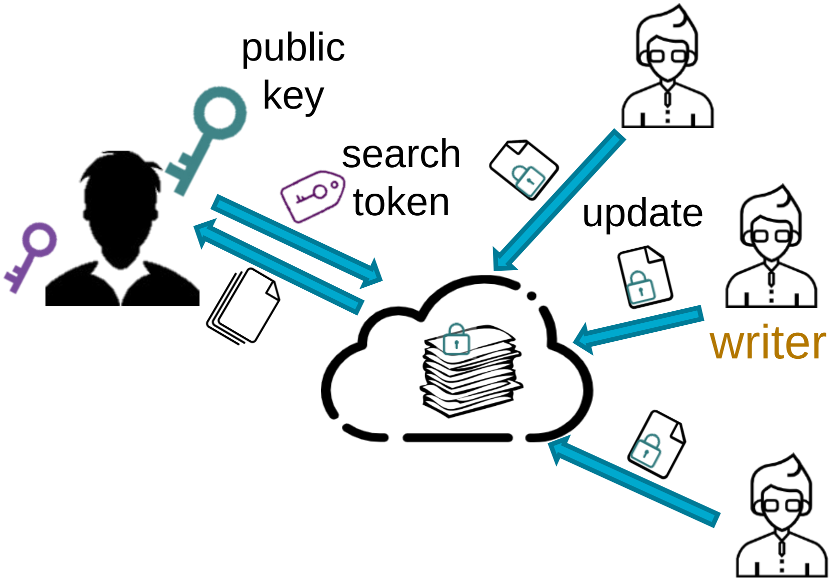
✓ Sublinear search
- index data for optimal search time

✓ Forward privacy [Bost16, Lai-**Chow**17]
- updates can't be searched by old search tokens
- upon any related search, "update" update tokens
- update "changed" so old search token won't work

✘ No multi-client support
- writer = reader = secret-key owner
- symmetric setting hinders multi-writer

Searching Encrypted Data in the Cloud

- Public-key Encryption with Keyword Search (PEKS) [BDOP04]



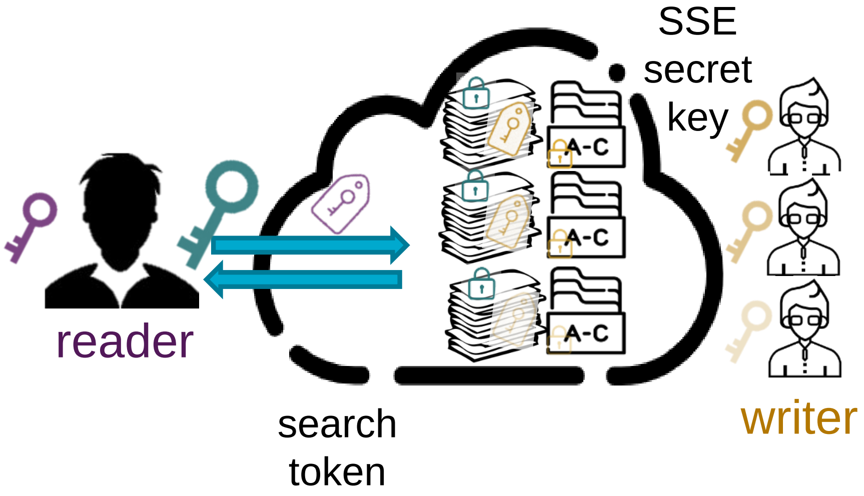
✓ Multiple writers for a reader
- no secret-key distribution
- no synchronous communication

✘ Often require linear testing
- challenging to jointly index with no shared secret/coordination

✘ Hard to be forward private
- writers don't know search state from reader
- nor when to "change" update tokens

Hybrid Searchable Encryption [**Wang-Chow22**]

- 1st non-trivial attempt *towards* the best of SSE [SWP00] & PEKS [BDOP04]



✓Multiple writers for a single reader
- *"All for One"* (*"Omnes pro uno"*)
- access writers' SSE tokens via PEKS

