# CODEX – An Application of Distributed Trust

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joint work with Fred B. Schneider and Lidong Zhou

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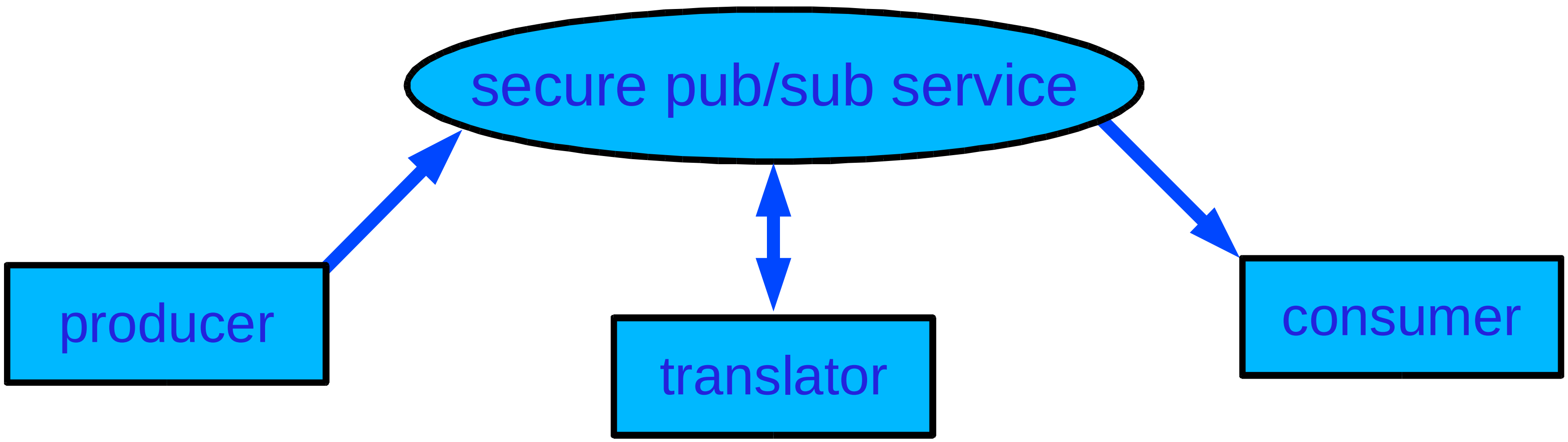
# Motivating Example




need access control

Common access privileges for publishing or subscribing:

- encrypt with (symmetric) keys
- key distribution equivalent to access control
- check access privileges iff new key issued

# The Problem

critical systems on Internet

- commerce
- power grids
- military

trustworthiness

- unreliable network
- faulty (compromised) processors

$\Longrightarrow$ Distributed Trust

# Outline of Talk

- Distributed Trust
- COrnell Data EXchange (CODEX)
- Composing Systems
- Distributed Blinding

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# Assumptions

reasonable to assume:

- fair links

  repeated sends $\Rightarrow$ eventual delivery

  allow wiretapping, message delays

  (can build secure links with PKI)

- asynchronous

  free of assumptions about timing

- compromised processors (fewer than 1/3)

