Dual System Encryption via Doubly Selective Security:

Framework, Fully-secure Functional Encryption for Regular Languages, and More

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@Eurocrypt 2014, Copenhagen

Our Results in One Slide

Framework
for fully-secure FE
(with tighter reduction)

Instantiations:

The first fully secure

- FE for regular languages
- ABE with short ciphertext
- unbounded ABE

and more

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Framework
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focus in this talk

Instantiations:

The first fully secure

- FE for regular languages
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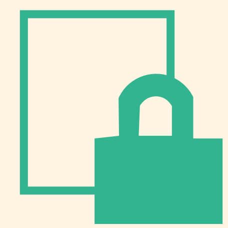
and more

1 Introduction

Functional Encryption Syntax

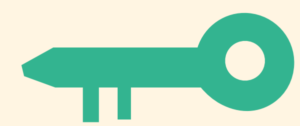
FE for predicate $R{:}A \times B \to \{0,1\}$ or family $\{R_k\}_k$

- Setup($k, 1^\lambda$) $\longrightarrow$ PK, MSK
- Encrypt(Y, M, PK) $\longrightarrow$ CT



for ciphertext
attribute Y

- KeyGen(X, MSK, PK) $\longrightarrow$ SK

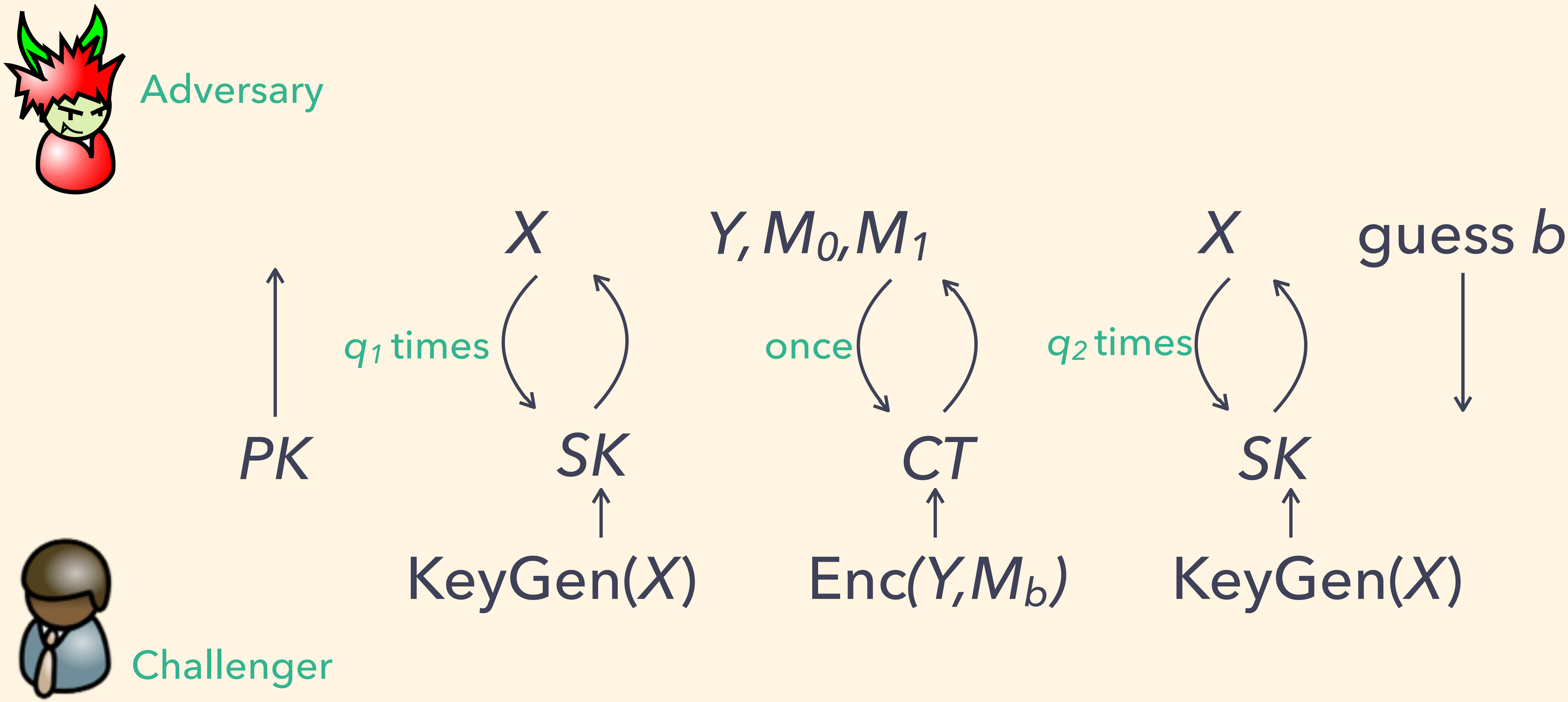


for key
attribute X

- Decrypt(CT, SK) $\longrightarrow$ M if $R(X,Y)=1$

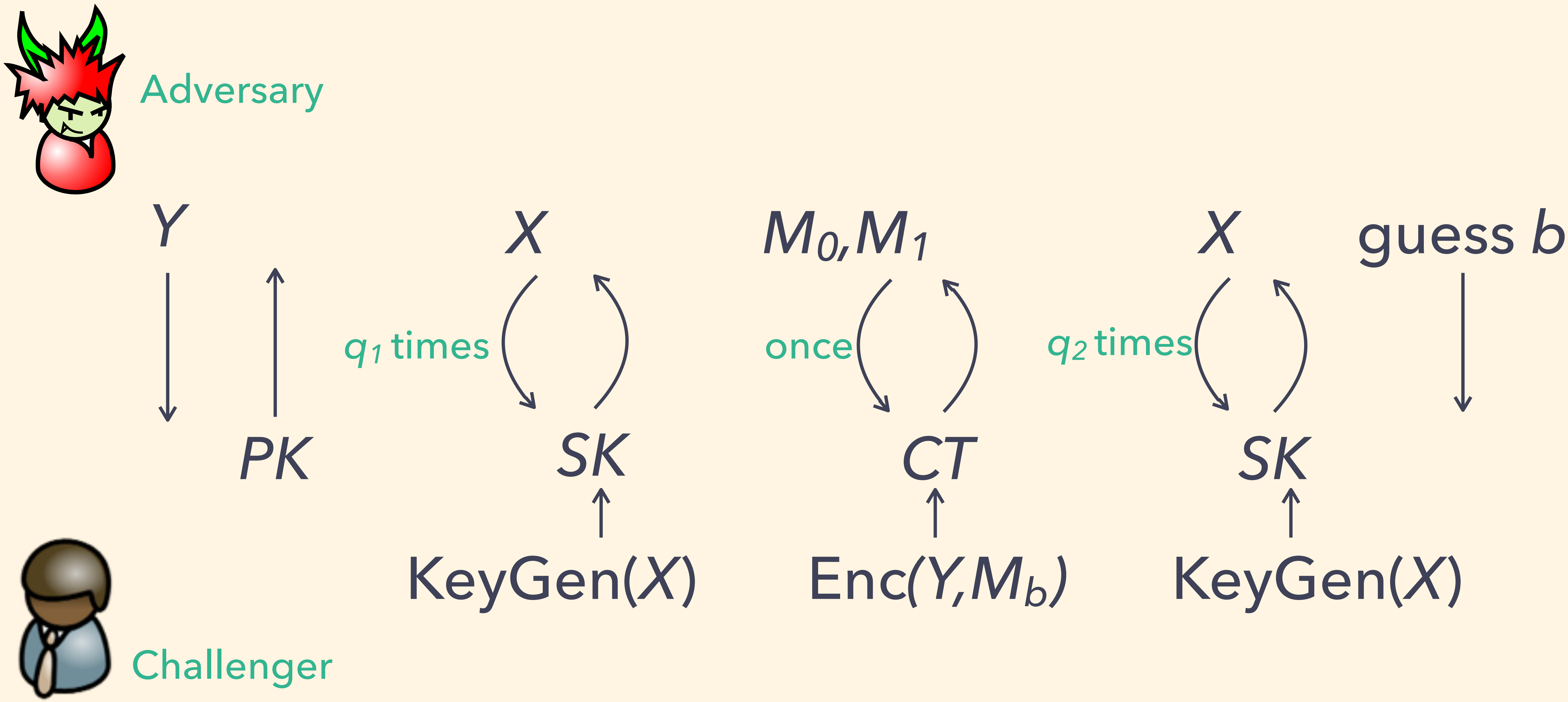
FE here means the class
"Public-index Predicate Encryption" of FE [BSW11].

Definition of Full Security for FE



Non-triviality condition: $R(X,Y)=0$

Definition of Selective Security for FE

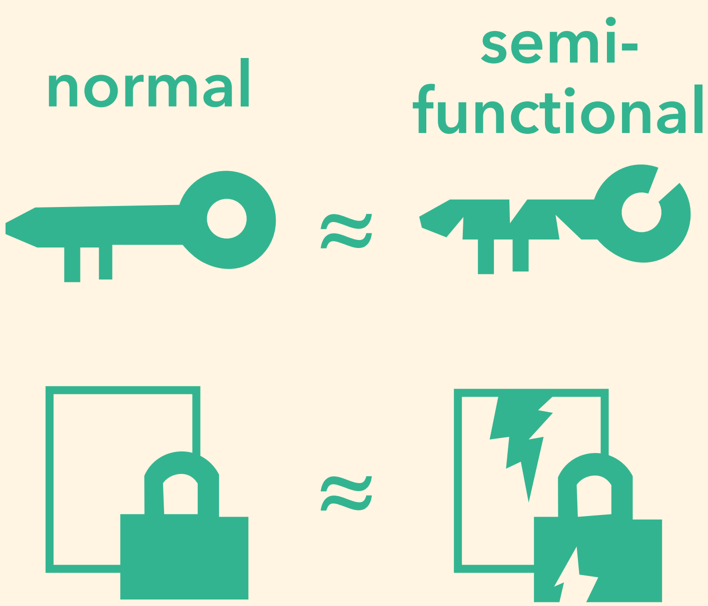


Non-triviality condition: $R(X,Y)=0$

Approaches for Full Security

Partitioning

- IBE [BB04b, Waters05]
- Seem not to work with richer FE



Dual-System Encryption [Waters09]

- Work also with richer FE:
  - ABE [LOSTW10,OT10,LW12,…]
  - Inner-product enc [OT12,…]
  - Spatial encryption [AL10,…]

Dual System Also Offers Simplicity.

An original FE scheme

Selectively-secure

Similar scheme but in composite-order bilinear group

A candidate for fully-secure scheme

Boneh-Boyen IBE

(selectively secure)

$CT=(g^s, g^{s(h_1+h_2 ID)}, e(g,g)^{as}M)$

$SK=(g^{a+r(h_1+h_2 ID')}, g^r)$

Lewko-Waters IBE

(fully secure)

$CT=(g_1^s, g_1^{s(h_1+h_2 ID)}, e(g_1,g_1)^{as}M)$

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Abstract Selective Secure FE

$CT=(g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})}, e(g_1,g_1)^{as}M)$

$SK=g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})}$

Abstract Fully Secure FE ?

$CT=(g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})}, e(g_1,g_1)^{as}M)$

$SK=g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_3^{\mathbf{w}}$

Apply to any scheme?

Successful Applications

	Selective	Full
IBE	BB04	LW10
ABE	GPSW06	LOSTW10
Spatial Encryption	BH08	AL10

Unsuccessful Applications

	Selective	Full
FE for regular languages	Waters12	?
ABE w/ short ciphertexts	ALP11	?
Fully-unbounded ABE	RW13	?

Open problem!

We ask:

Why did “traditional” dual systems fail for some schemes?

How to overcome that barrier?

To systematically answer, we provide a generic framework.

Our Framework Result

New primitive: Pair Encoding → **Generic** → **FE Scheme**

Perfectly secure pair encoding

Computationally secure encoding

"Doubly selective security"

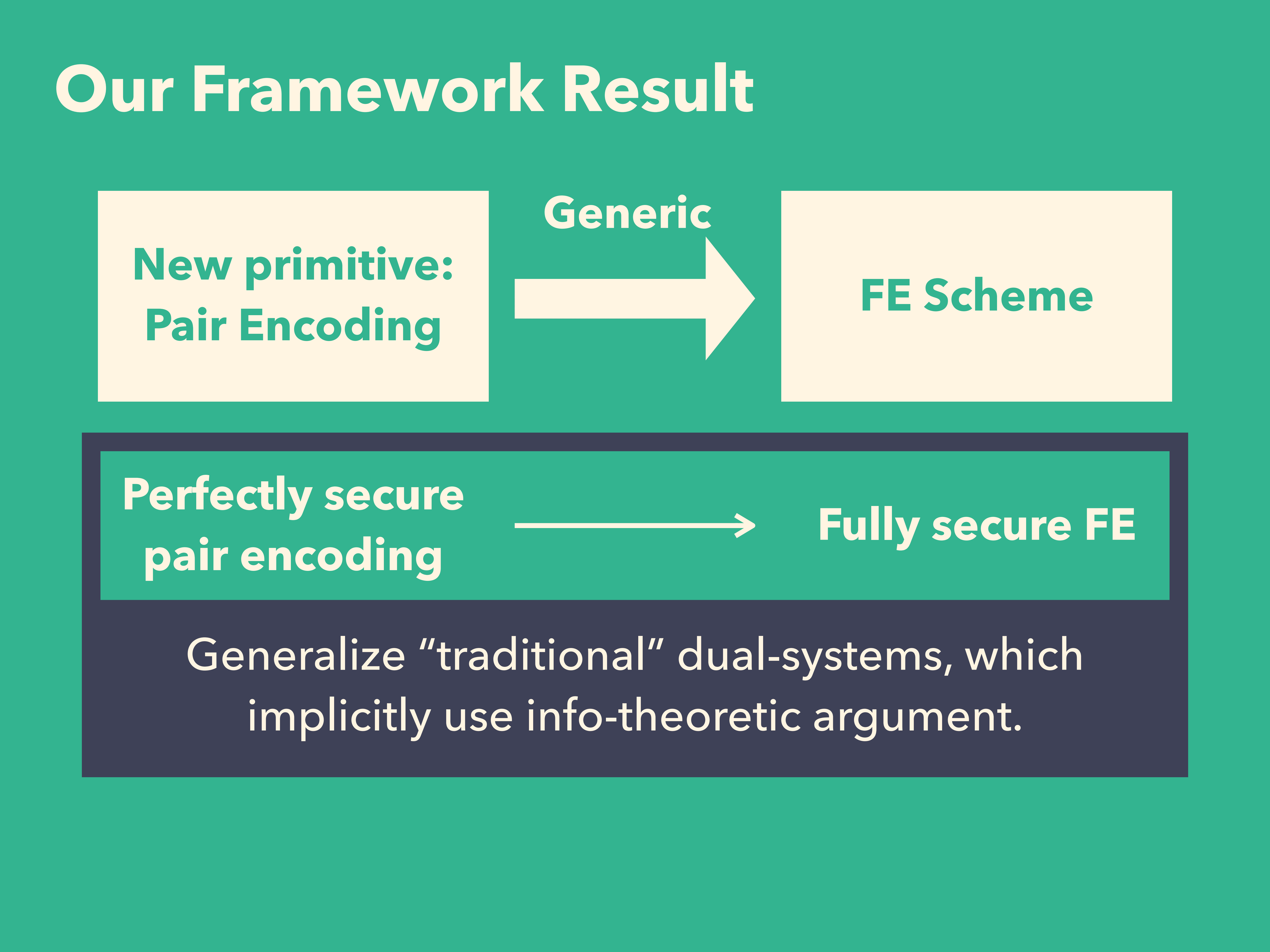
Our Framework Result

New primitive: Pair Encoding → (Generic) → FE Scheme

Perfectly secure pair encoding → Fully secure FE

Computationally secure encoding → Fully secure FE + tighter reduction

"Doubly selective security"


Our Framework Result
New primitive:
Pair Encoding
Generic
FE Scheme
Perfectly secure
pair encoding
Fully secure FE
Generalize “traditional” dual-systems, which
implicitly use info-theoretic argument.