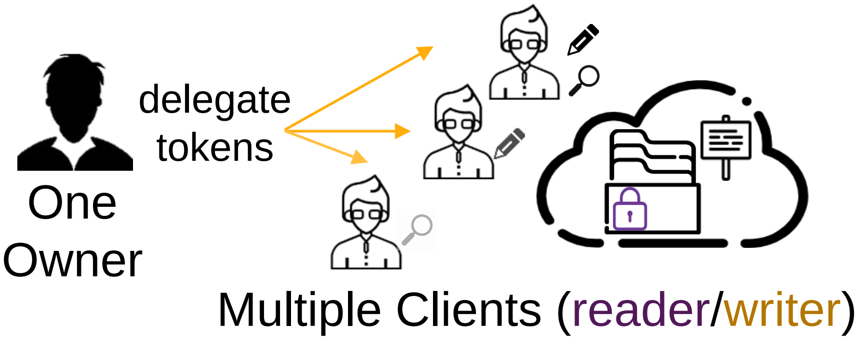
✓Sublinear search
- PEKS.Search for tokens + SSE.Search for files
- PEKS from *ID-Coupling Key-Aggregate Enc.*

✓Forward privacy (per epoch)
- synchronize writers with a global clock
- writers rebuild (per epoch) for fast search

"One for All": Delegatable Searchable Encryption

SSE	PEKS	HSE
✓ Sublinear/optimal search	✓ Multi-writer support	✓ Sublinear search (not optimal ✗)
✓ Forward privacy	✗ Linear Search	✓ Multi-writer support
✗ No multi-client support	✗ No forward privacy	✓ Confined forward privacy (epoch + rebuild ✗)

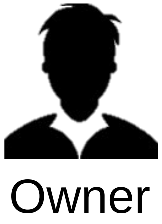
DSE: A New Notion Advancing Searchable Encryption



- ✓ Standard Forward Privacy
- ✓ Search is Optimal Asymptotically
- ✓ Multi-Writer Multi-Reader Support
- ✓ Construction allows Extensibilities

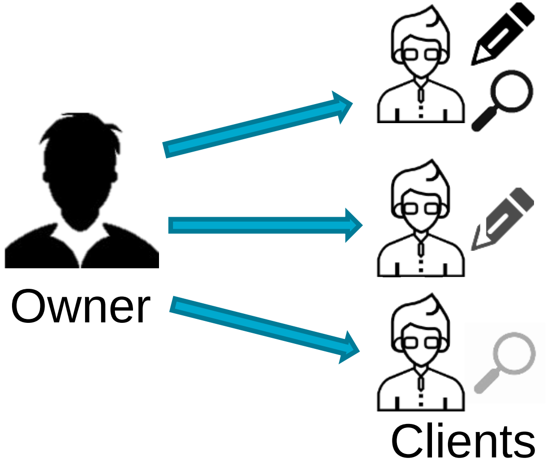
DSE: Access Control on Joint Index

- A data owner initializes the global state and empty database



DSE: Access Control on Joint Index

- A data owner initializes the global state and empty database
- Simple *one-time* (token) delegation (*per client*) by the data owner
  - grant *keyword-specific* updating and/or searching rights