  Byzantine (arbitrary) failures

  all might collude with adversary

# Replication

availability – often overlooked

- unavailable system/data not useful
- potentially dangerous

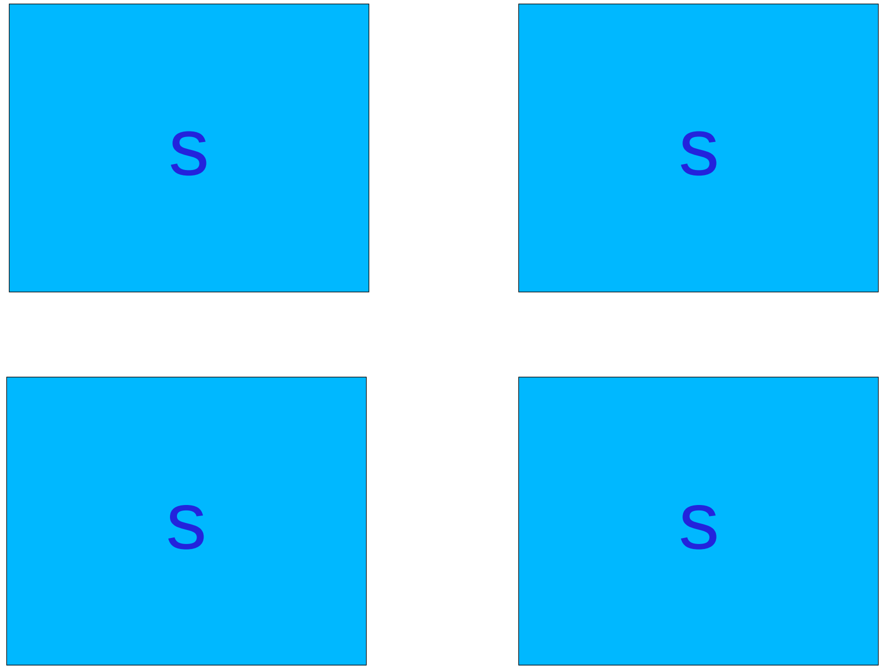
replication

- data in multiple locations
- lose one replica, others still available

design system to tolerate up to $t$ failures

# Secret Sharing

replication of secrets:



# Secret Sharing

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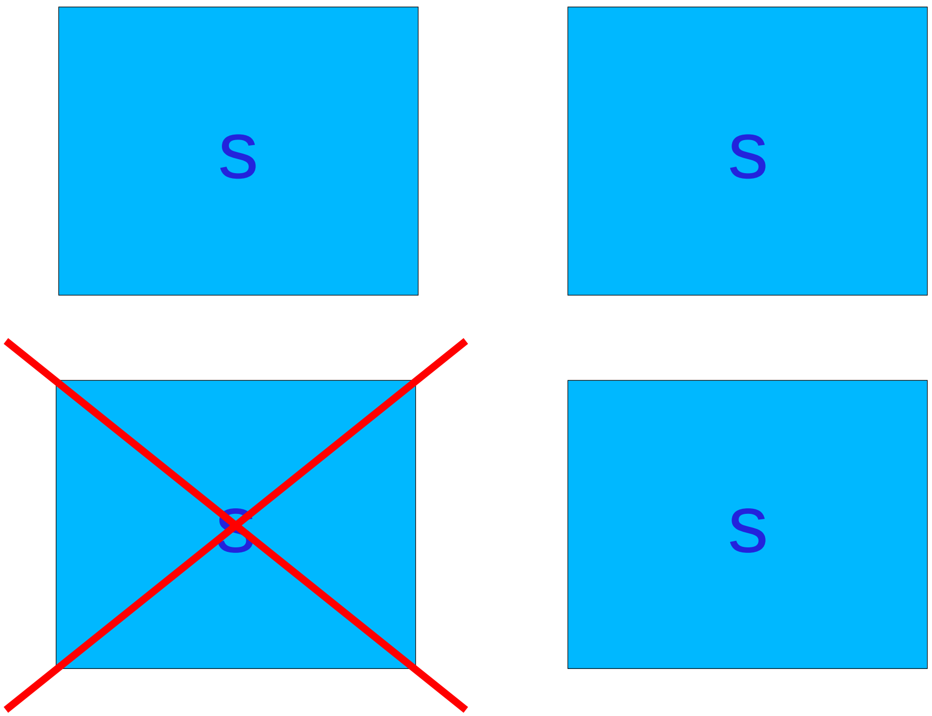
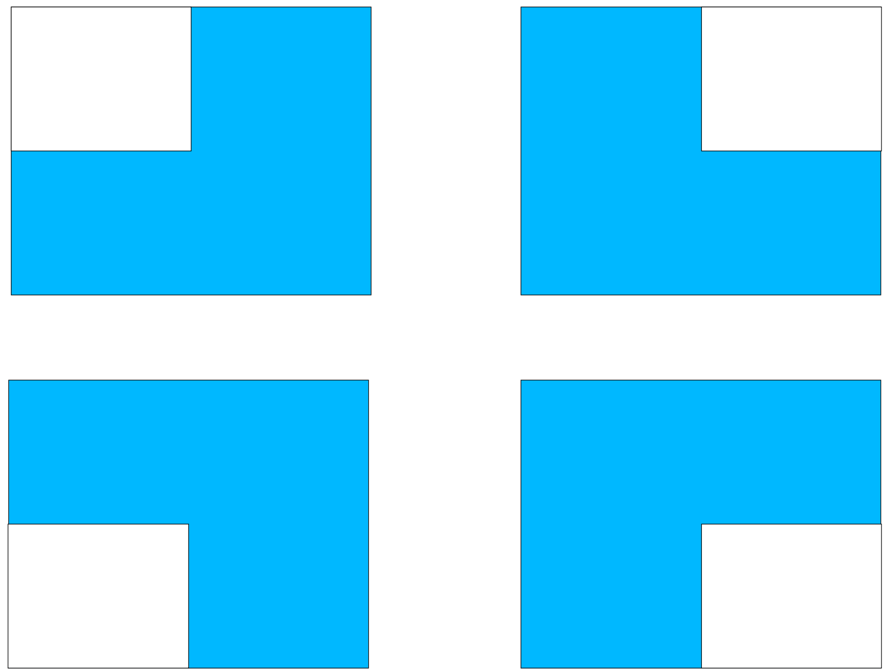



