The KeY-verified Verified Keyserver

VerifyThis Long Term Challenge

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Our program verifier KeY

Deductive verification

100% Java Card

Java Modeling Language (JML)

Mostly automatic

Modular Reasoning

User Interaction Concepts

collaboration with TU Darmstadt and Chalmers University, Gothenburg

Modelling HAGRID in KeY

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The **array** model

- uses arrays to implement database and open requests
- specification on these arrays
- 70 loc, 90 los, 10 POs, **fully automatic**

loc/los = lines of code/spec, POs = # of proof obligations

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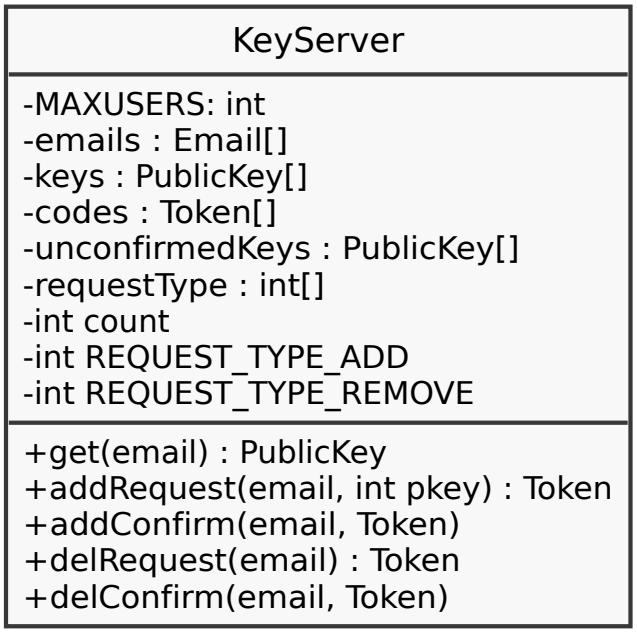
The **map** model

- uses map data structures to implement db and open requests
- specification on ADT maps
- "object singularities"
- 146 loc, 262 los, 40 POs, **89 interactions**

Array model



- Backend of Hagrid
  - retrieving of public keys
  - verified adding of entries
  - verified deletion of entries
- Simplifications
  - All data types are (array of) `int`'s.
  - Maps are represented by a key/value array.
- simplified/Keyserver.java

Array Model: Invariants

ruling out aliasing

```
invariant emails != keys && emails != codes && emails != unconfirmedKeys;
invariant emails != requestType;
invariant keys != codes && keys != unconfirmedKeys;
invariant keys != requestType;
invariant codes != unconfirmedKeys && codes != requestType;
invariant unconfirmedKeys != requestType;
```

All arrays are non-null and have the same length (# of users)

```
invariant emails != null && keys != null && codes != null;
invariant unconfirmedKeys != null && requestType != null;
invariant emails.length == MAXUSERS && keys.length == MAXUSERS;
invariant codes.length == MAXUSERS && unconfirmedKeys.length == MAXUSERS;
invariant requestType.length == MAXUSERS;
```

Number of users is bounded

```
invariant 0 <= count && count <= MAXUSERS;
```

Emails are unique

```
invariant (\forall int i,j ;
                0 <= i && i < j && j < count;
                    emails[i] != emails[j]);
```

Array Model: Method Contract

Informal Contract: addRequest(Email, PublicKey)

Stores request to add the given key for the specified user. The key still needs to be confirmed with #addConfirm(Email, Token). Does nothing if the specified user does not exist.

- `id` the email of the user
- pkey – public key to added after confirmation
- **returns** the array index where the key will be stored

```
public int addRequest(int id, int pkey) {
  int pos = posOfId(id);                    // find the entry in the current
  if(pos < 0) { pos = count++; }            // not found, use an empty entry
  emails[pos] = id;                         // store user's email
  codes[pos] = random();                    // generate/store the auth. token
  unconfirmedKeys[pos] = pkey;              // store the key in a additional list
  requestType[pos] = REQUEST_TYPE_ADD;      // entry is an addition
  return pos;                               // ! return the position of the entry
}
```

