# Verifying a Hotel Key Card System

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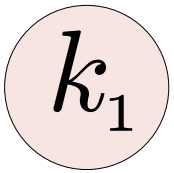
# Outline

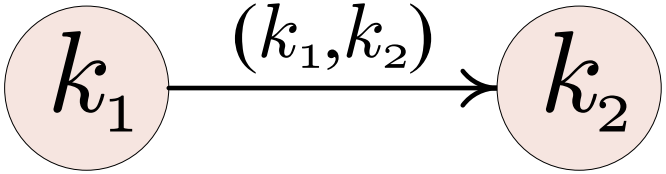
# Hotel Key Card

- Decentralized system
- Two key numbers in a card
  - $key_1$: old key of the previous occupant
  - $key_2$: new key of the current occupant
- One key number in a lock
  - $key_L = key_2$: Open
  - $key_L = key_1$: Open & Recode $key_L := key_2$

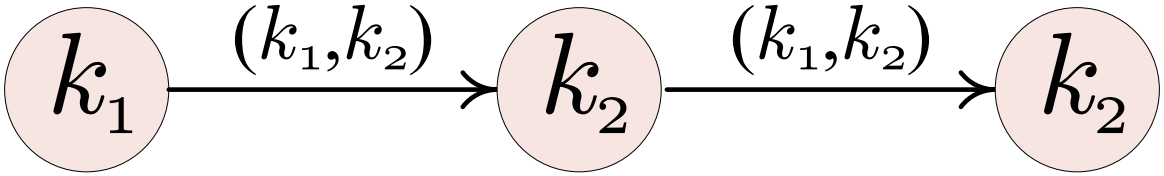
# Hotel Key Card



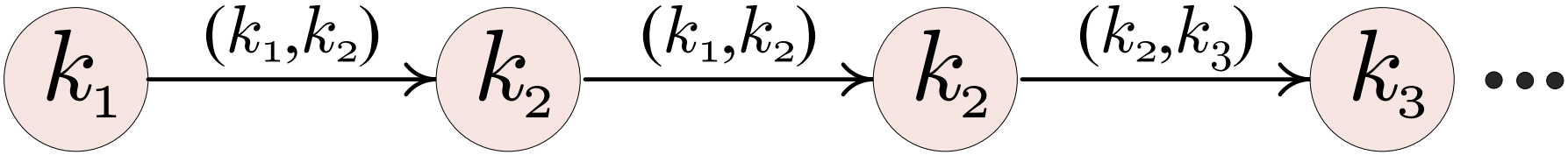
# Hotel Key Card



# Hotel Key Card



# Hotel Key Card



# Correctness

- Is the system correct?
- Safety: Only the owner of a room can be in a room
- Liveness?
- Verify the correctness of the system using Alloy and Isabelle/HOL
  - Alloy implementation is taken from "Software Abstractions: Logic, Language, and Analysis", Daniel Jackson

# Outline

# Objects

```
sig Key, Time {}
sig Card { fst, snd: Key }
sig Room { key: Key one → Time}
one sig Desk {
   issued: Key → Time,
   prev: (Room → lone Key) → Time}
sig Guest {
 cards: Card → Time}
```

```
pred init [t: Time] {
   Desk.prev.t = key.t
   Desk.issued.t = Room.key.t and no cards.t }
```

# Checkin

```
pred checkin [t,t': Time, r: Room, g: Guest] {
 some c: Card {
     c.fst = r.(Desk.prev.t)
     c.snd not in Desk.issued.t
     cards.t' = cards.t + g → c
     Desk.issued.t' = Desk.issued.t + c.snd
     Desk.prev.t' = Desk.prev.t ++ r → c.snd
     }
 key.t = key.t'
 }
```

# Enter

```
pred enter [t,t': Time, r: Room, g: Guest] {
 some c: g.cards.t |
     let k = r.key.t {
     c.snd = k and key.t' = key.t
     or c.fst = k and key.t' = key.t ++ r → c.snd
     }
 issued.t = issued.t' and prev.t = prev.t'
 cards.t = cards.t'
 }
```