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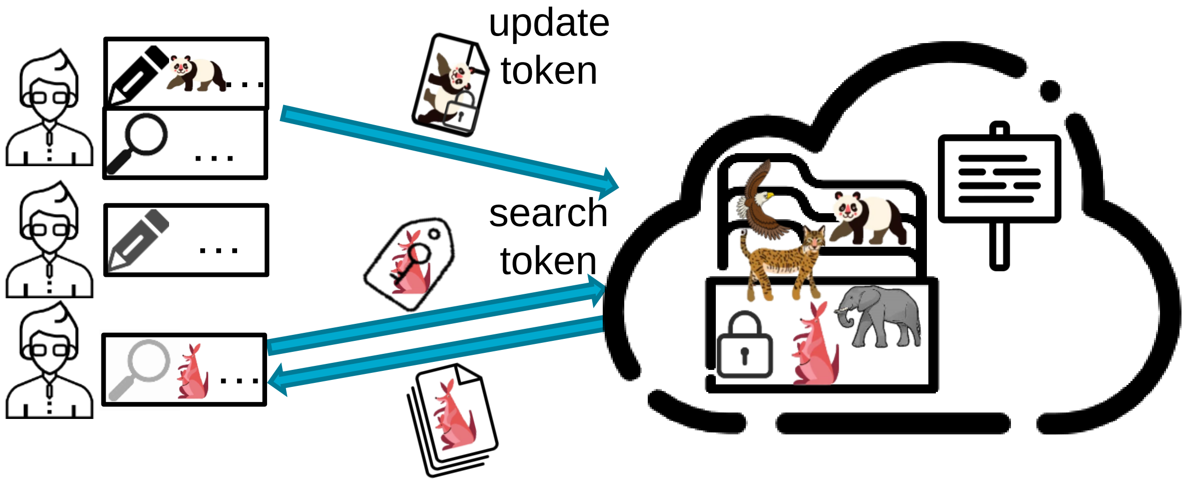
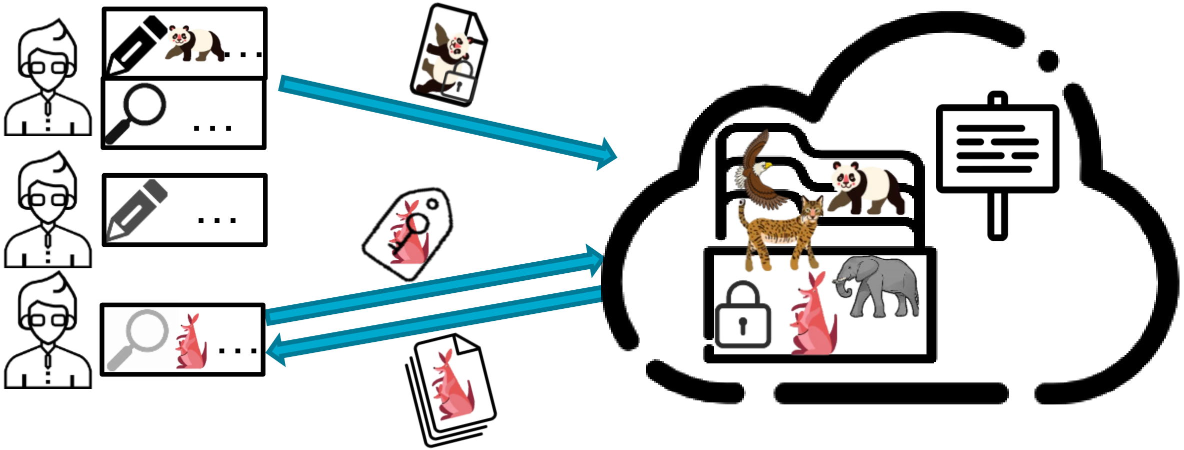
  - without the help of the data owner



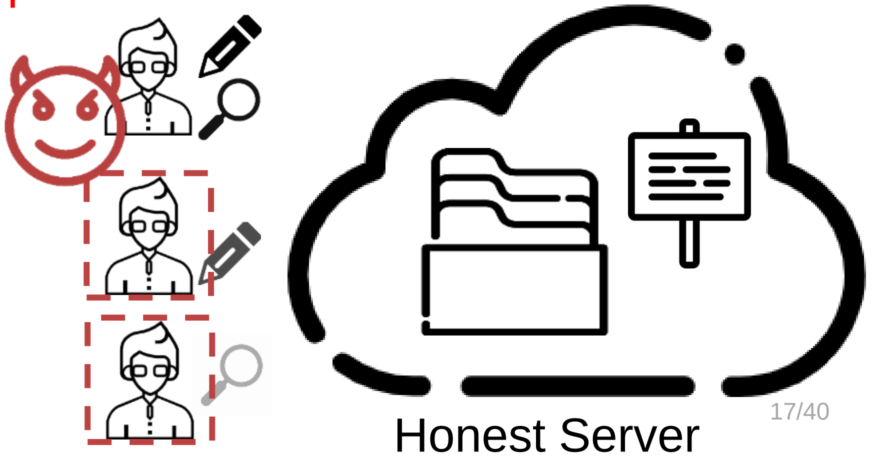
DSE: Access Control on Joint Index

- A client becomes a writer and/or reader of specific keywords
  - make updates and/or searches on these keywords
  - without the help of the data owner
- Delegation makes *joint indices* feasible, boosting searches



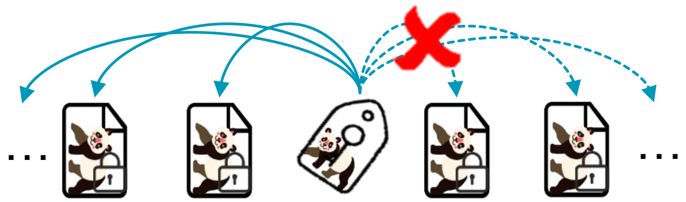
DSE Threat Models

- Server and some clients are possibly corrupted and collusive
- Maintain data privacy and integrity for the trusted data owner
- Clients with searching/updating rights pose *an “orthogonal” threat*
  - leakage to an honest server + corrupted clients could be *less*