Our Framework Result

New primitive: Pair Encoding → **Generic** → **FE Scheme**

Generalize Lewko-Waters12 ABE
+ New techniques for tighter reduction.

Computationally secure encoding → **Fully secure FE + tighter reduction**

A Glance at Pair Encoding

Recall the abstract scheme

$CT=(g_1^{\mathbf{c(s,h)}},\ e(g_1,g_1)^{as}M)$

$SK=g_1^{\mathbf{k(a,r,h)}}\cdot g_3^{\mathbf{w}}$

Pair encoding consists of *c*( ) and *k*( ).

Our Answer to Instantiations

	Selective	Fully-secure
FE for regular languages	Waters12	
ABE w/ short ciphertexts	ALP11	
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↓

Why traditional dual systems failed:
(Implicit) encodings were not perfect.

Our Answer to Instantiations

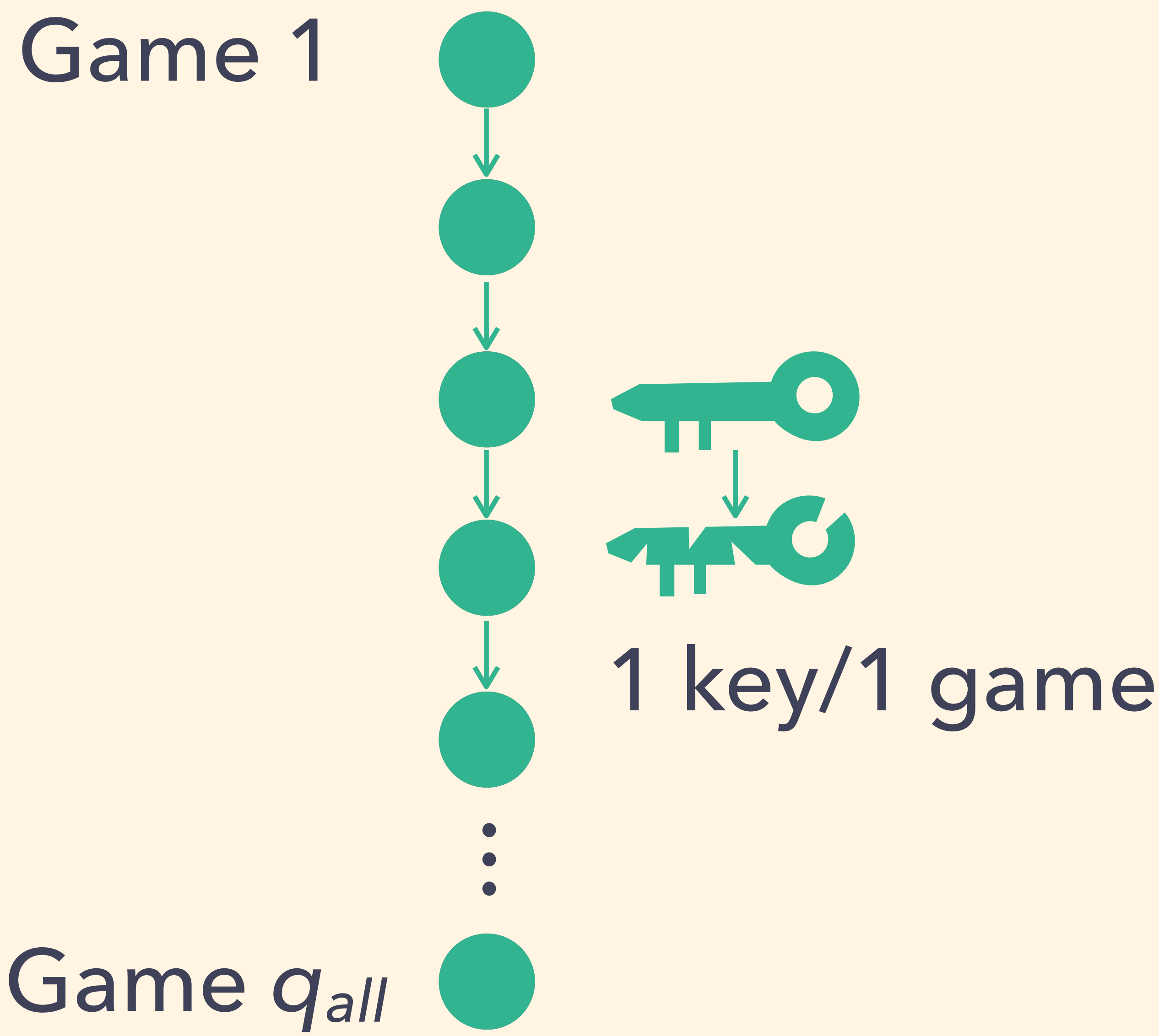
	Selective	Fully-secure
FE for regular languages	Waters12	**New!**
ABE w/ short ciphertexts	ALP11	**New!**
Fully-unbounded ABE	RW13	**New!**

Why traditional dual systems failed: (Implicit) encodings were not perfect.

How to overcome: Use computationally secure encodings

A Glance at Tighter Reduction

All prior dual-system proofs
(except [Chen-Wee Crypto13])



Reduction=$O(q_{all})$, $q_{all} = q_1 + q_2$

A Glance at Tighter Reduction

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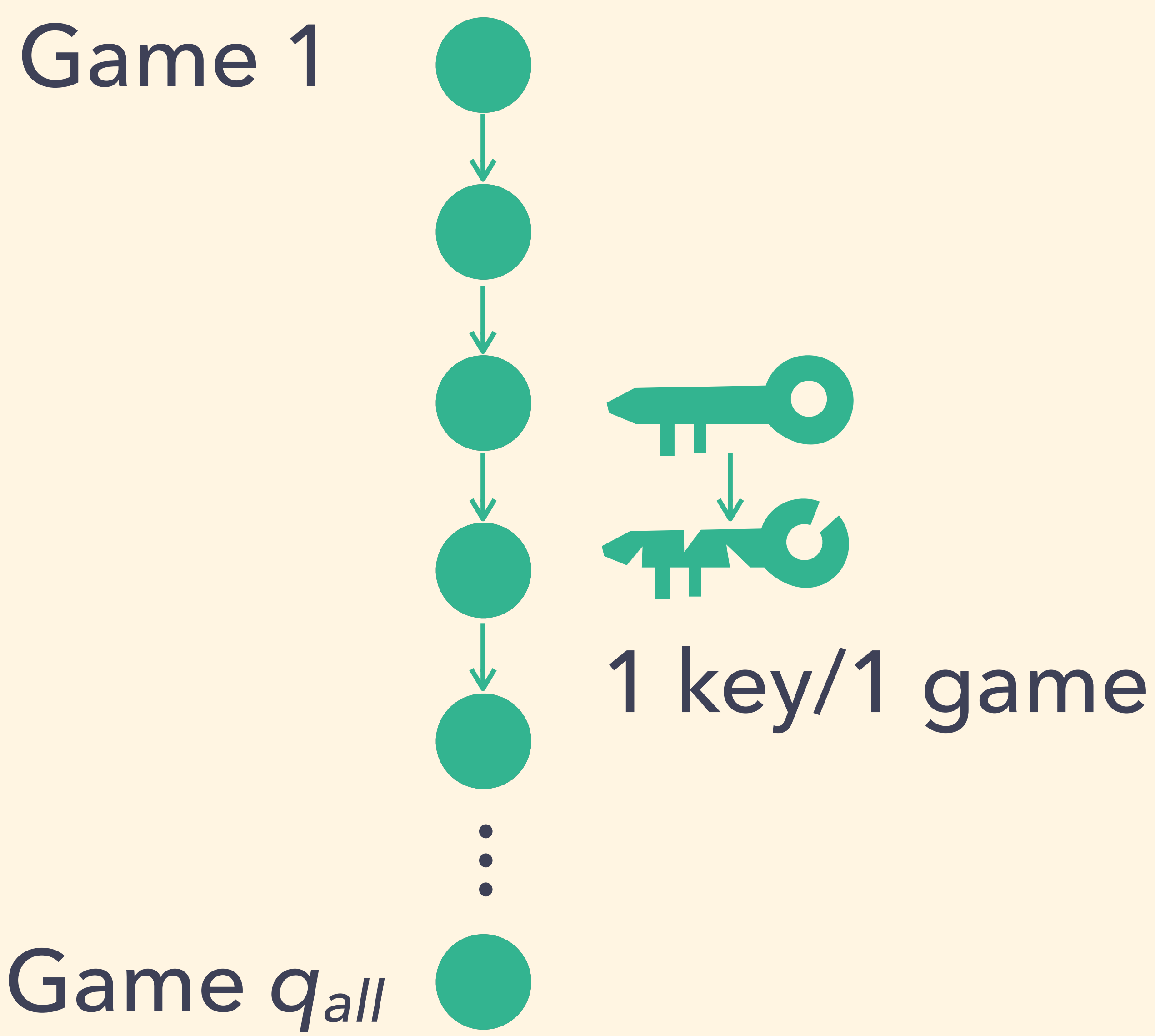
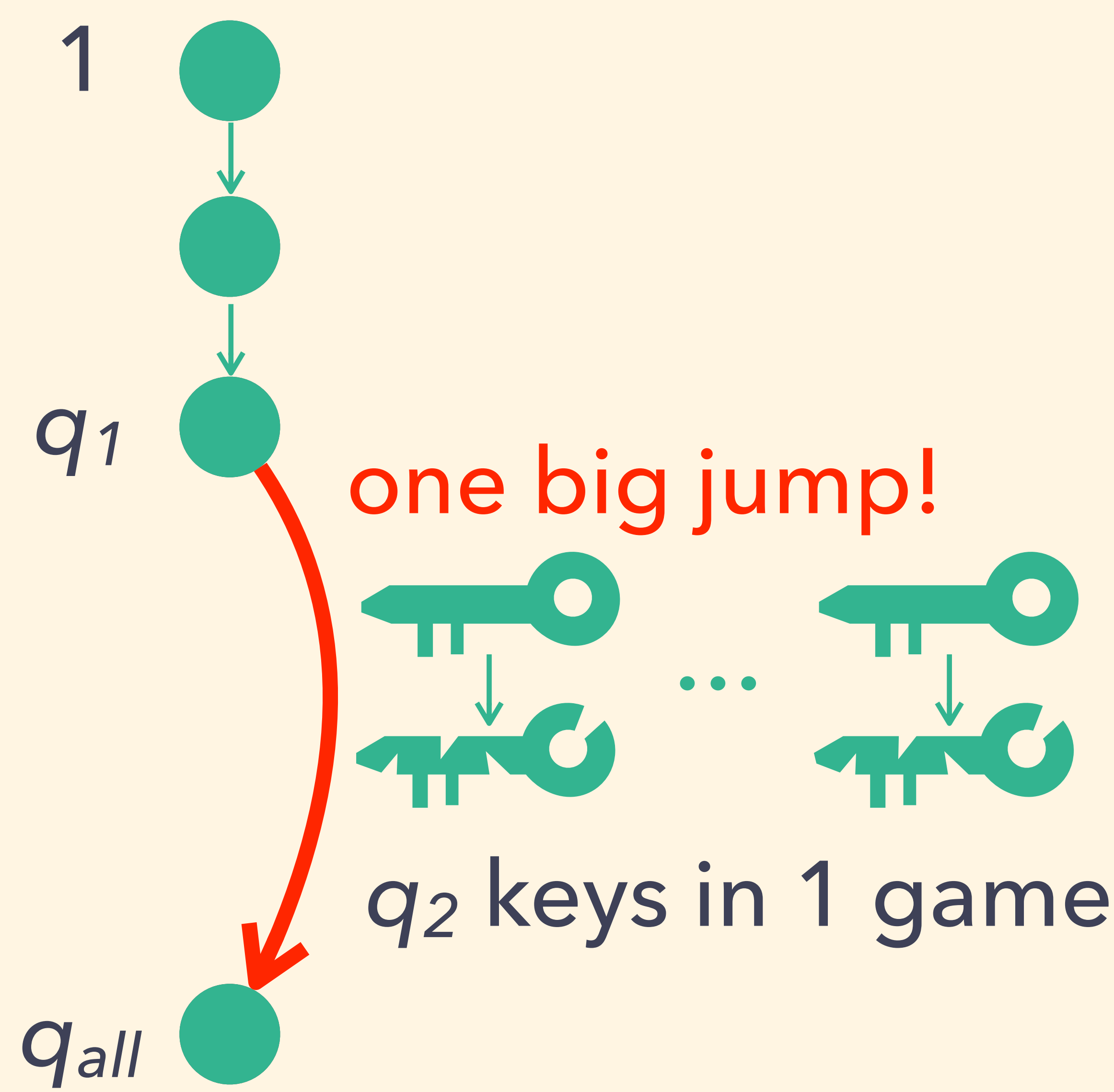


Reduction=$O(q_{all})$, $q_{all}= q_1+q_2$

Our new approach



Reduction=$O(q_1)$

Related work on Dual-System Framework

- [Chen-Wee Crypto13]: Dual-system groups
  - Unify prime- and composite-order groups but only to specific predicates (HIBE).
  - Ours unifies for any predicate (but specific to composite-order).
- [Wee TCC14]: Predicate Encoding
  - Independently abstracting perfectly secure encoding.