one compromise ⇒ secret leaked

# Secret Sharing

splitting a secret:



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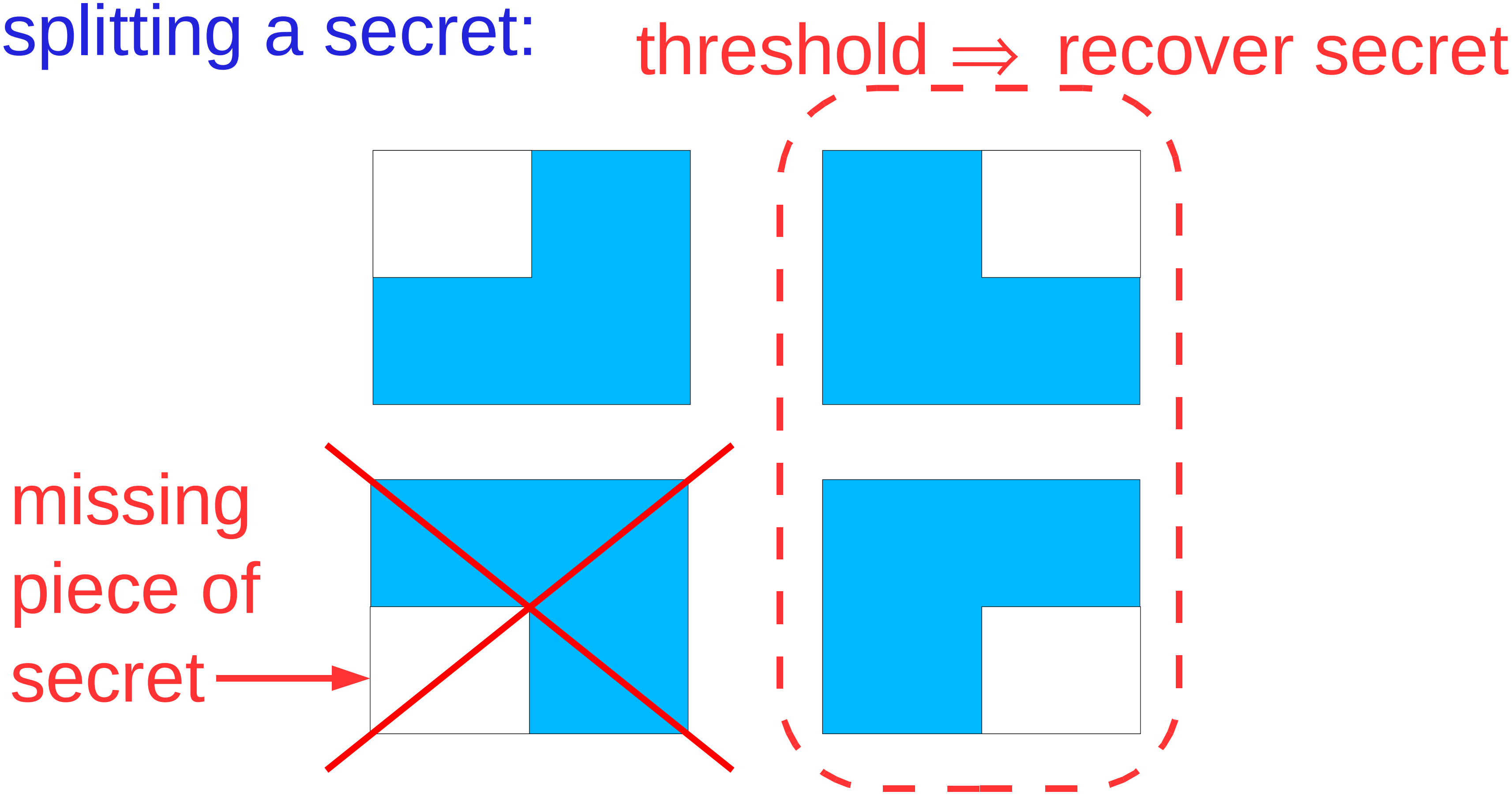