DSE Security

- Forward privacy: search token can't work for *any* future update
  - given the updated keyword *not delegated to any corrupt client*
  - any update *hides anything* w.r.t. non-corrupt keywords



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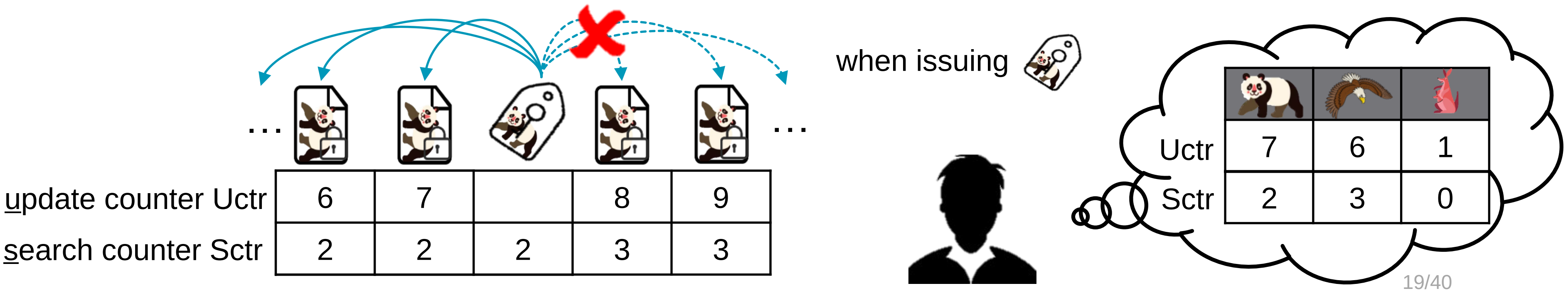
  - a usual trick in SSE: *state maintenance (per keyword)* on the client side



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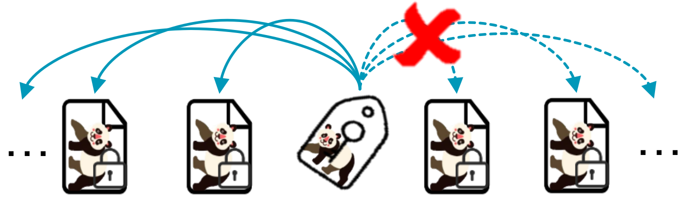
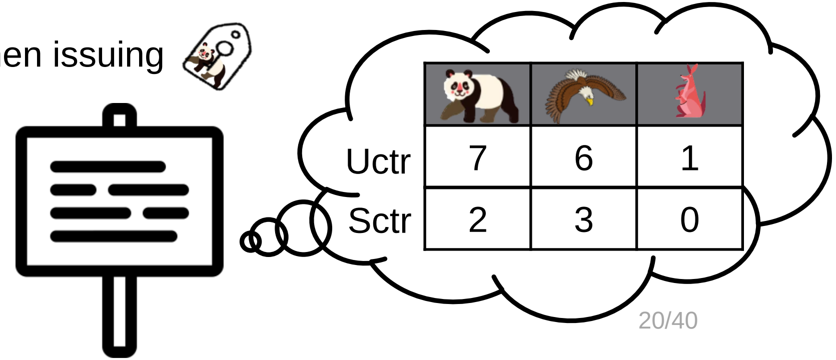


update counter Uctr	6	7		8	9
search counter Sctr	2	2	2	3	3

when issuing



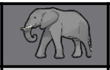
DSE Security

- Forward privacy: search token can't work for *any* future update
  - given the updated keyword *not delegated to any corrupt client*
  - any update *hides anything* w.r.t. non-corrupt keywords

- Integrity: malicious clients can't tamper with the database
  - new concern in DSE to make clients behave themselves
  - ensure correct modification of the global state
  - later searches by honest clients can locate others' updates in the right places

Shiftable Multi-Recipient Encryption (SME)

- A tailor-made *homomorphic* encryption for *a set of messages*
  - *shiftable*: homomorphic shifting can be publicly computed

			
8	4	2	7
9	**5**	2	7

Shiftable Multi-Recipient Encryption (SME)

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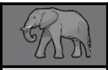
  - *expandable*: more recipients can be included (with new secret keys)

				
8	4	2	7	
9	**5**	2	7	
9	5	2	7	**0**

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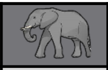
  - *shift non-committing*: ciphertexts can be simulated without knowing the shifted messages and the shifted offsets

				
?	?	?	?	
?	?	?	?	
?	?	?	?	0

Shiftable Multi-Recipient Encryption (SME)