2 Framework

Pair Encoding: Definition

Pair Encoding for predicate $R=\{R_k\}_k$

$\text{Enc1}(X) \longrightarrow \boldsymbol{k}(a, \boldsymbol{r}, \boldsymbol{h})$ where $\boldsymbol{r}=(r_1,\ldots,r_m)$

$\text{Enc2}(Y) \longrightarrow \boldsymbol{c}(\boldsymbol{s}, \boldsymbol{h})$ where $\boldsymbol{s}=(s, s_1,\ldots,s_w)$

Pair Encoding: Definition

Pair Encoding for predicate $R=\{R_k\}_k$

$$\mathrm{Param}(k) \longrightarrow |\boldsymbol{h}| \qquad \text{where } \boldsymbol{h}=(h_1,\ldots,h_m)$$

$$\mathrm{Enc1}(X) \longrightarrow \boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h}) \qquad \text{where } \boldsymbol{r}=(r_1,\ldots,r_m)$$

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Pair Encoding: Definition

Pair Encoding for predicate $R=\{R_k\}_k$

Param(k)	$\longrightarrow$	$\lvert \boldsymbol{h} \rvert$	where $\boldsymbol{h}=(h_1,\ldots,h_m)$
Enc1(X)	$\longrightarrow$	$\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})$	where $\boldsymbol{r}=(r_1,\ldots,r_m)$
Enc2(Y)	$\longrightarrow$	$\boldsymbol{c}(\boldsymbol{s},\boldsymbol{h})$	where $\boldsymbol{s}=(s,s_1,\ldots,s_w)$
Pair(X,Y)	$\longrightarrow$	$\boldsymbol{E}$	

- Correctness : If $R(X,Y)=1$, $\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})\,\boldsymbol{E}\,\boldsymbol{c}(\boldsymbol{s},\boldsymbol{h})^{\top}=as$

Pair Encoding: Definition

Pair Encoding for predicate $R=\{R_k\}_k$

Param(k) $\longrightarrow$ $|\boldsymbol{h}|$ where $\boldsymbol{h}=(h_1,\ldots,h_m)$

Enc1(X) $\longrightarrow$ $\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})$ where $\boldsymbol{r}=(r_1,\ldots,r_m)$

Enc2(Y) $\longrightarrow$ $\boldsymbol{c}(\boldsymbol{s},\boldsymbol{h})$ where $\boldsymbol{s}=(s,s_1,\ldots,s_w)$

Pair(X,Y) $\longrightarrow$ $\boldsymbol{E}$

- Correctness : If $R(X,Y)=1$, $\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})\,\boldsymbol{E}\,\boldsymbol{c}(\boldsymbol{s},\boldsymbol{h})^{\top}=as$
- Security: If $R(X,Y)=0$, …to be defined.

Additional Requirements

Parameter-vanishing $\boldsymbol{k}(a,\mathbf{0},\boldsymbol{h}) = \boldsymbol{k}(a,\mathbf{0},\mathbf{0})$

Linearity for $\boldsymbol{k}$ $\boldsymbol{k}(a_1,\boldsymbol{r}_1,\boldsymbol{h})+\boldsymbol{k}(a_2,\boldsymbol{r}_2,\boldsymbol{h}) = \boldsymbol{k}(a_1+a_2,\boldsymbol{r}_1+\boldsymbol{r}_2,\mathbf{0})$

Linearity for $\boldsymbol{c}$ $\boldsymbol{c}(\boldsymbol{s}_1+\boldsymbol{s}_2,\boldsymbol{h}) = \boldsymbol{c}(\boldsymbol{s}_1,\boldsymbol{h})+\boldsymbol{c}(\boldsymbol{s}_2,\boldsymbol{h})$

Linearity implies homogeneity: $\boldsymbol{k}(0,\mathbf{0},\mathbf{0})=0$, $\boldsymbol{c}(\mathbf{0},\mathbf{0})=0$

Pair Encoding: Example for IBE

Param $\longrightarrow$ 2 That is, $\boldsymbol{h}=(h_1,h_2)$

Enc1(ID) $\longrightarrow$ $\boldsymbol{k}(a,r,\boldsymbol{h}) = (\ a+r(h_1+h_2 ID)\ ,\ \ r)$

Enc2(ID') $\longrightarrow$ $\boldsymbol{c}(s,\boldsymbol{h}) = (\ s\ ,\ \ s(h_1+h_2 ID')\ )$

Pair(ID,ID') $\longrightarrow$ $\boldsymbol{E} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

- Correctness If $ID=ID'$

$$(a+r(h_1+h_2 ID), r)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} s \\ s(h_1+h_2 ID') \end{pmatrix} = as$$

Composite-order Bilinear Groups

G, G_T of order $N=p_1p_2p_3$

with bilinear map e: $G \times G \rightarrow G_T$

have prime-order subgroups G_1, G_2, G_3

Orthogonality: $e(g_i, g_j)=1$ iff $i \neq j$

Subgroup Decision: Decide if $T \in G_1$ or $T \in G_{12}$

Constructing FE from Pair Encoding

FE for predicate *R* from Pair encoding for *R*

Setup $\longrightarrow$ $PK=(g_1, g_1^{\mathbf{h}}, e(g_1,g_1)^{a}, g_3)$, $MSK=a$

Encrypt(*Y*,*M*,*PK*) $\longrightarrow$ $CT=(g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})}, e(g_1,g_1)^{as}M)$

Enc2(*Y*)=**c**(**s**,**h**)

KeyGen(*X*,*MSK*) $\longrightarrow$ $SK=g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot \mathbf{R}_3$

Enc1(*X*)=**k**(*a*,**r**,**h**)

Decrypt(*CT*,*SK*) $\longrightarrow$ $\mathbf{e}(g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})\mathbf{E}}, g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot \mathbf{R}_3)$

$= e(g_1,g_1)^{as}$

$\mathbf{k}(a,\mathbf{r},\mathbf{h})\ \mathbf{E}\ \mathbf{c}(\mathbf{s},\mathbf{h})^{\mathsf{T}} = as$

Security Proof of Our Framework

Semi-functional Ciphertexts/Keys

Can Be Defined in Terms of Pair Encoding Scheme

$g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot g_2^{\mathbf{c}(0,0)=0}$

$g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot g_2^{\mathbf{c}(\hat{\mathbf{s}},\hat{\mathbf{h}})}$

$e(g_1,g_1)^{as}$ unmodified

$g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})=0}$

$g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$

$g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\hat{\mathbf{r}},\hat{\mathbf{h}})}$

$g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}$

Each randomness except “semi-param” $\hat{\mathbf{h}}$ is fresh for each.

Semi-functional Ciphertexts/Keys

Can Be Defined in Terms of Pair Encoding Scheme

C $g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot g_2^{\mathbf{c}(0,0)=0}$

C $g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot g_2^{\mathbf{c}(\hat{\mathbf{s}},\hat{\mathbf{h}})}$

$e(g_1,g_1)^{as}$ unmodified

K $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})=0}$

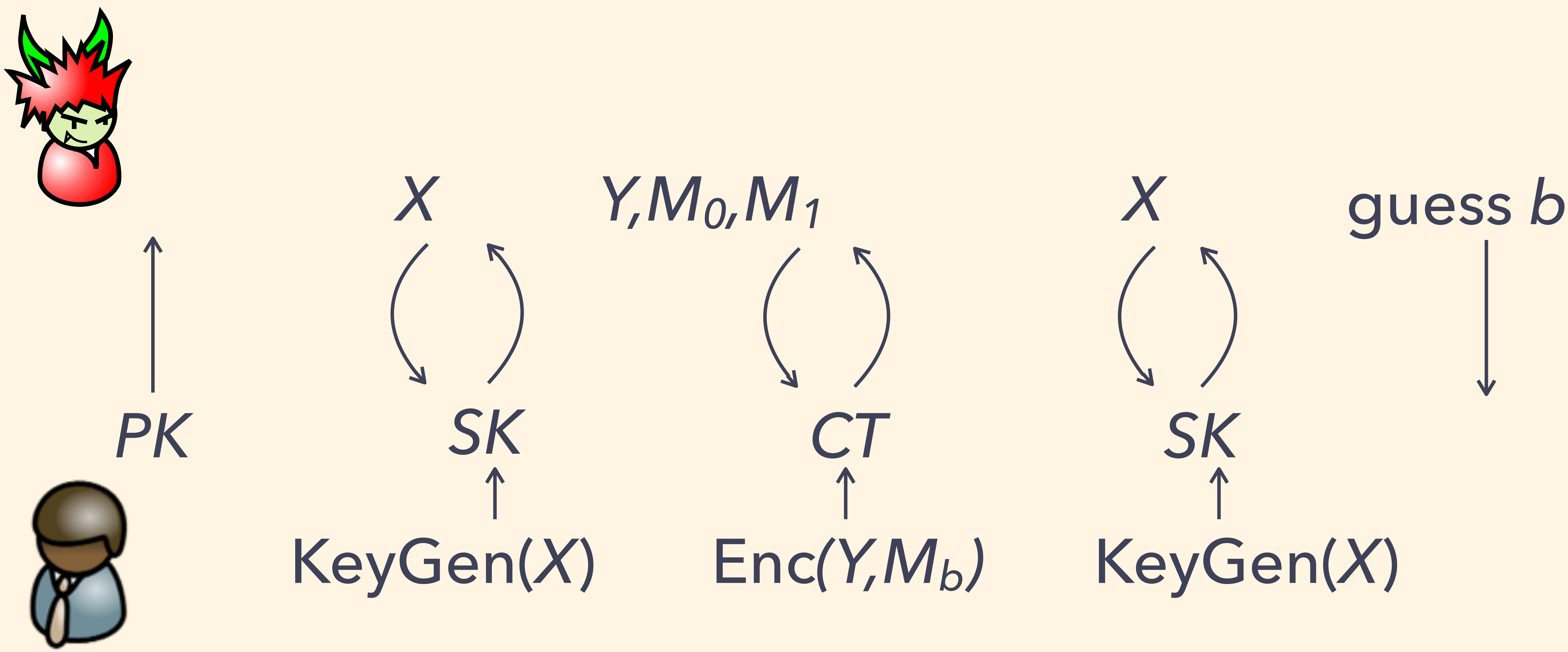
K1 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$

K2 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\hat{\mathbf{r}},\hat{\mathbf{h}})}$

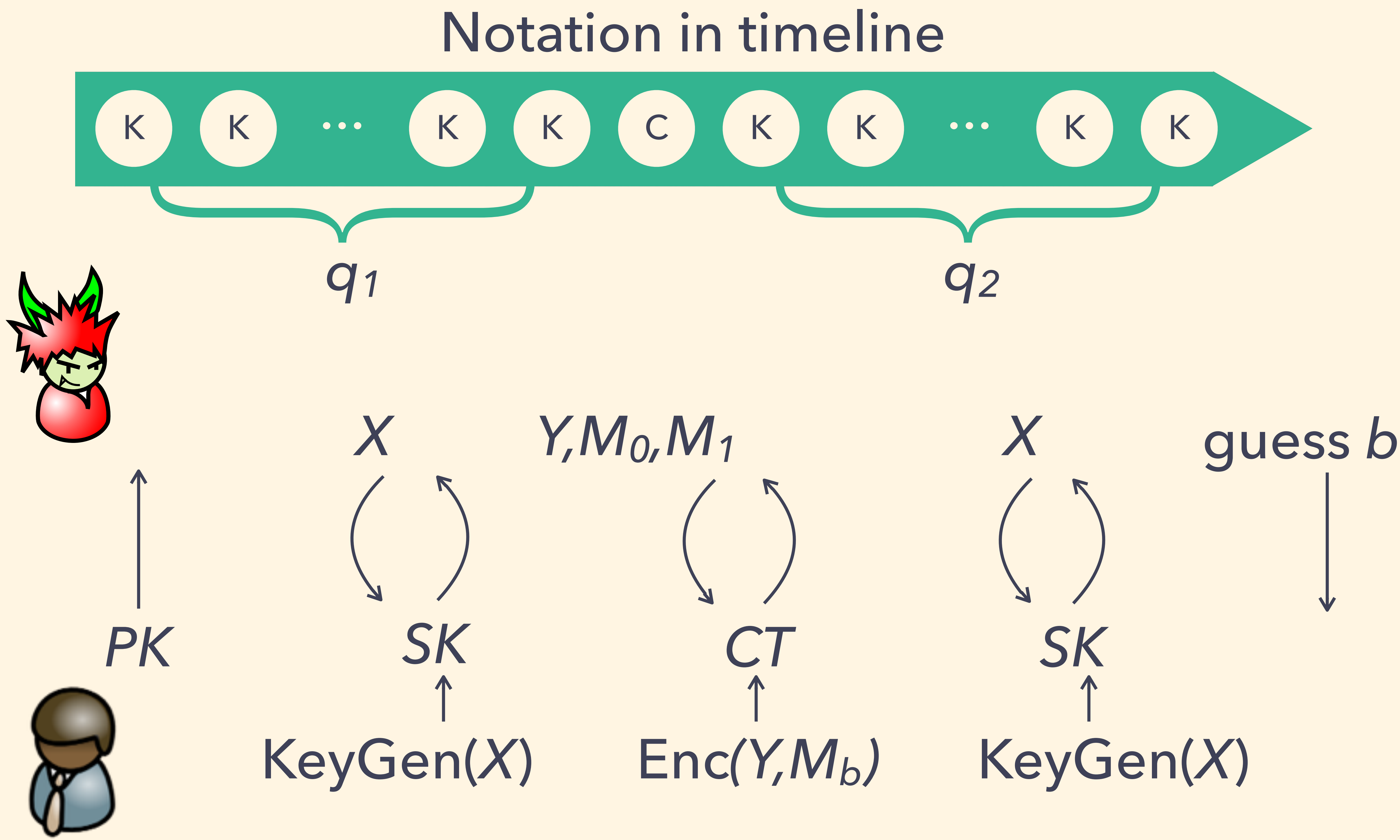
K3 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}$

Each randomness except "semi-param" $\hat{\mathbf{h}}$ is fresh for each.