The array model: addConfirm

```
/*@ public normal_behaviour

  @ requires count < MAX_USERS;

  @ ensures 0 <= \result;

  @ ensures count == \old(count) && \result < count
        ||  count == \old(count) + 1 && \result == count - 1;

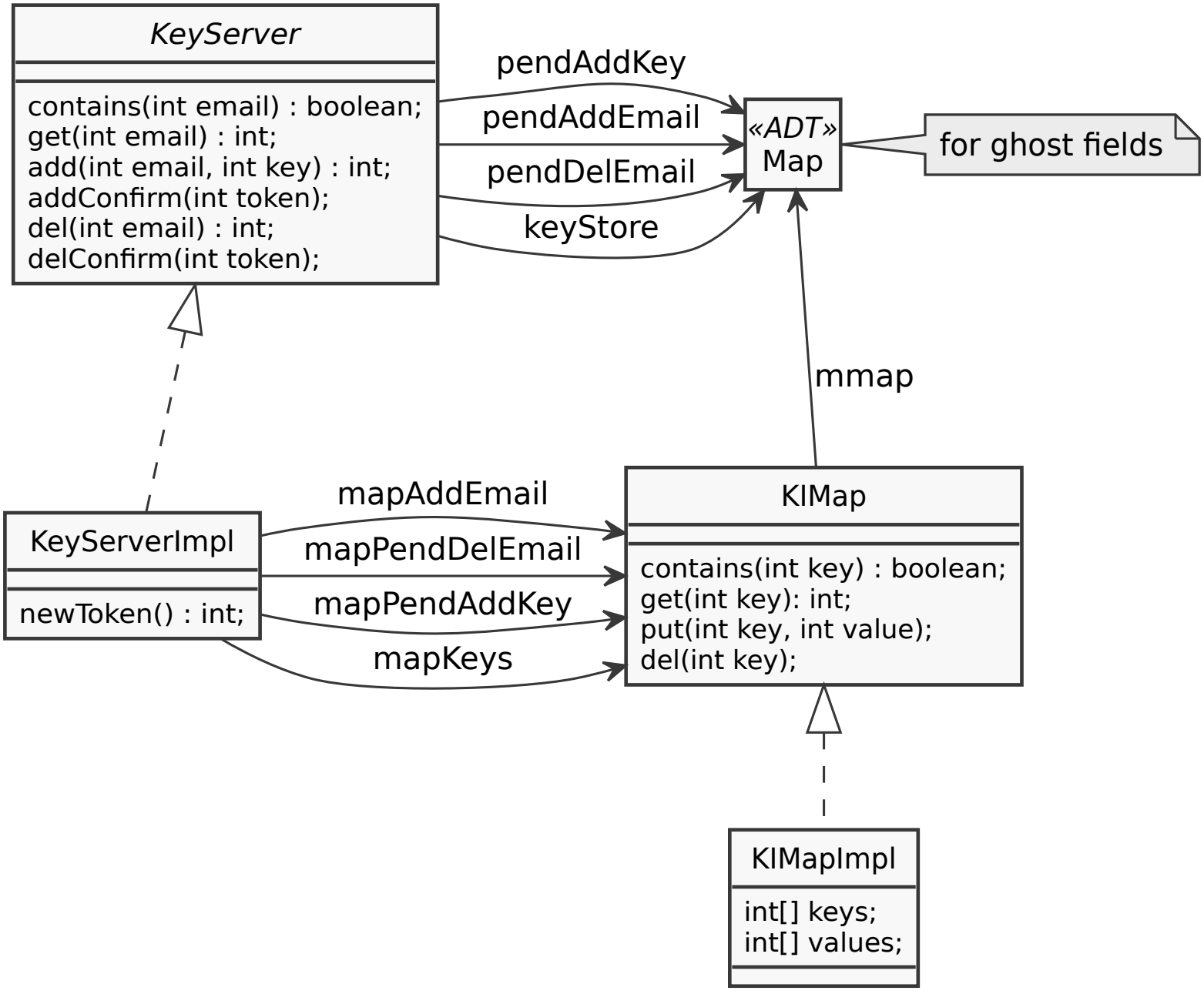
  @ ensures emails[\result] == id && unconfirmedKeys[\result] == pkey
            && codes[\result]>0;

  @ ensures requestType[\result] == REQUESTTYPE_ADD;

  @ ensures (\forall int i; 0<=i && i<count;
              (emails[i] == (i == \result ? id : \old(emails[i])))
     && (unconfirmedKeys[i] ==
                  (i == \result ? pkey : \old(unconfirmedKeys[i])))
     && (i != \result ==> (codes[i] == \old(codes[i])))
     && (i != \result ==> (requestType[i] == \old(requestType[i]))));

  @ assignable emails[*], unconfirmedKeys[*],
               codes[*],  requestType[*],     count;
*/
```

The map model



Confirming a new key

Original syntax:

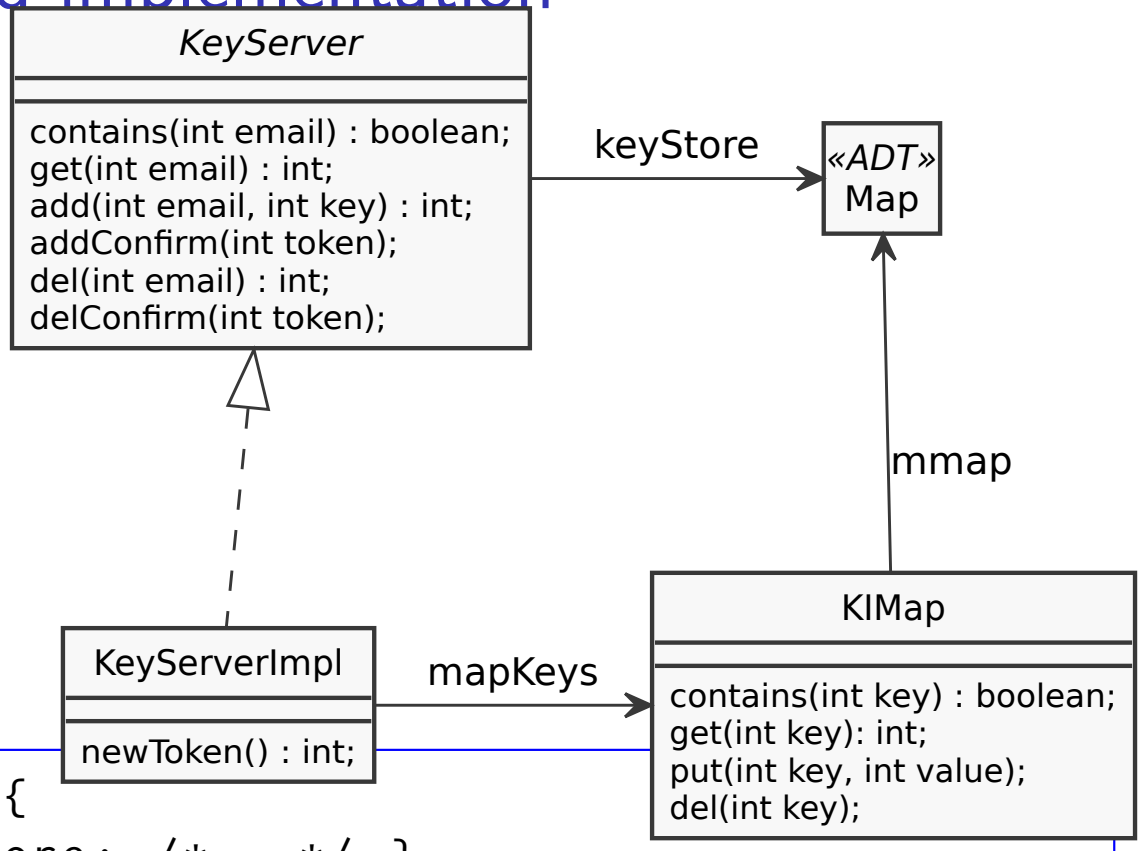
```
/*@ public normal_behavior
  @  requires \dl_inDomain(pendAddEmail, token);
  @  ensures keyStore ==
  @   \dl_mapUpdate(\old(keyStore),
  @      \dl_mapGet(\old(pendAddEmail), token),
  @      \dl_mapGet(\old(pendAddKey), token));
  @  ensures pendAddEmail ==
  @   \dl_mapRemove(\old(pendAddEmail), token);
  @  ensures pendAddKey ==
  @   \dl_mapRemove(\old(pendAddKey), token);
  @  ensures pendDelEmail == \old(pendDelEmail);
  @  assignable footprint;
  /public void addConfirm(int token);
```

Confirming a new key

More mathematical syntax:

```
/*@ public normal_behavior
  @   requires token \in pendAddEmail;
  @
  @   ensures keyStore == \old(keyStore)[
  @     \old(pendAddEmail)[token] <-
  @     \old(pendAddKey)[token]];
  @
  @   ensures pendAddEmail == \old(pendAddEmail) - token;
  @
  @   ensures pendAddKey == \old(pendAddKey) - token;
  @
  @   ensures pendDelEmail == \old(pendDelEmail);
  @
  @   assignable footprint;
  /public void addConfirm(int token);
```

Connecting ghosts and implementation




```
interface KeyServer {
    ghost \map keyStore; /*...*/ }

class KeyServerImpl implements KeyServer {
    KIMap mapKeys = KIMap.newMap();
    invariant mapKeys.<inv>;
    invariant keyStore == mapKeys.mmap; /*...*/}
```

Dynamic Frames – “Singularities”

Proofs cannot be conducted due to framing problems.

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Singularities

Original class

```
interface Map {
 //@ ghost \locset footprint;

 //@ model \map mmap;

 /*@ ensures \result == mmap[k];
   @ accessible footprint; */
 int get(int k) {...}

 /*@ ensures mmap == \old(mmap)[k<-v];
   @ assignable footprint; */
  int get(int k, int v) {...}
}
```

Singularities

Original class

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interface Map {
 //@ ghost \locset footprint;

 //@ model \map mmap;

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}
```

Singularity replacement

```
interface Map {
 //@ ghost \free footprint;

  ... copy the rest
```

\free is uninterpreted sort

"footprint" captures the "state"

Summary

- *we presented two models:*
  one automatic, one pretty interactive
- Limitations and open challenges:
  - integers instead of strings ($\rightarrow$ thesis @ KIT)
  - linear maps, not hash maps ($\rightarrow$ thesis @ OU)
  - framing, singularities ($\rightarrow$ thesis @ KIT)
- Long-term goals:
  - Specify and verify secure information flow (using KeY)