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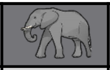
  - expandable: more recipients can be included (with new secret keys)
  - *shift non-committing*: ciphertexts can be simulated without knowing the shifted messages and the shifted offsets
  - can “explain” (previously) simulated ciphertexts when the key is revealed

				
?	?	?	?	
?	?	?	?	
?	?	?	?	0

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?	?	?	?	
?	?	?	?	
?	?	?	?	0

- Efficient SME construction
  - from randomness-reusing ElGamal encryption
  - *non-committing* proven under the generic group model
  - synchronize updates via the global state for *standard forward privacy*

DSE-F: Foundation with Forward Privacy

- Data owner sets up the DSE system with a master key
  - an SME instance, with each ctxt slot corresponding to one keyword
    - SME ctxt to encrypt *update counters* of each keyword
  - multiple IBE instances, each corresponding to one keyword
    - (Anonymous Identity-Based Encryption implies PEKS)
    - to encrypt documents for each keyword, using its *search counter* as identity
  - pseudorandom function PRF to locate addresses for tuples

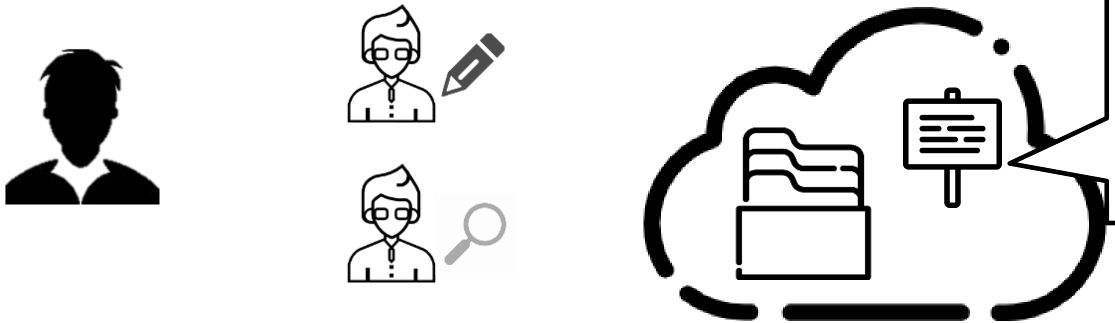
DSE-F: Foundation with Forward Privacy

- Global state (Uctr: update counters; Sctr: search counters)
  - public keys + SME-encrypted Uctr + Sctr (in plain, & “pseudonym” of keyword)

Uctr	0	0	0
Sctr	0	0	0

DSE-F: Foundation with Forward Privacy

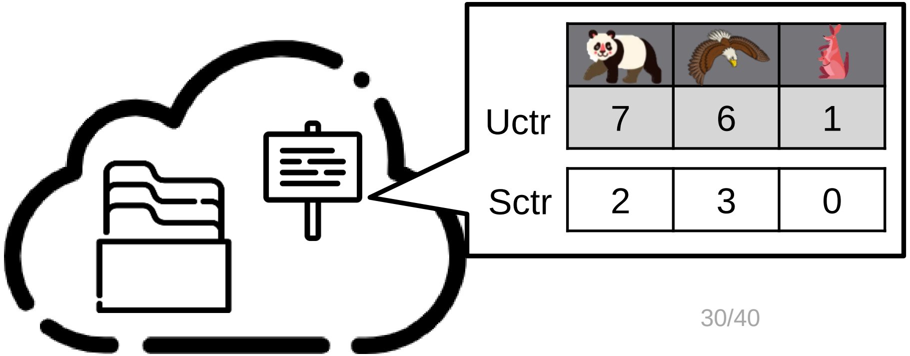
- Global state (Uctr: update counters; Sctr: search counters)
  - public keys + SME-encrypted Uctr + Sctr (in plaintext, pseudonym)
- Data owner provides keyword-specific keys to clients
  - : SME secret key + PRF secret key + IBE secret key
  - : SME secret key + PRF secret key (PRF operates over Index Key (IK))



Uctr	0	0	0
Sctr	0	0	0

DSE-F: Foundation with Forward Privacy

- To insert a new tuple (, Fid), a writer outputs
  - addr as PRF(IK, Uctr[ ] + 1), with IK = PRF(Sctr[ ]), Uctr from SME
  - val as IBE(Fid, Sctr[ ]) using ’s IBE instance
- The writer also outputs SME-encrypted offset