Recall Definition for Full Security

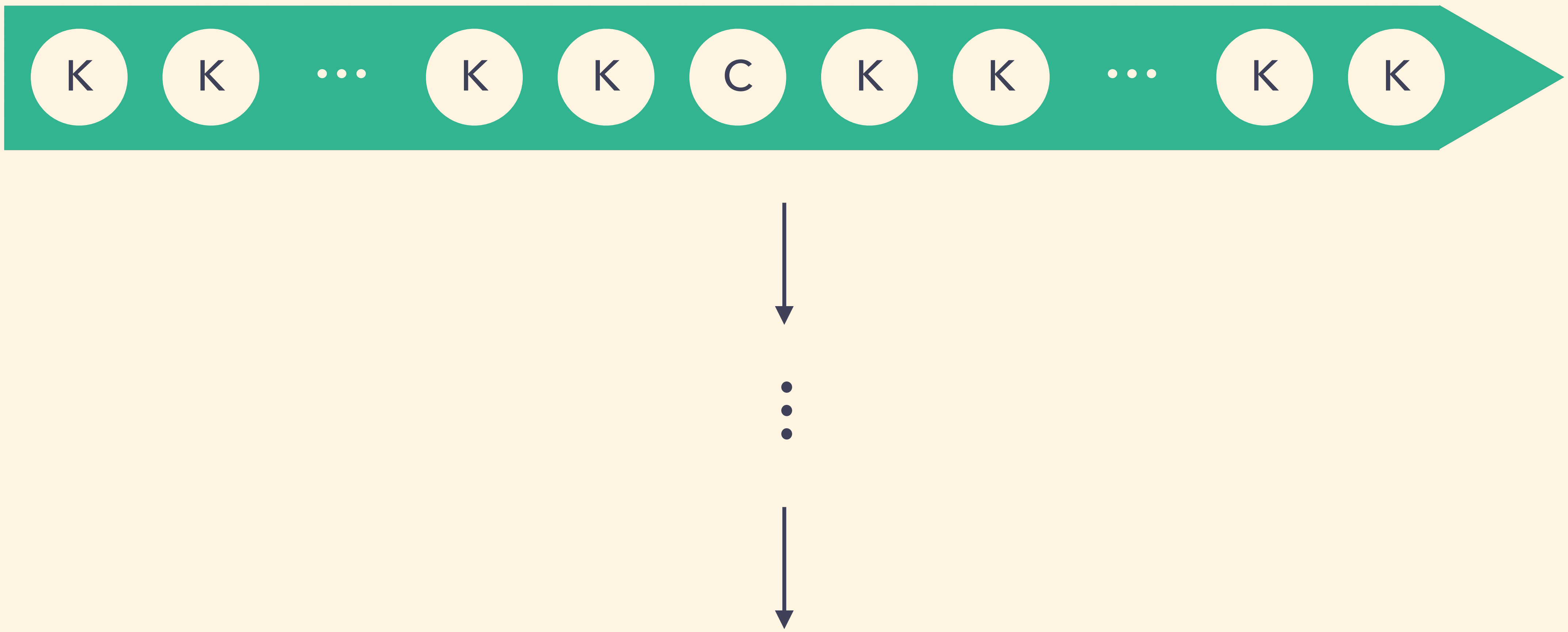


Recall Definition for Full Security

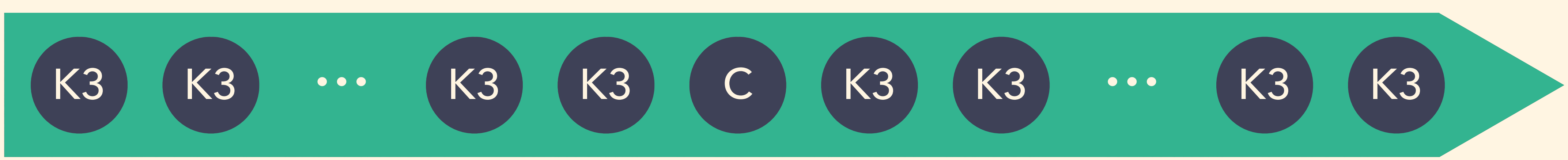


Aim of the Proof

Real game: all normal



Final game: all semi-functional

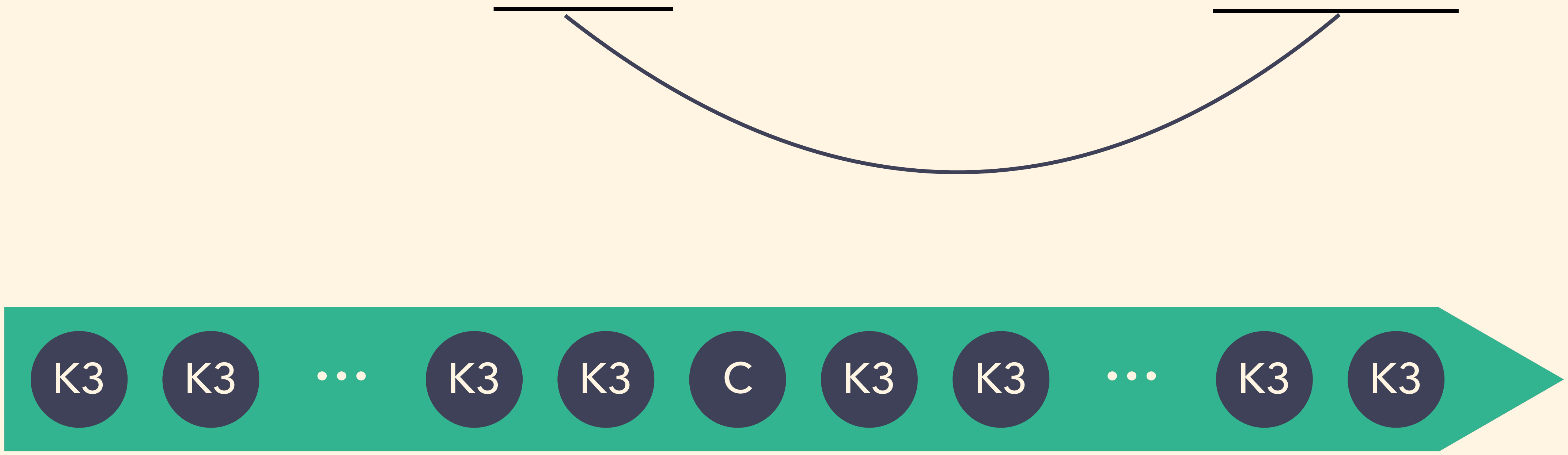


Final Game

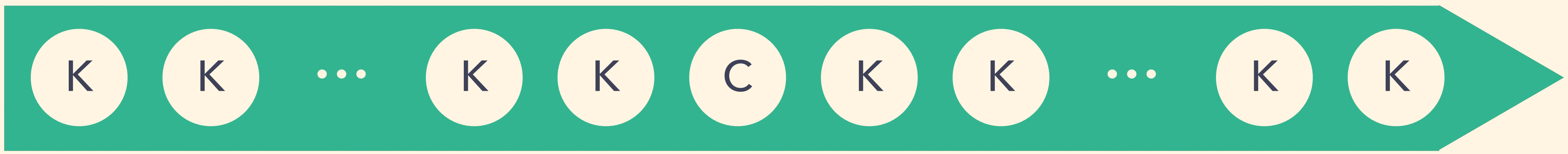
Adversary will have no advantage.

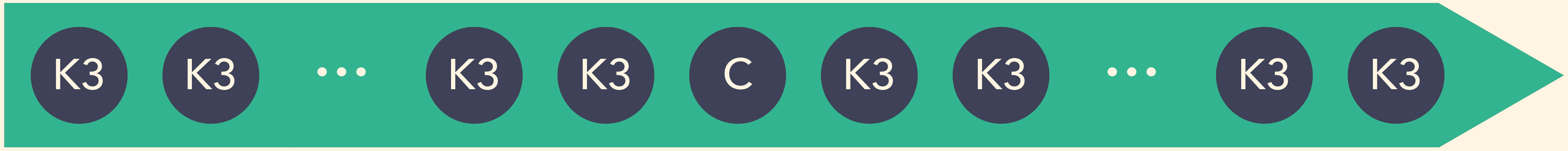
Intuition: decryption contains random $e(g_2,g_2)^{\hat{a}\hat{s}}$

C $g_1^{\mathbf{c}(\mathbf{s},\mathbf{h})} \cdot \underline{g_2^{\mathbf{c}(\hat{\mathbf{s}},\hat{\mathbf{h}})}}$ K3 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot \underline{g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}}$



Game Sequence in the Proof





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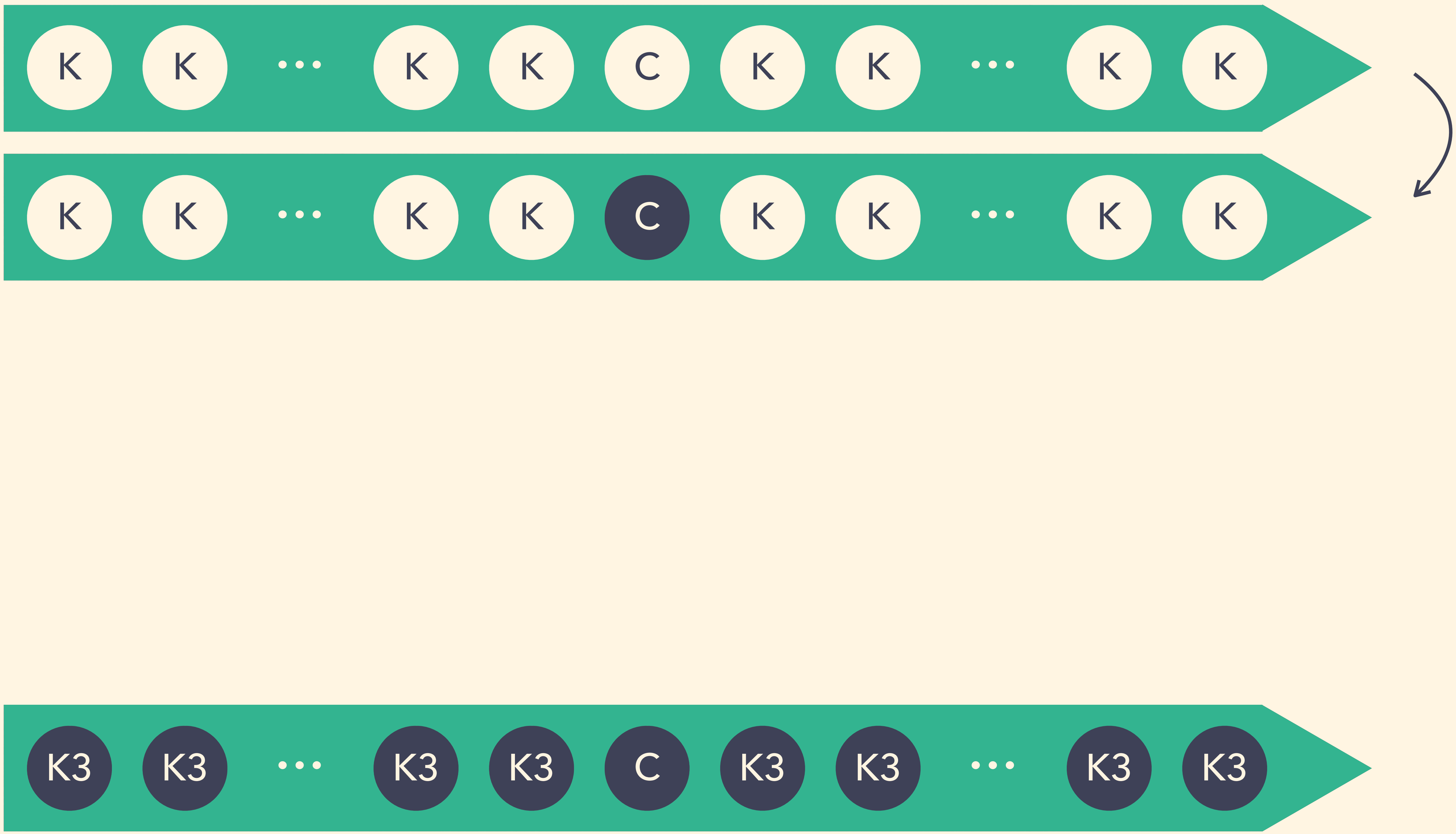

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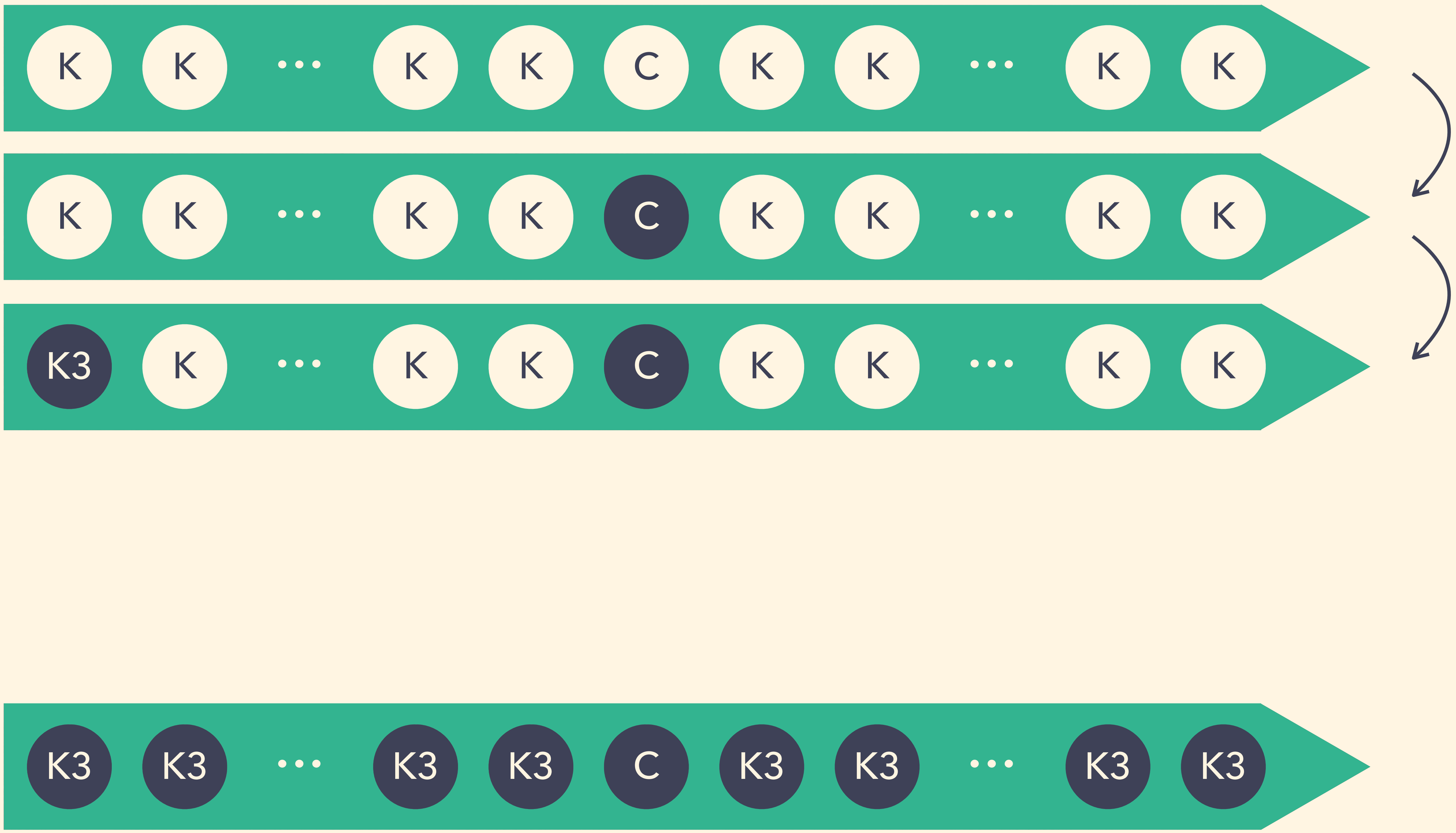