# Mobile Adversaries

recover compromised processors

$\Longrightarrow$ disclosed shares still disclosed

mobile adversary [OY91]

- changes targets
- never more than t compromises
- eventually collect >t shares

# Proactive Recovery

intrusion detection difficult, periodically assume:

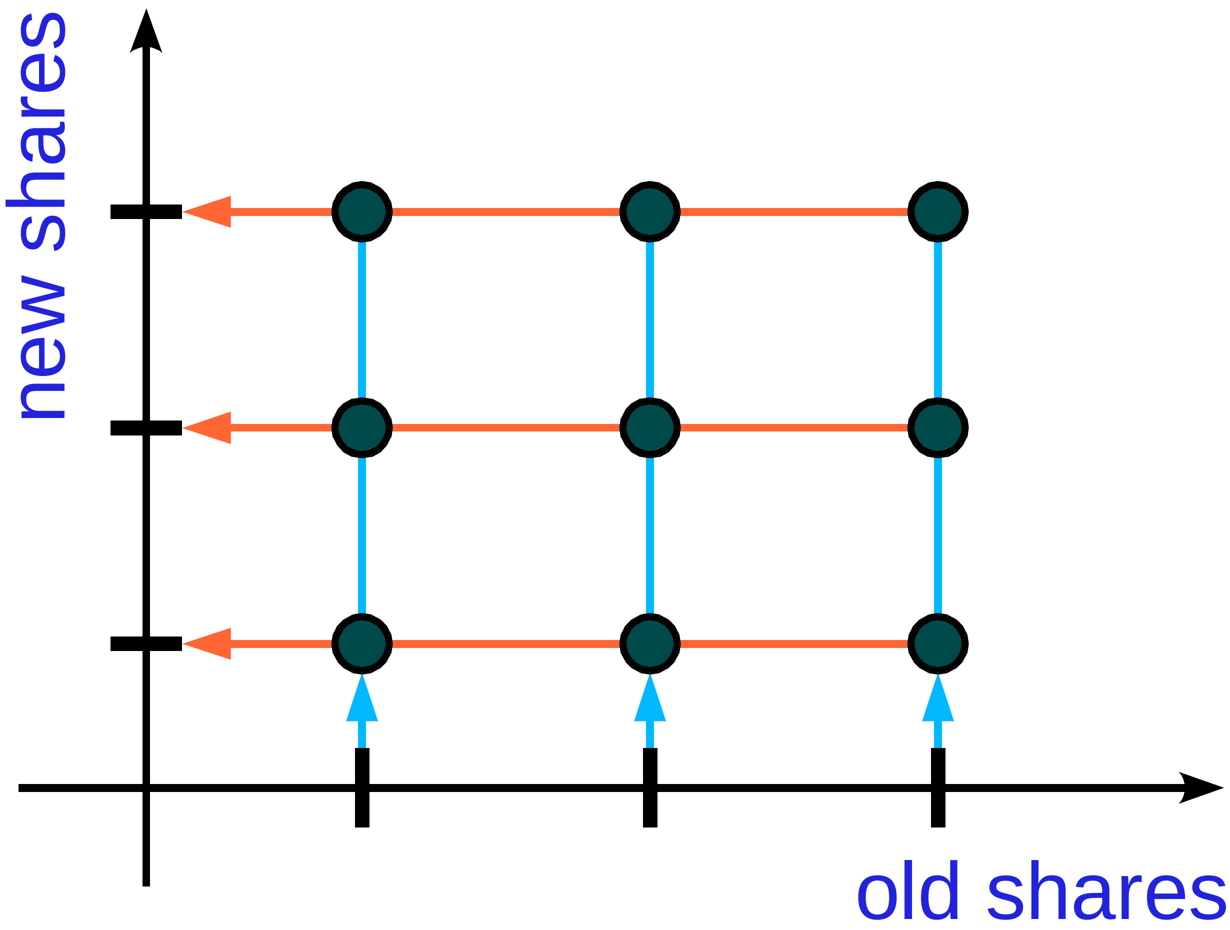
processor might be in corrupted state

- reboot from up-to-date clean media

secrets might have been disclosed

- processor's private key
  - $\Longrightarrow$ generate new public/private key pair
- shares of split secrets (mobile adversary)
  - $\Longrightarrow$ new shares for same secret
    (proactive secret sharing) [HJKY95]

# Proactive Secret Sharing



# Distributed Trust

building trustworthy systems

- replication for availability
- secret sharing for confidentiality
- proactive recovery for long-term security
  (PSS, rekey, reboot from clean media)

existing implementations:
COCA [ZSvR02], SINTRA [CP02]

we have added:
data storage, distribution

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# CODEX – Distributed Trust in a Key Distribution Service

stores clients' secrets (keys)

access control

confidentiality of secrets

transparent – client sees single "server", does not see *changes* to service

could also layer on top of OceanStore [KBC+00]

# Maintaining Confidentiality of Client Data

unauthorized clients

- access control lists

compromised servers

- encryption with service public key
- private key $\rightarrow$ shared secret
    - threshold decryption/signature
    - does not use private key explicitly

retrieval requires decryption

# CODEX Operations

create_key: associates ownership and access policies with a name

create_key,name,owner,policies

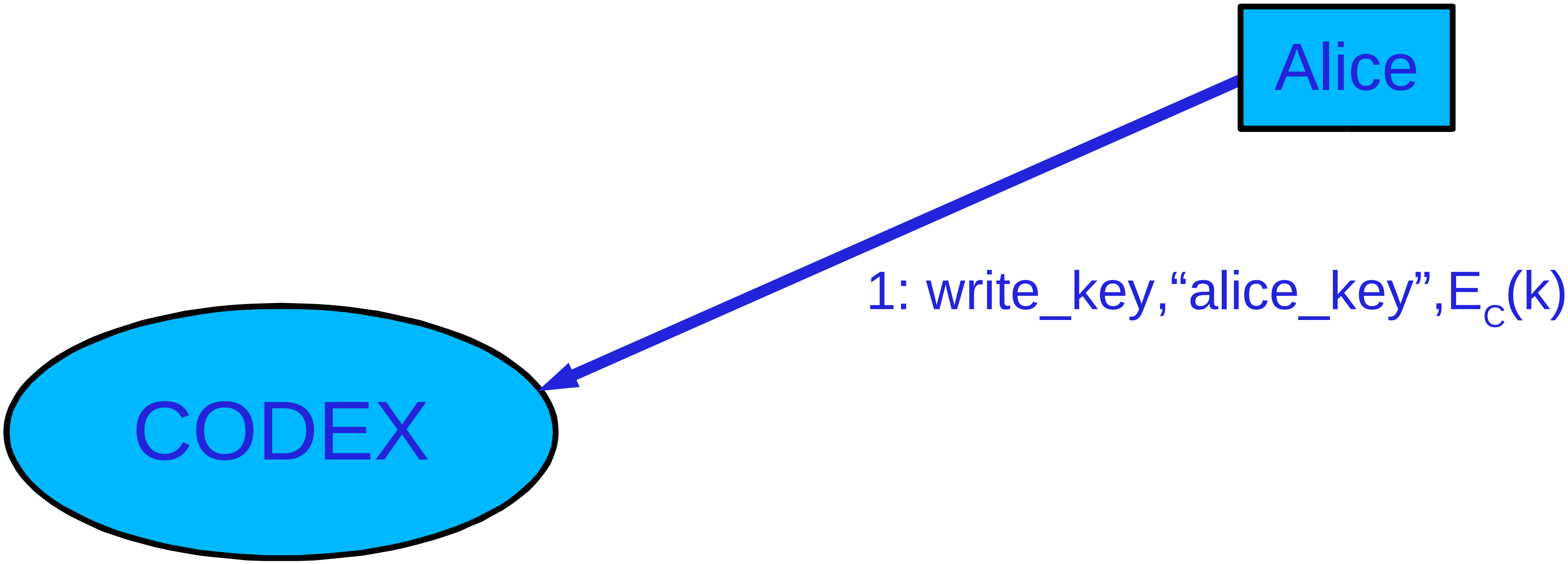
write_key: stores a value for a name, if access policy satisfied