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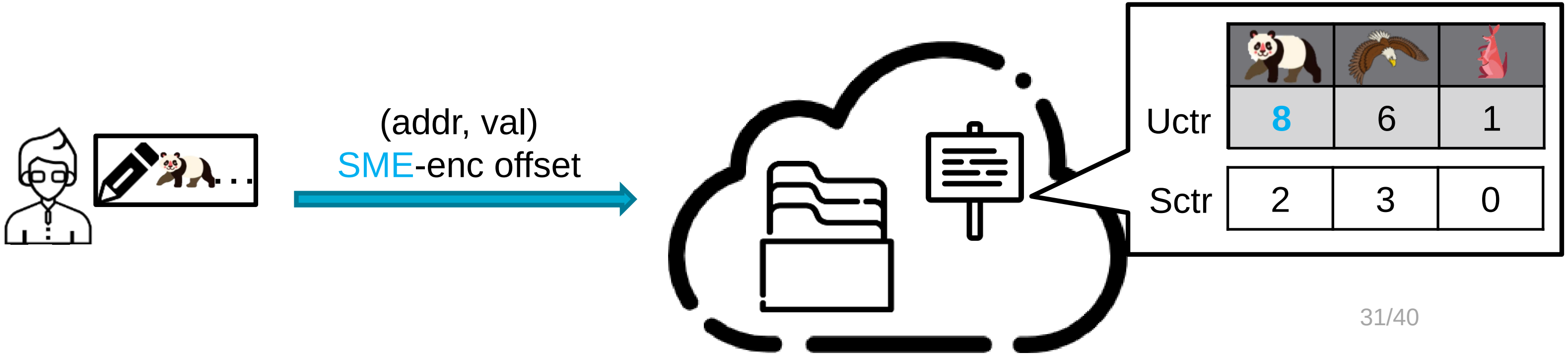
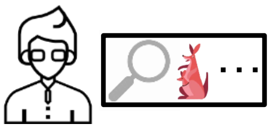
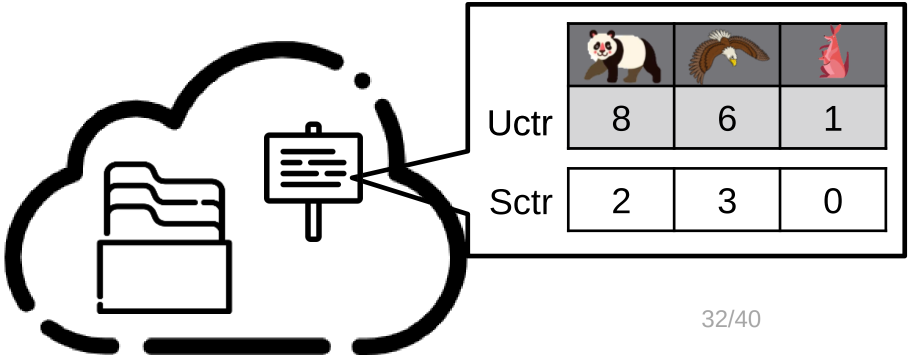
- The writer also outputs SME-encrypted offset
- The server stores val at addr and shifts SME ctxt



DSE-F: Foundation with Forward Privacy

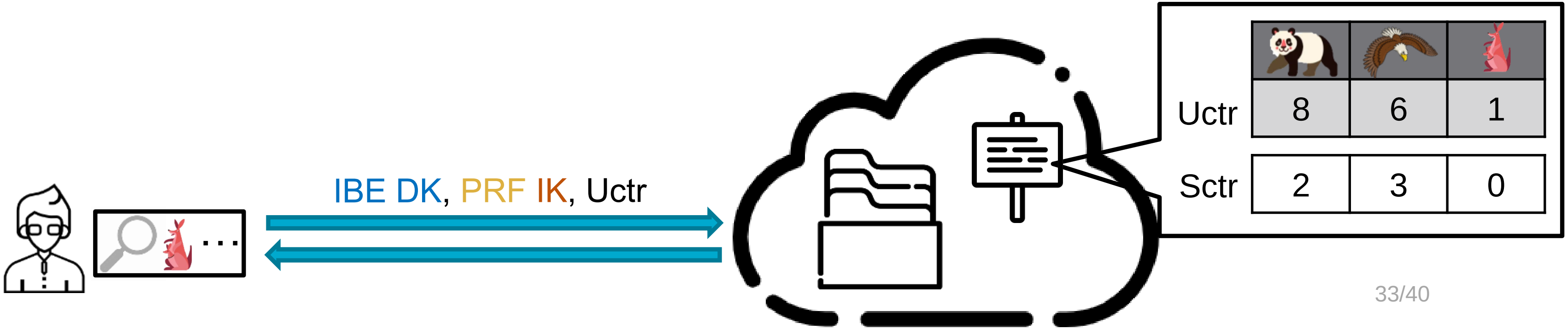
- To search for , a reader outputs
  - Decryption key DK for 's IBE instance, w.r.t. Sctr[ ]
  - Index key IK for PRF as IK = PRF(Sctr[ ])
  - Uctr[ ], by decrypting the corresponding slot of SME ctxt