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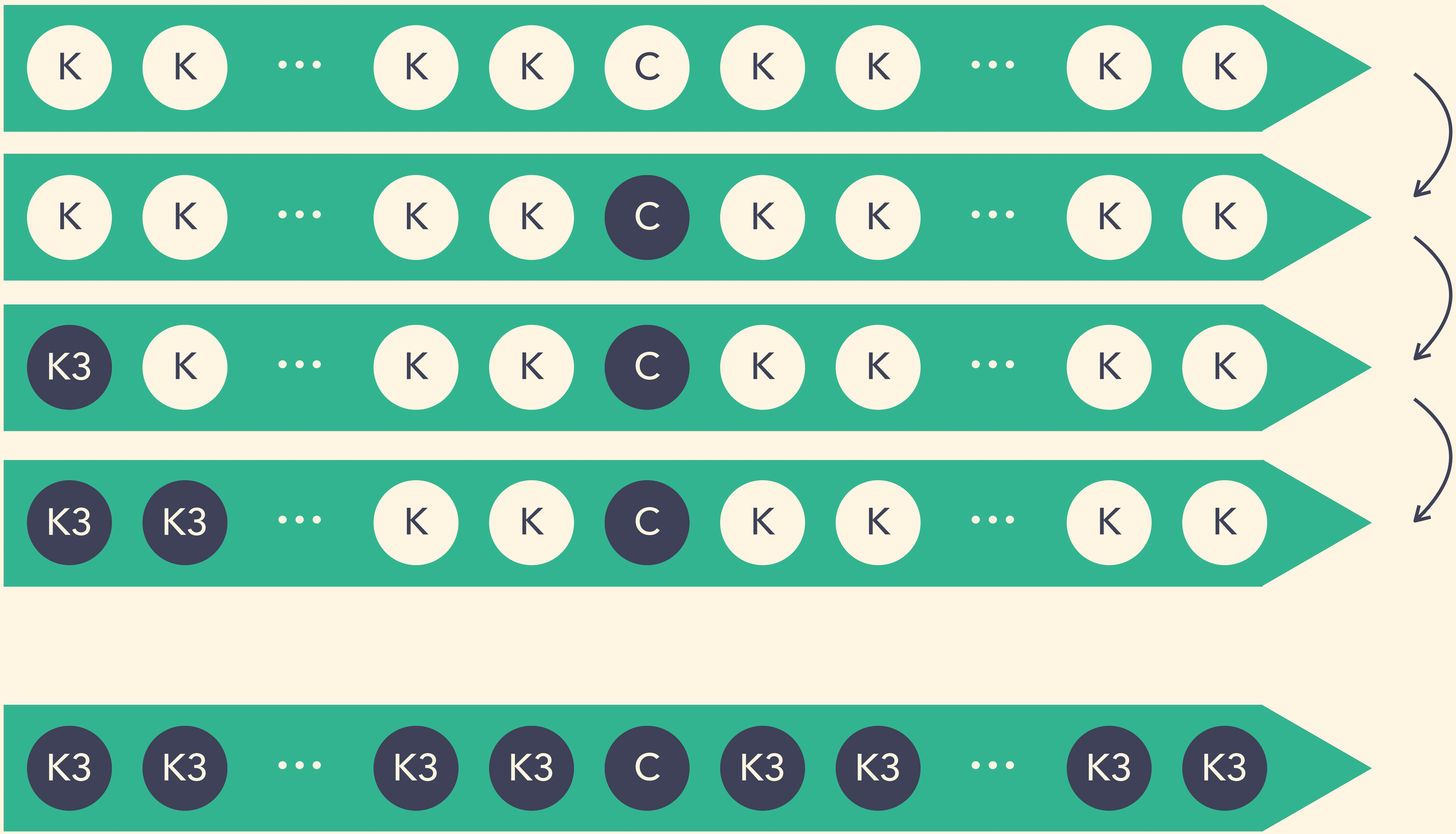

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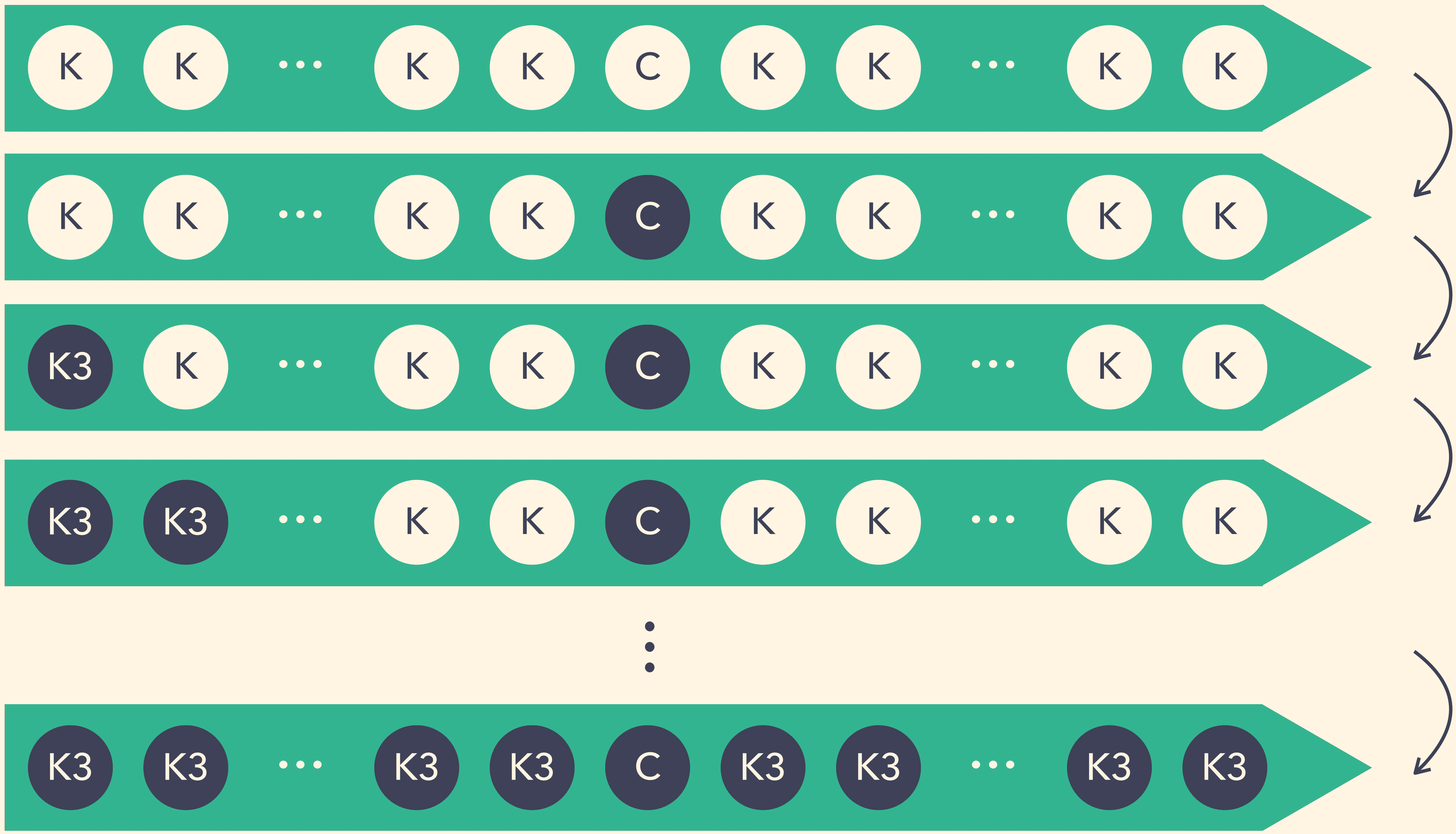
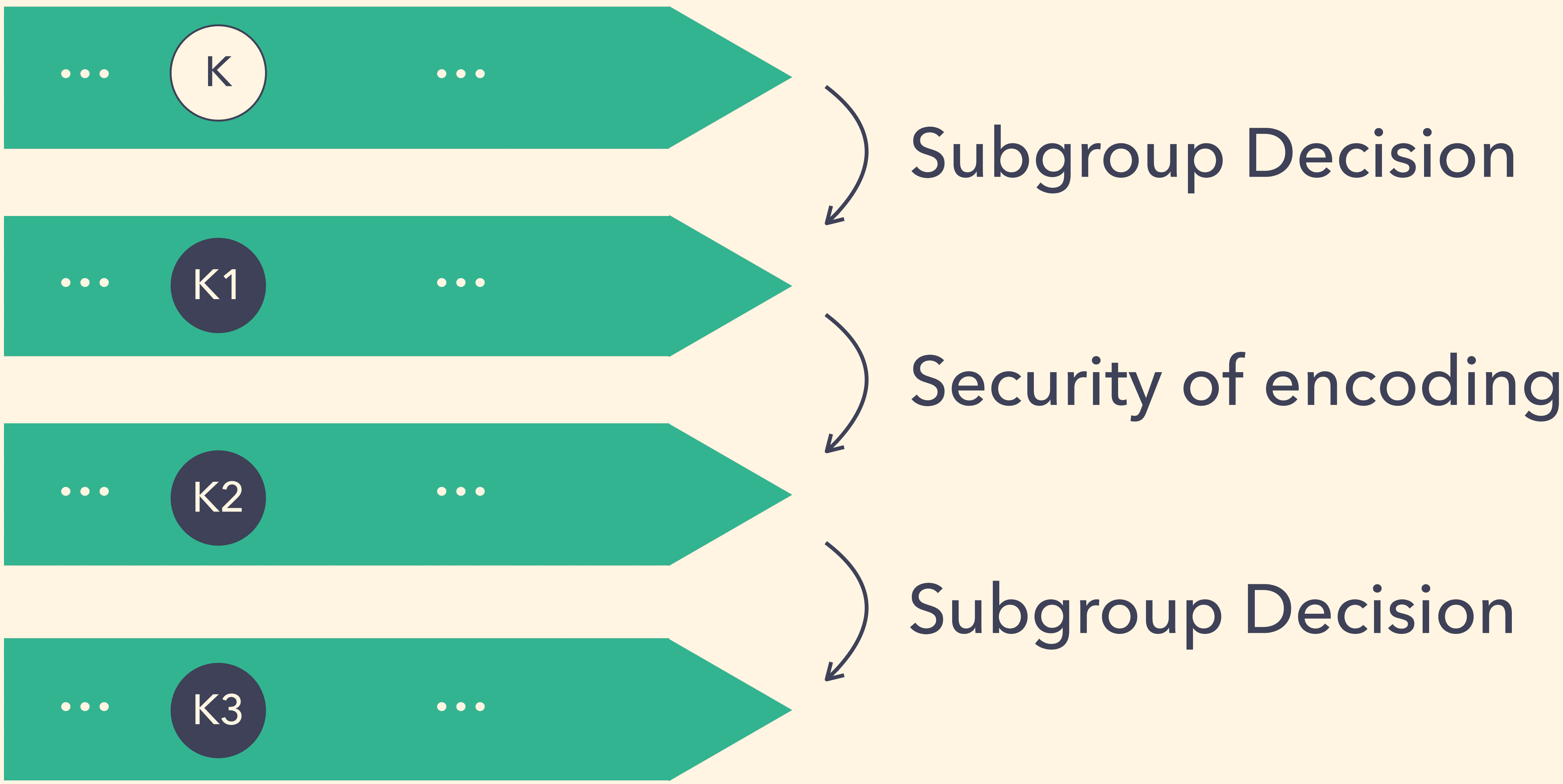
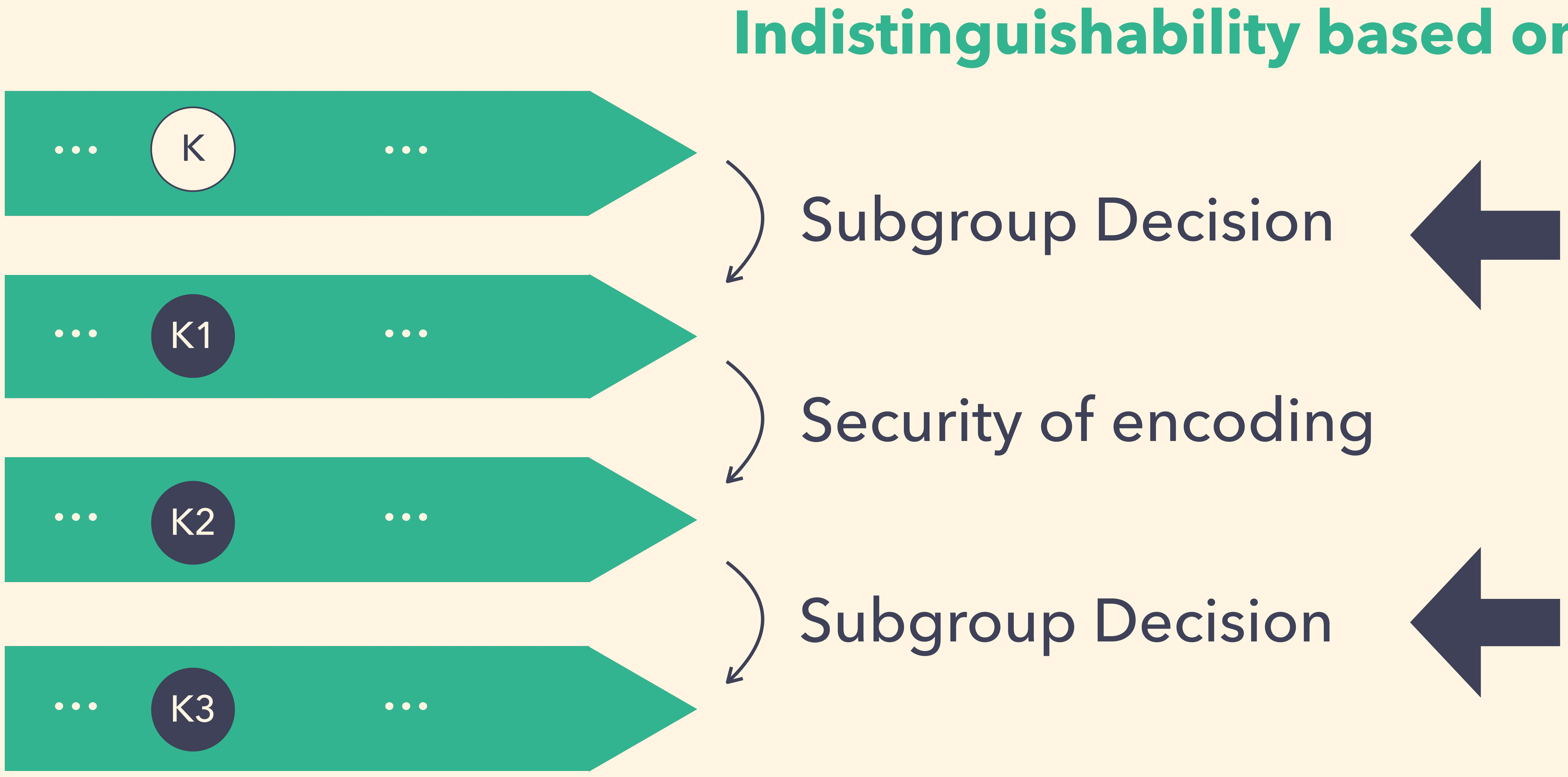