# Demo (Alloy)

# Guest-in-the-middle attack

Check-in $G_1$ $(k_1, k_2)$

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |
| Check-in | $G_2$ | $(k_2, k_3)$ |

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |
| Check-in | $G_2$ | $(k_2, k_3)$ |
| Check-out | $G_2$ | |

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |
| Check-in | $G_2$ | $(k_2, k_3)$ |
| Check-out | $G_2$ | |
| Check-in | $G_1$ | $(k_3, k_4)$ |

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |
| Check-in | $G_2$ | $(k_2, k_3)$ |
| Check-out | $G_2$ | |
| Check-in | $G_1$ | $(k_3, k_4)$ |
| Enter-room | $G_1$ | $(k_1, k_2)$ |

# Guest-in-the-middle attack

| | | |
|---|---|---|
| Check-in | $G_1$ | $(k_1, k_2)$ |
| Check-out | $G_1$ | |
| Check-in | $G_2$ | $(k_2, k_3)$ |
| Check-out | $G_2$ | |
| Check-in | $G_1$ | $(k_3, k_4)$ |
| Enter-room | $G_1$ | $(k_1, k_2)$ |
| Enter-room | $G_2$ | $(k_2, k_3)$ |

# General Case

## Alloy solution

- Assume everybody returns their old cards upon check-in
- cards.t' = cards.t + g $\rightarrow$ c
- cards.t' = cards.t ++ g $\rightarrow$ c

## Theorem proving

- Alloy conjecture: No attack for 4 keys and cards, 7 time instants, two guests and one room
- Prove the conjecture in Isabelle/HOL

# Outline

# Record state

(* reception *)

| | | |
|---|---|---|
| *owns* | :: | $room \Rightarrow guest$ |
| *currk* | :: | $room \Rightarrow key$ |
| *issued* | :: | $key\ set$ |

(* guests *)

| | | |
|---|---|---|
| *cards* | :: | $guest \Rightarrow card\ set$ |

(* rooms *)

| | | |
|---|---|---|
| *roomk* | :: | $room \Rightarrow key$ |
| *isin* | :: | $room \Rightarrow guest\ set$ |

# Initialization

$$
\begin{aligned}
(\!| \; & owns = arbitrary, \\
& currk = initk, \\
& issued = range\ initk, \\
& cards = (\lambda g.\emptyset), \\
& roomk = initk, \\
& isin = (\lambda r.\emptyset), \\
|\!) & \in R
\end{aligned}
$$

# Check-in

$s \in R$ and $k \notin \mathit{issued}\ s$ then

$(\!|$ $\mathit{owns} := (\mathit{owns}\ s)(r := g)$,
$\mathit{cards} := (\mathit{cards}\ s)(g := \mathit{cards}\ s\ g \cup \{(\mathit{currk}\ s\ r, k)\})$,
$\mathit{currk} := (\mathit{currk}\ s)(r := k)$,
$\mathit{issued} := \mathit{issued}\ s \cup \{\mathrm{k}\}$
$|\!) \in R$

# Enter room

$s \in R$ and $(k, k') \in \mathit{cards}\ s\ g$ and $\mathit{roomk}\ s\ r \in \{k, k'\}$ then

$(\!|\ \mathit{isin} := (\mathit{isin}\ s)(r := \mathit{isin}\ s\ r \cup \{g\}),$

$\quad \mathit{roomk} := (\mathit{roomk}\ s)(r := k')$

$|\!) \in R$

# Safety formalized

- Add state component *safe* :: *room* $\Rightarrow$ *bool*
- Initially *safe* is *True* everywhere
- Check-in for room *r* sets *safe r* to *False*
- Enter for room *r* sets *safe r* to *True*
  if the owner entered an empty room
  with card $(-, k')$ such that $k'$ is *currk r* (at reception)
- Proof: If a room is *safe*, only its owner can be in it

# Demo (Isabelle/HOL)

# Two approaches

| Alloy | Isabelle/HOL |
|---|---|
| Software specs | General purpose |
| Set theory | Higher-Order Logic |
| Search for finite counter examples | Interactive & automatic proof |