DSE-F: Foundation with Forward Privacy

- To search for , a reader outputs
  - Decryption key DK for ’s IBE instance, w.r.t. Sctr[]
  - Index key IK for PRF as IK = PRF(Sctr[])
  - Uctr[], by decrypting the corresponding slot of SME ctxt
- The server retrieves entries with IK, decrypts them with DK



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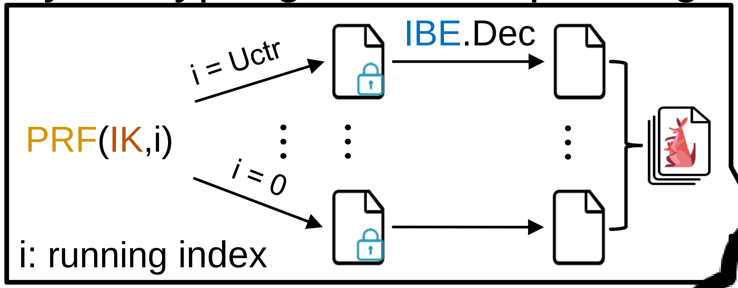
- Server 

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DSE-F: Foundation with Forward Privacy

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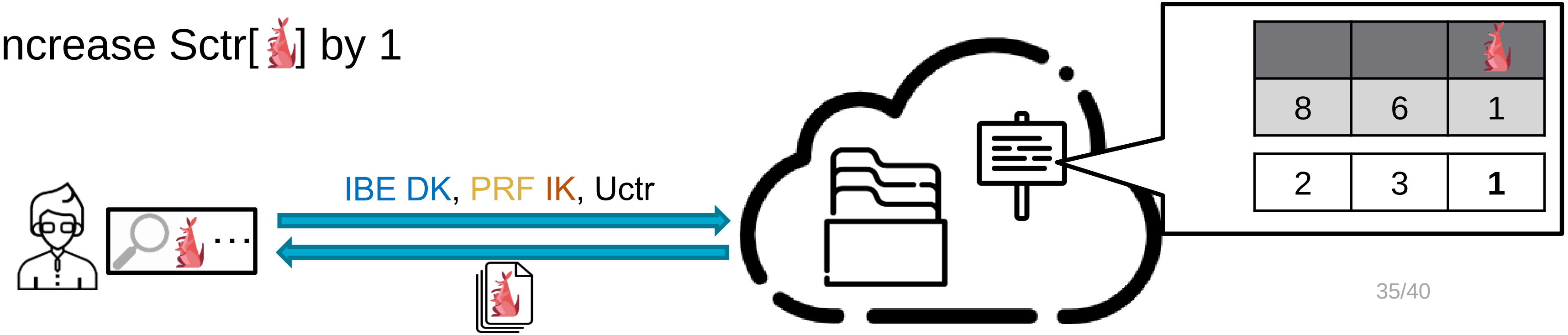
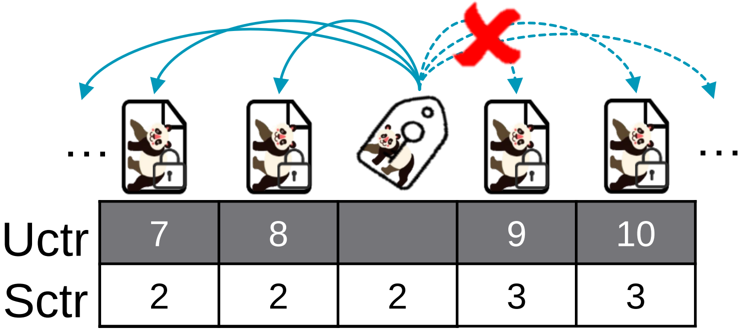
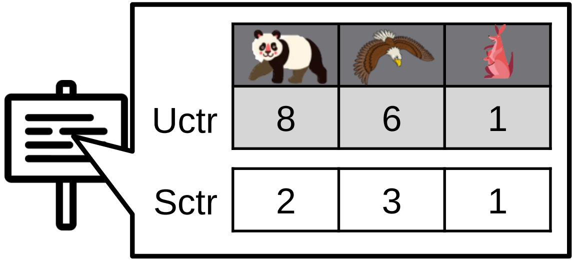
  - Uctr[ ], by decrypting the corresponding slot of SME ctxt
- The server retrieves entries with IK, decrypts them with DK
  - Increase Sctr[ ] by 1