Game Subsequence

Indistinguishability based on



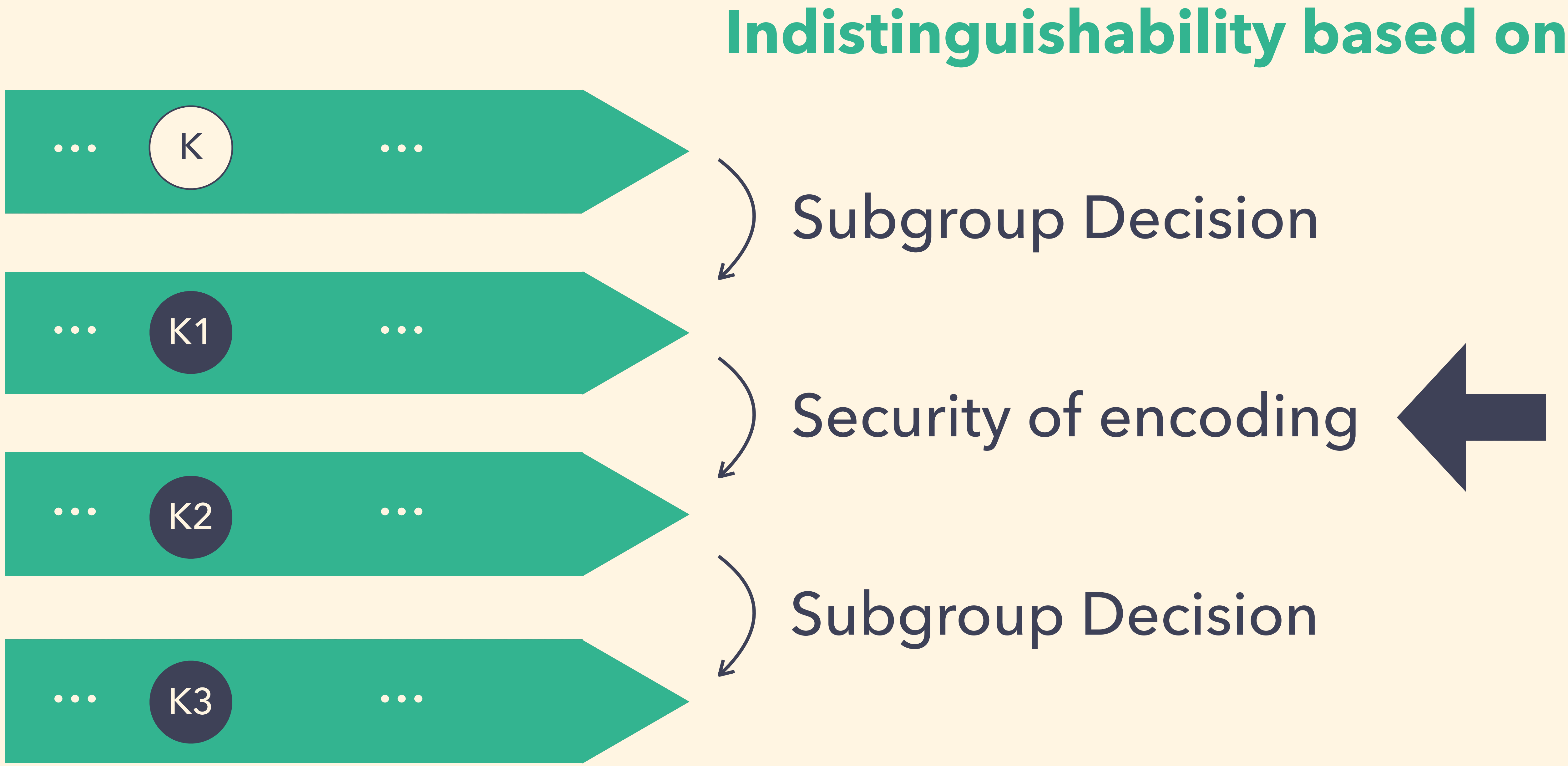
Game Subsequence



Intuition: These two do not depend on encoding.

Use linearity, param-vanishing of ***k*** and orthogonality of *G*.

Game Subsequence



The 2nd Transition

K1 $g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(0,\hat{\boldsymbol{r}},\hat{\boldsymbol{h}})}$

K2 $g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(\hat{a},\hat{\boldsymbol{r}},\hat{\boldsymbol{h}})}$

Security of encoding

(to be defined)

The 2nd Transition

K1 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$

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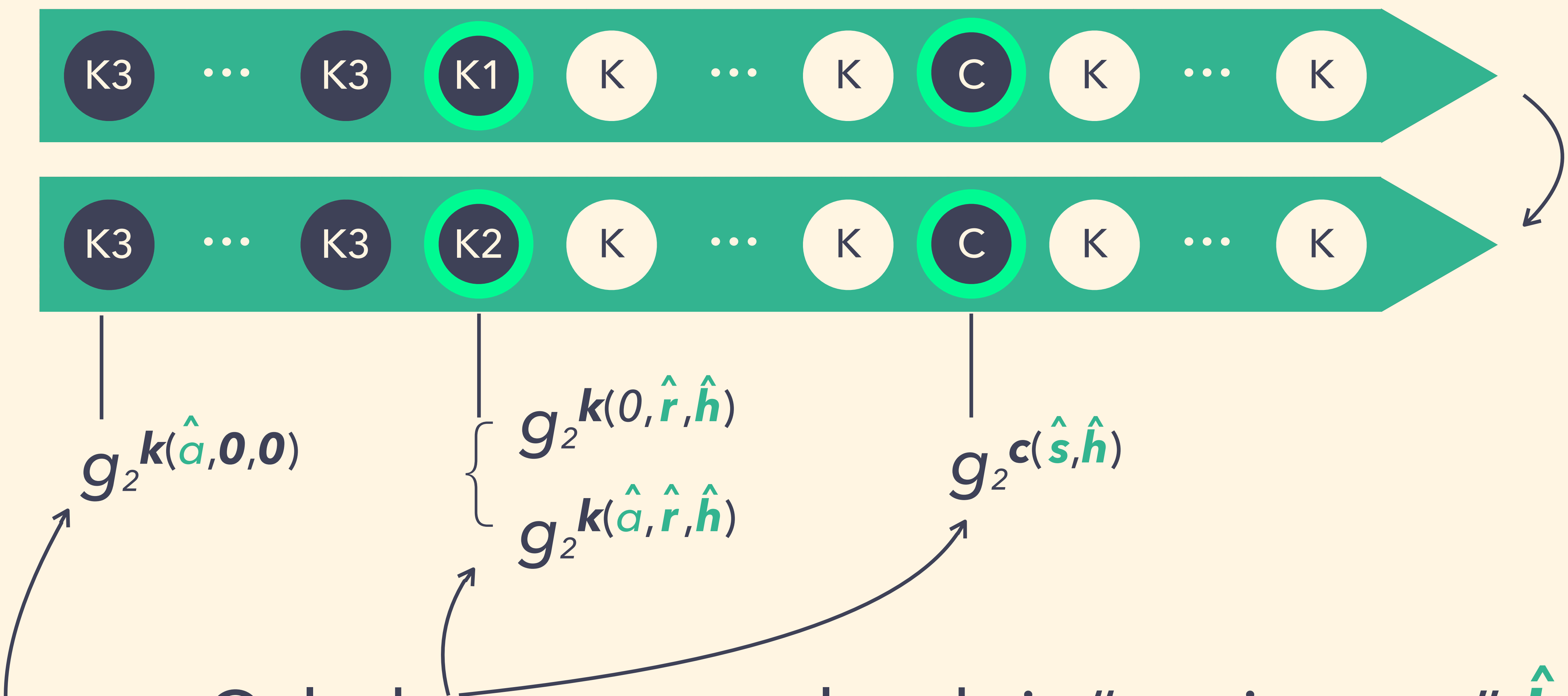
Security of encoding

(to be defined)

Idea: just define security of encoding to be exactly the indistinguishability of these two games!

The 2nd Transition

In More Details



- Only these are correlated via "semi-param" $\hat{h}$.
- "Isolating" all other keys.

Defining Security of Encoding

Computationally secure encoding

Cannot distinguish

$$\left\{\begin{array}{l} g_2^{\mathbf{k}(0,\hat{r},\hat{h})} \\ g_2^{\mathbf{k}(\hat{a},\hat{r},\hat{h})} \end{array}\right.$$

$$g_2^{\mathbf{c}(\hat{s},\hat{h})}$$

Defining Security of Encoding

Perfectly secure encoding

Identical (info-theoretic) $\left\{ \begin{array}{l} \boldsymbol{k}(0, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}}) \\ \boldsymbol{k}(a, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}}) \end{array} \right.$

$$\boldsymbol{c}(\hat{\boldsymbol{s}}, \hat{\boldsymbol{h}})$$

Computationally secure encoding

Cannot distinguish ← $\left\{ \begin{array}{l} g_2^{\boldsymbol{k}(0, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}})} \\ g_2^{\boldsymbol{k}(\hat{a}, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}})} \end{array} \right.$

$$g_2^{\boldsymbol{c}(\hat{\boldsymbol{s}}, \hat{\boldsymbol{h}})}$$

Defining Security of Encoding

Perfectly secure encoding

Identical (info-theoretic)

$$\left\{ \begin{array}{l} \boldsymbol{k}(0, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}}) \\ \boldsymbol{k}(a, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}}) \end{array} \right. \qquad \boldsymbol{c}(\hat{\boldsymbol{s}}, \hat{\boldsymbol{h}})$$

Computationally secure encoding

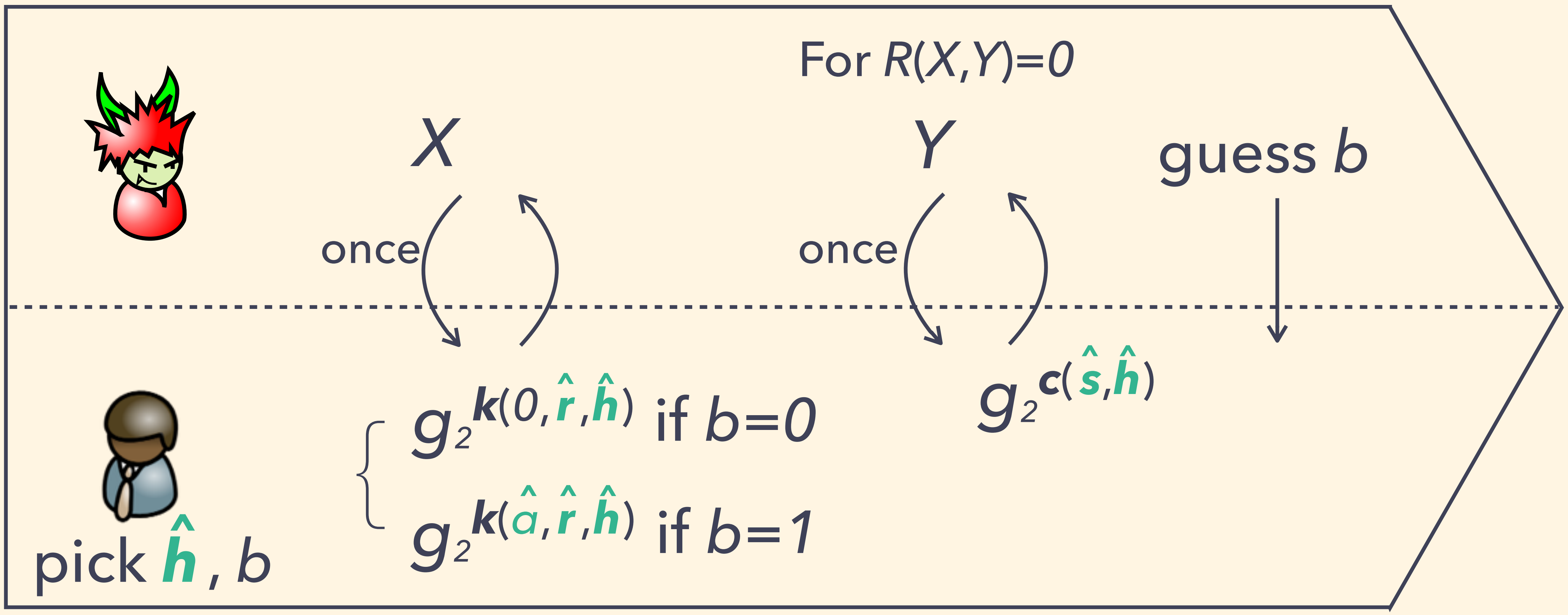
Cannot distinguish ←

$$\left\{ \begin{array}{l} g_2^{\boldsymbol{k}(0, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}})} \\ g_2^{\boldsymbol{k}(\hat{a}, \hat{\boldsymbol{r}}, \hat{\boldsymbol{h}})} \end{array} \right. \qquad g_2^{\boldsymbol{c}(\hat{\boldsymbol{s}}, \hat{\boldsymbol{h}})}$$