write_key,name,$E_C$(k),auth

read_key: retrieves the value for a name, if access policy satisfied

read_key,name,auth

# Preventing Known Ciphertext Attacks



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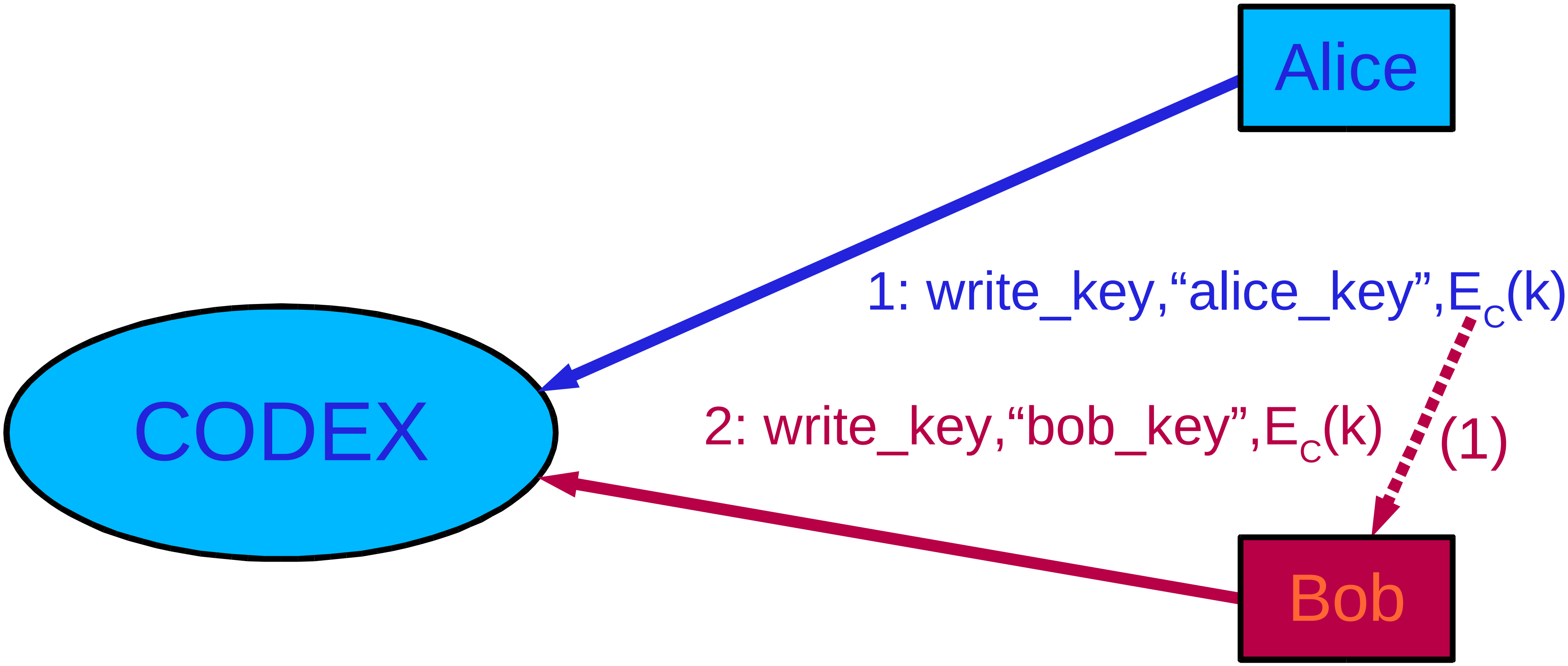