Security Analysis of DSE-F

- Update leaks nothing of non-corrupt keywords
- IBE.Enc and PRF IK are w.r.t *current* search & update counter
- Standard forward privacy



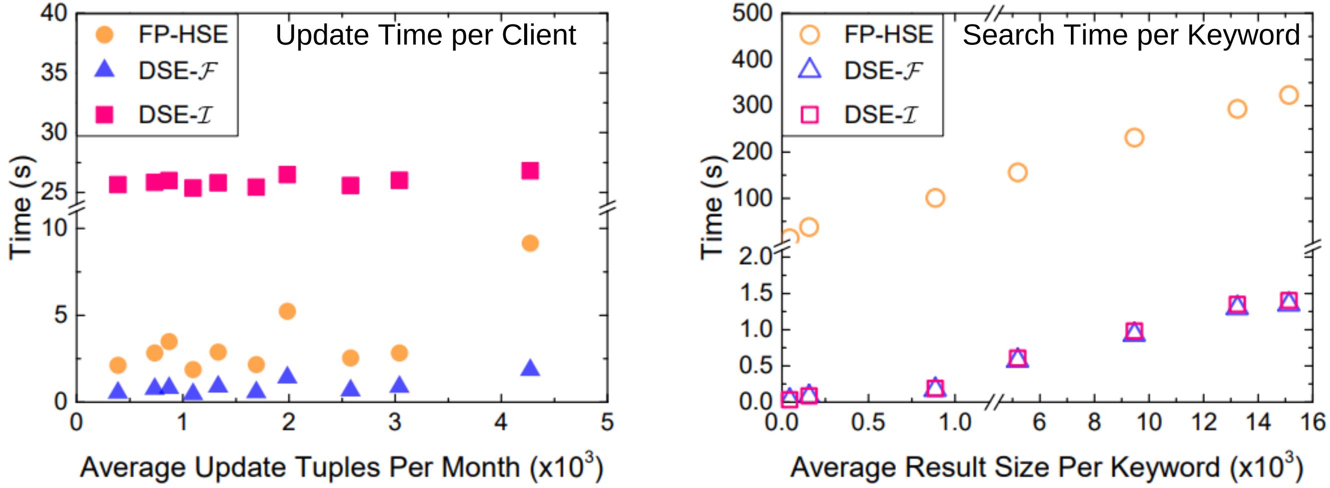


DSE-I: Instrument for Integrity

- Any search or update comes with a proof
  - using commitment [Pedersen91] and argument of knowledge [LMR19]
  - update: prove SME ctxt is correctly shifted
  - search: prove IBE DK and PRF IK are generated w.r.t correct Sctr

Experimental Evaluations

- Enron: 510K e-mails from 146 employees from 1999 to 2002
  - each client has an average of 460 keywords and 3493 emails
  - each client updates per month; regular searches per half year
  - amortize rebuild time (per half year) into HSE update time



Summary of Ideas

- *One-time* delegation to grant reading and/or writing ability
  - with respect to a keyword by the data owner
- Global state for synchronization needed for forward privacy
  - Maintained by *shiftable multi-recipient non-committing encryption* (SME)
  - *Forward privacy is now possible without client interactions*
- Jointly build and retrieve *one* index
  - Instead of adding a public-key layer over multiple indexes in HSE
  - *Multi-writer multi-reader with sublinear search*

Conclusion and Future Work

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- DSE-F and DSE-I
  - Adaptively secure
  - Forward-private
  - DSE-I achieves *integrity* (with overhead)

	SSE	PEKS	HSE	DSE
Sublinear Search	✓	×	✓	✓
Standard Forward Privacy	✓	×	×	✓
Multiple Clients	×	W	W	W/R

- Versatility and Extensibility
  - Extended defence: backward privacy, volume hiding, mitigating keyword guess
  - Optimized efficiency: fewer public-key operations via HSE-like hybrid technique
  - See the paper for more