1st flavor: ***k*** before ***c***

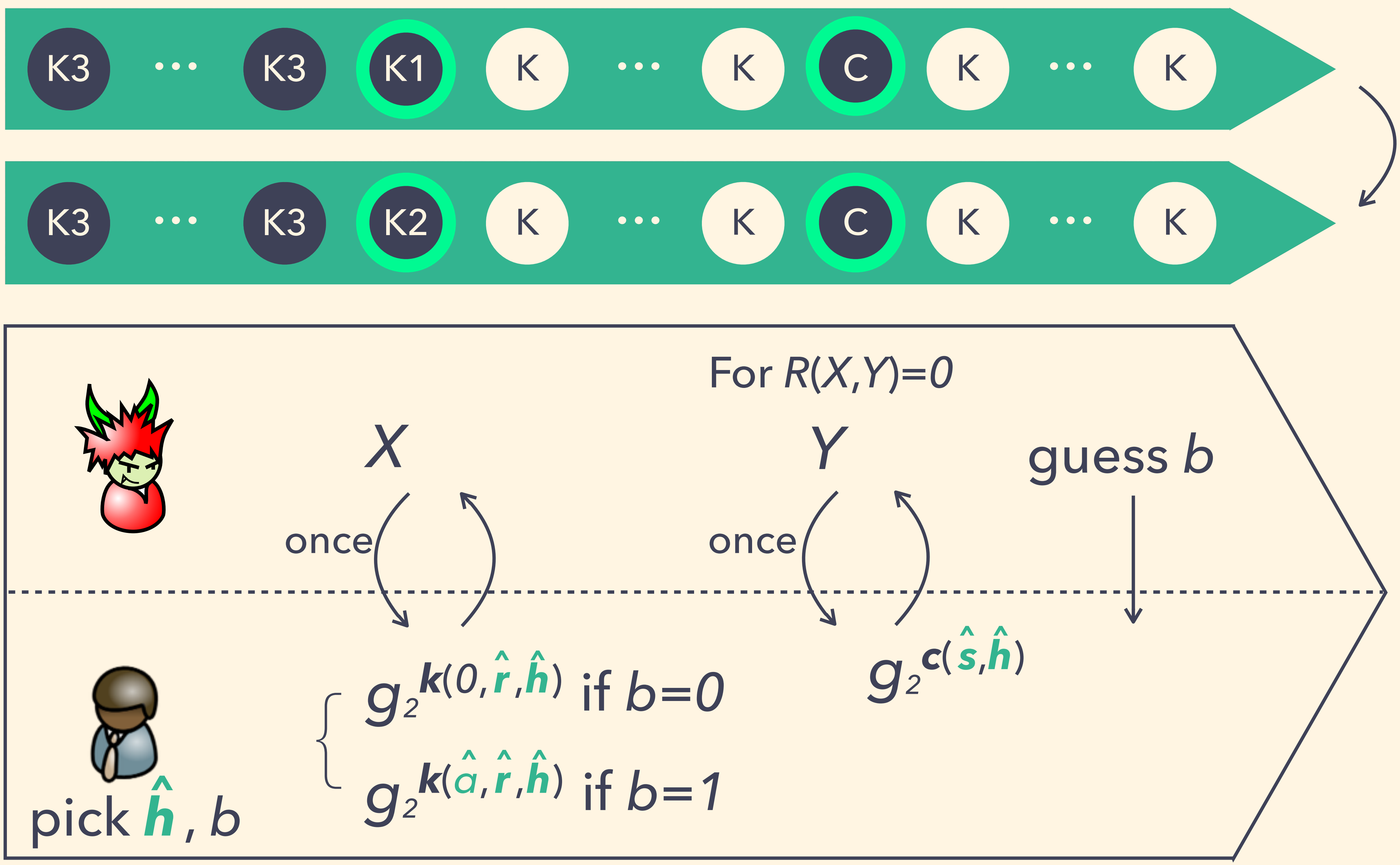
2nd flavor: ***c*** before ***k***

Computationally Security 1: *k* before *c*

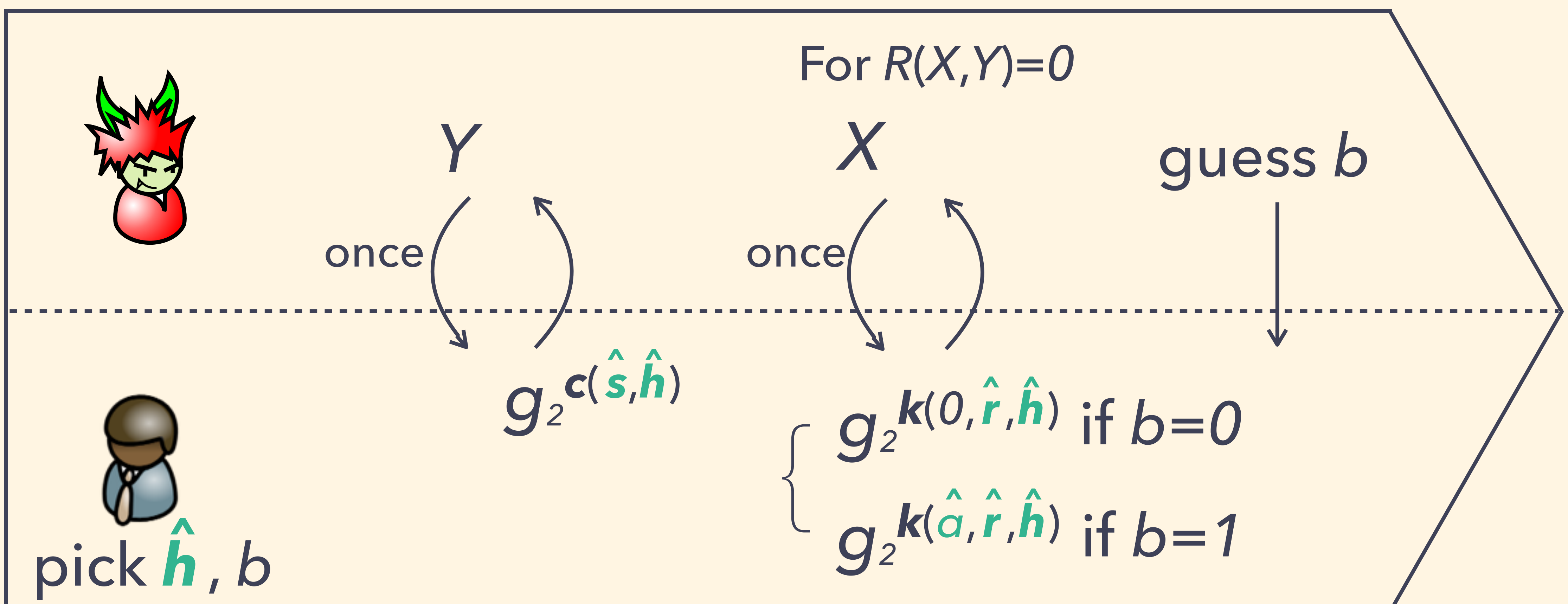


Computationally Security 1: *k* before *c*

For Transitions of *Pre-challenge Keys*

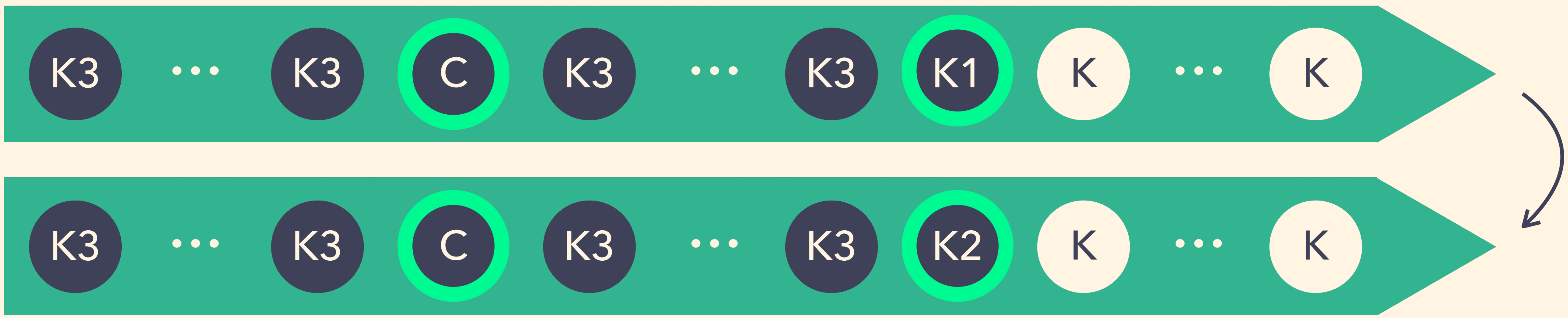


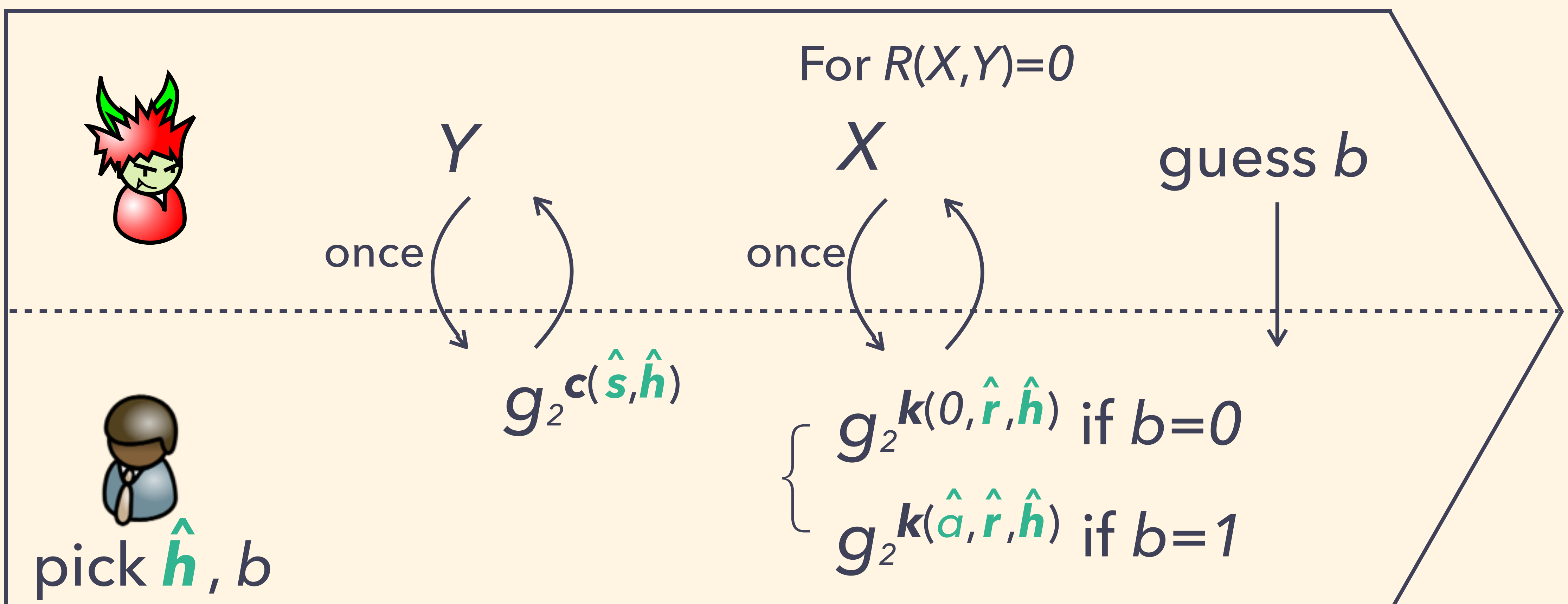
Computationally Security 2: c before *k*



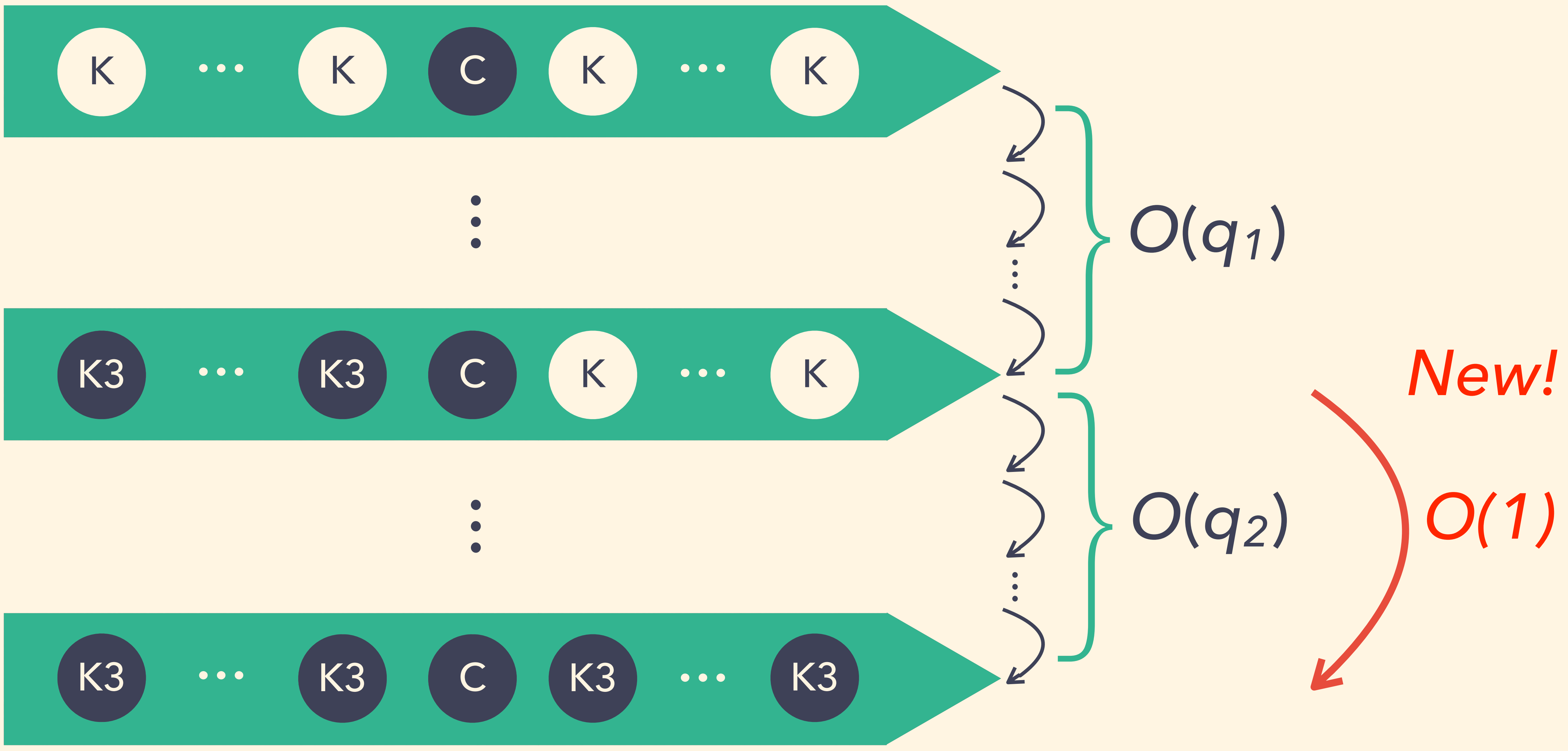
Computationally Security 2: c before *k*

For Transitions of *Post*-challenge Keys



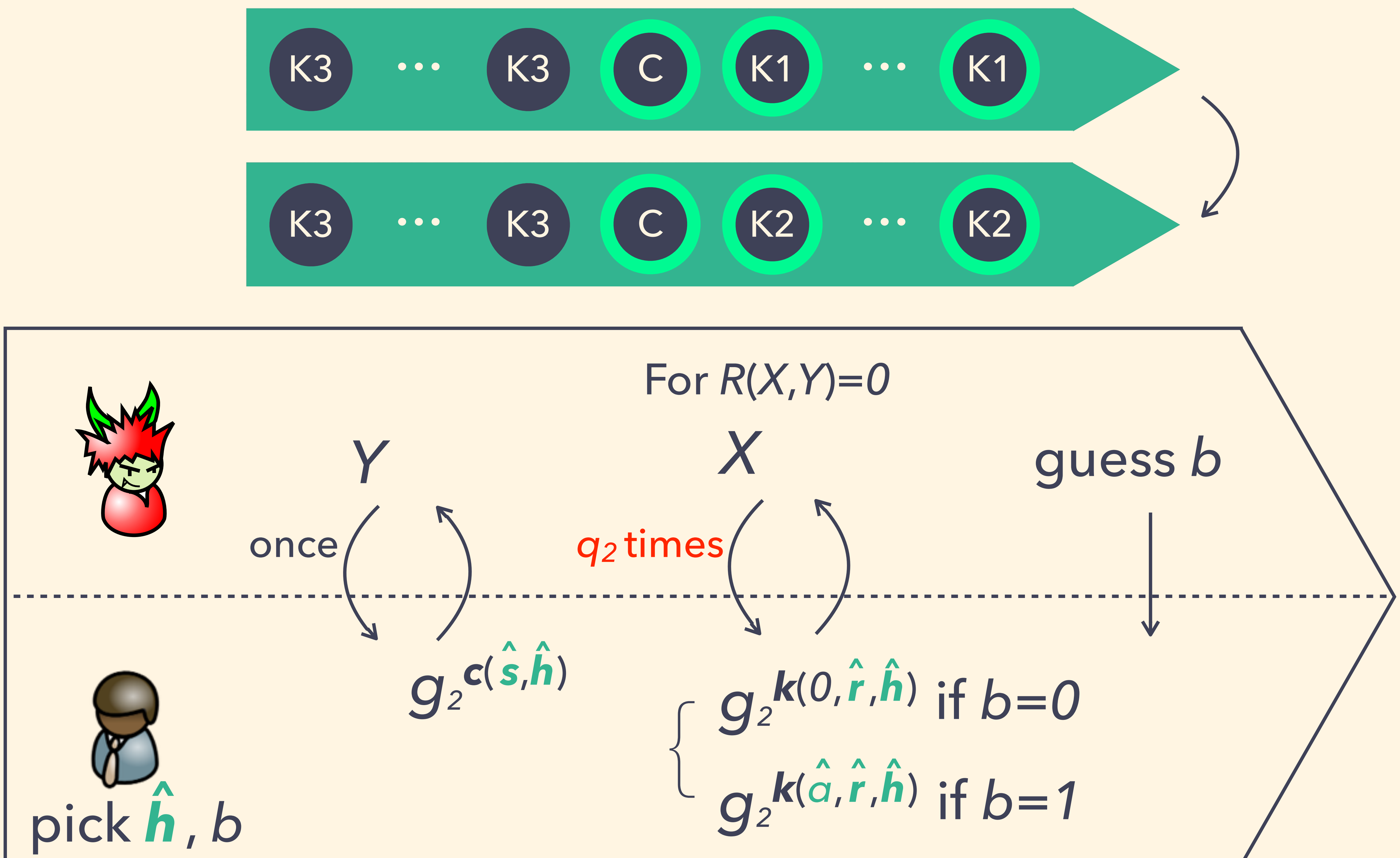


Tighter Security Proof

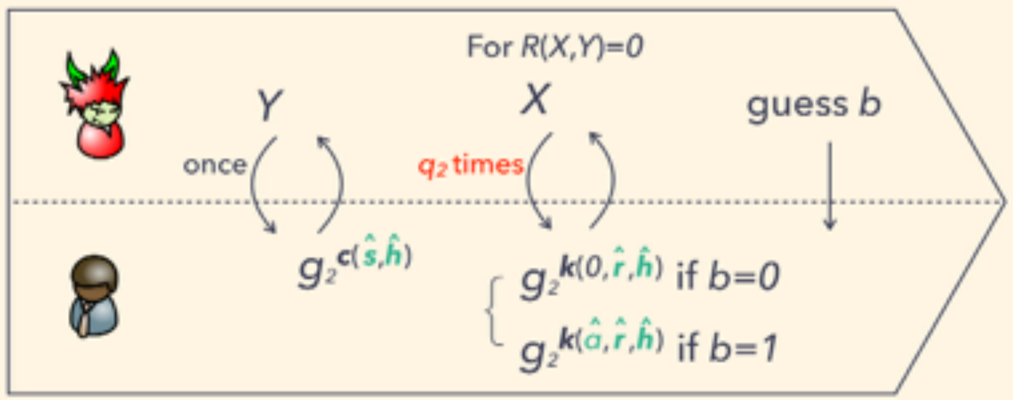


Refining Computationally Security 2

For Transitions of *Post*-challenge Keys

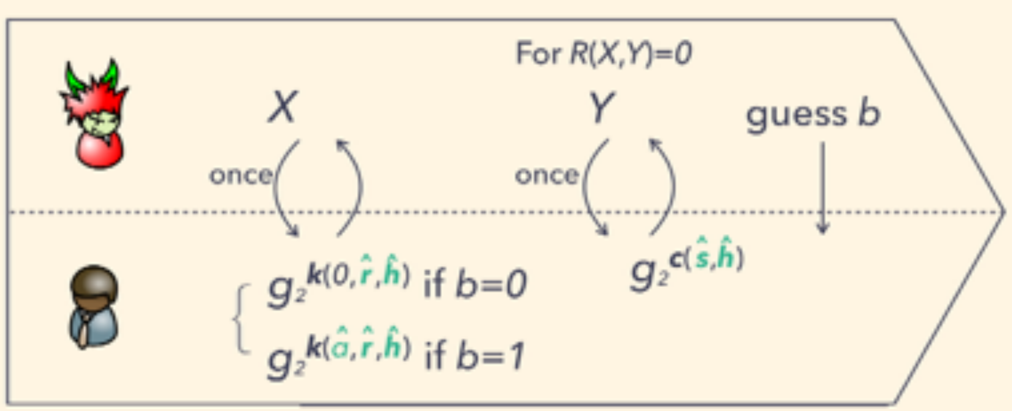


“Doubly Selective Security”



$Y \rightarrow$ program $\hat{h} \rightarrow X$

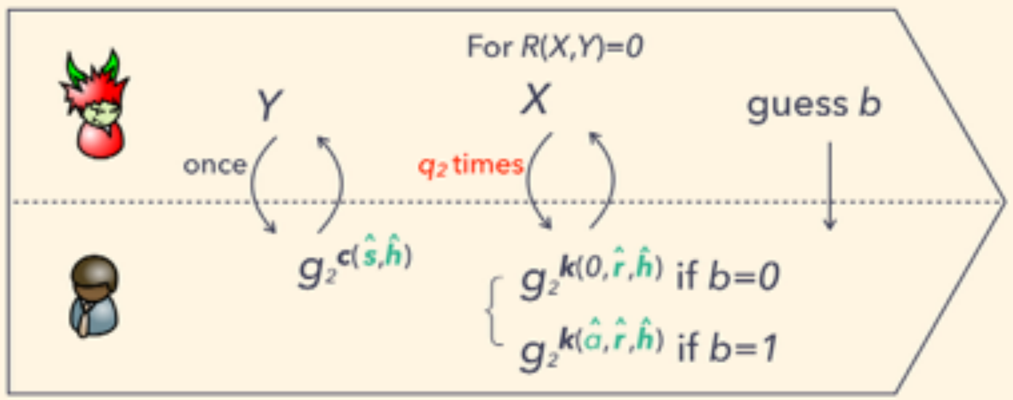
The 2nd notion is called **Selective** Master-key Hiding since the order of queries mimics selective security of FE but in semi-functional space.



$X \rightarrow$ program $\hat{h} \rightarrow Y$

The 1st notion is called **Co-Selective** Master-key Hiding since the order of queries mimics co-selective security of FE but in semi-functional space.

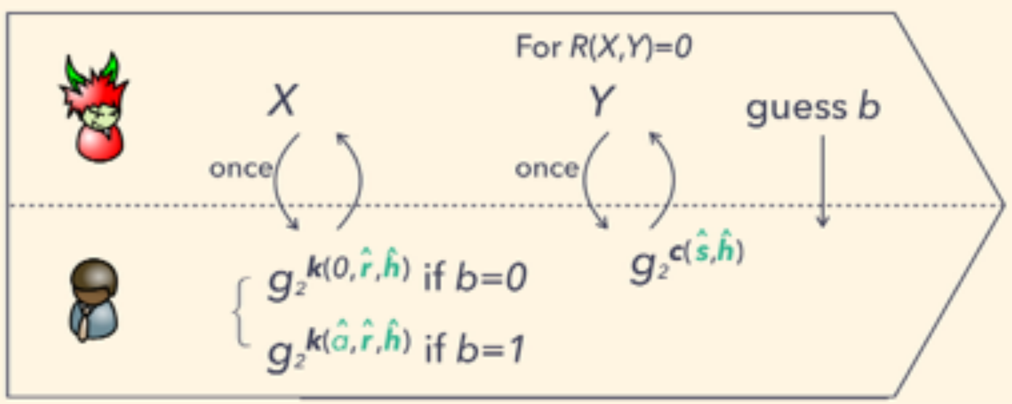
"Doubly Selective Security"



$Y \rightarrow$ program $\hat{h} \rightarrow X$

The 2nd notion is called **Selective** Master-key Hiding

Can borrow proof techniques for selective security of FE



$X \rightarrow$ program $\hat{h} \rightarrow Y$

The 1st notion is called **Co-Selective** Master-key Hiding

Can borrow proof techniques for co-selective security of FE or selective security of its dual!

3 Instantiations

Fully Secure IBE

Lewko-Waters IBE $\boldsymbol{h}=(h_1,h_2)$

$\boldsymbol{k}=(a+r(h_1+h_2ID), r)$

$\boldsymbol{c}=(s, s(h_1+h_2ID'))$

- Encoding is perfect.
  - $f(x)=h_1+h_2x$ is pair-wise independent
- Full security of IBE: $O(q_{all})$ to Subgroup Decision

Our new IBE $\boldsymbol{h}=(h_1,h_2,h_3)$

$\boldsymbol{k}=(a+r_1(h_1+h_2ID)+r_2h_3, r_1, r_2)$

$\boldsymbol{c}=(s, s(h_1+h_2ID'), sh_3)$

- Encoding is perfect.
- Encoding is also selective under 3-party DH.
- Full security of IBE: $O(q_1)$ to Subgroup Decision plus $O(1)$ to 3-party DH

Fully Secure IBE

	|Public key|	|Ciphertext|, |key|	Reduction	Assumption
Waters 05	$O(n)$	$O(1)$	$O(nq_{all})$	DBDH
Gentry 06	$O(1)$	$O(1)$	$O(1)$	q_{all}-ABDHE
Waters 09	$O(1)$	$O(1)$	$O(q_{all})$	DBDH,DLIN
Lewko-Waters 10	$O(1)$	$O(1)$	$O(q_{all})$	subgroup
Chen-Wee 13	$O(n)$	$O(1)$	$O(n)$	DLIN
Our IBE	$O(1)$	$O(1)$	$\mathbf{O(q_1)}$	3DH, subgroup

n = ID length

FE for Regular Languages

	Security	Reduction	Assumption
Waters 12	selective	$O(1)$	Q-type
Our FE for regular languages	**full**	$O(q_1)$	Q-type, subgroup

FE for Regular Languages

Selective security of our encoding

- Borrow techniques from selective security of Waters'.
- Hence, use a similar "Q-type" assumption to Waters'.
  - Q is ciphertext attribute size of *one query*.
  - Q is *not* the number of queries (q_1,q_2).

Co-selective security of our encoding

- New techniques, new Q-type assumption.

KP-ABE with Short Ciphertext

	Ciphertext size	Key size	Security	Reduction	Assumption
A.-Libert-Panafieu 11	$O(1)$	$O(tk)$	selective	$O(1)$	Q-type
Takashima 14	$O(1)$	$O(tk)$	selective	$O(q_{all})$	DLIN
Our ABE w/ short ciphertext	$O(1)$	$O(tk)$	**full**	$O(q_1)$	Q-type, subgroup

t = max attribute set in ciphertext,   k= policy size for key

Unbounded KP-ABE

	Large universe ?	Unbounded attribute repetition?	Security	Reduction	Assumption
Lewko-Waters 11	yes	yes	selective	$O(q_{all})$	subgroup
Lewko-Waters 12	no	yes	full	$O(q_{all})$	Q-type, subgroup
Okamoto-Takashima 12b	yes	no	full	$O(q_{all})$	DLIN
Rouselakis-Waters 13	yes	yes	selective	$O(1)$	Q-type
Our unbounded ABE	**yes**	**yes**	**full**	$O(q_1)$	Q-type, subgroup

More Results

- Generic dual scheme conversion for perfectly-secure encoding.
  - Convert key-policy to ciphertext-policy (& vice versa)
- Fully-secure dual (ciphertext-policy) FE for regular languages.
- Unification of schemes based on dual systems and some improvements.

Take-Home Ideas

- Our framework can be considered as a method for boosting doubly selectively security (of encoding) to fully security (of FE).
- Why does it matters? Proving double selective security of encoding can use techniques from proving classical selective security.

Thank you

Recall the Definitions of Semi-Keys

K $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})}$

↓ Subgroup Decision

K1 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$

↓ Security of encoding

K2 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\hat{\mathbf{r}},\hat{\mathbf{h}})}$

↓ Subgroup Decision

K3 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}$

Proof for the 1st Transition

K $g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(0,\boldsymbol{0},\boldsymbol{0})}$

Subgroup Decision

K1 $g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(0,\hat{\boldsymbol{r}},\hat{\boldsymbol{h}})}$

Subgroup Decision problem: Decide if $T \in G_1$ or $T \in G_{12}$

Proof for the 1st Transition

Simulated by

(K) $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})}$ $\qquad$ $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1})^{\mathbf{k}(0,\mathbf{r}',\mathbf{h}')}$

T

(K1) $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$ $\qquad$ $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1} g_2^{t_2})^{\mathbf{k}(0,\mathbf{r}',\mathbf{h}')}$

Subgroup Decision problem: Decide if $T \in G_1$ or $T \in G_{12}$

Proof for the 1st Transition

Simulated by

K: $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})}$ — simulated by $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1})^{\mathbf{k}(0,\mathbf{r}',\mathbf{h}')}$

T

K1: $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$ — simulated by $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1} g_2^{t_2})^{\mathbf{k}(0,\mathbf{r}',\mathbf{h}')}$

Subgroup Decision problem: Decide if $T \in G_1$ or $T \in G_{12}$

Simulation is OK due to linearity, param-vanishing of $\mathbf{k}$ and "parameter-hiding" of G:

$\mathbf{h} = \mathbf{h}' \bmod p_1$ and $\hat{\mathbf{h}} = \mathbf{h}' \bmod p_2$ are independent.

Proof for the 3rd Transition is similar

Simulated by

K2 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\hat{\mathbf{r}},\hat{\mathbf{h}})}$ $\qquad$ $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1} g_2^{t_2})^{\mathbf{k}(a',\mathbf{r}',\mathbf{h}')}$

T

K3 $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}$ $\qquad$ $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h}')} \cdot (g_1^{t_1})^{\mathbf{k}(a',\mathbf{r}',\mathbf{h}')}$