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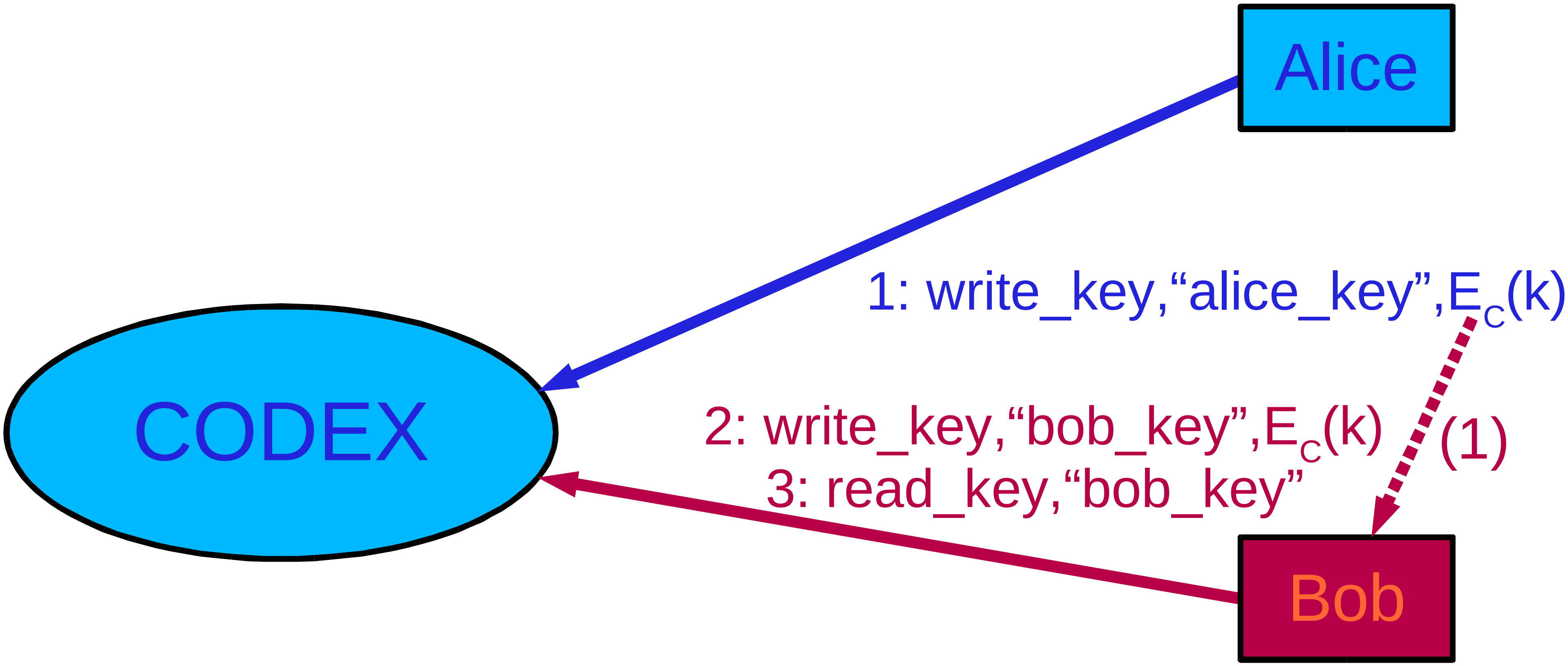

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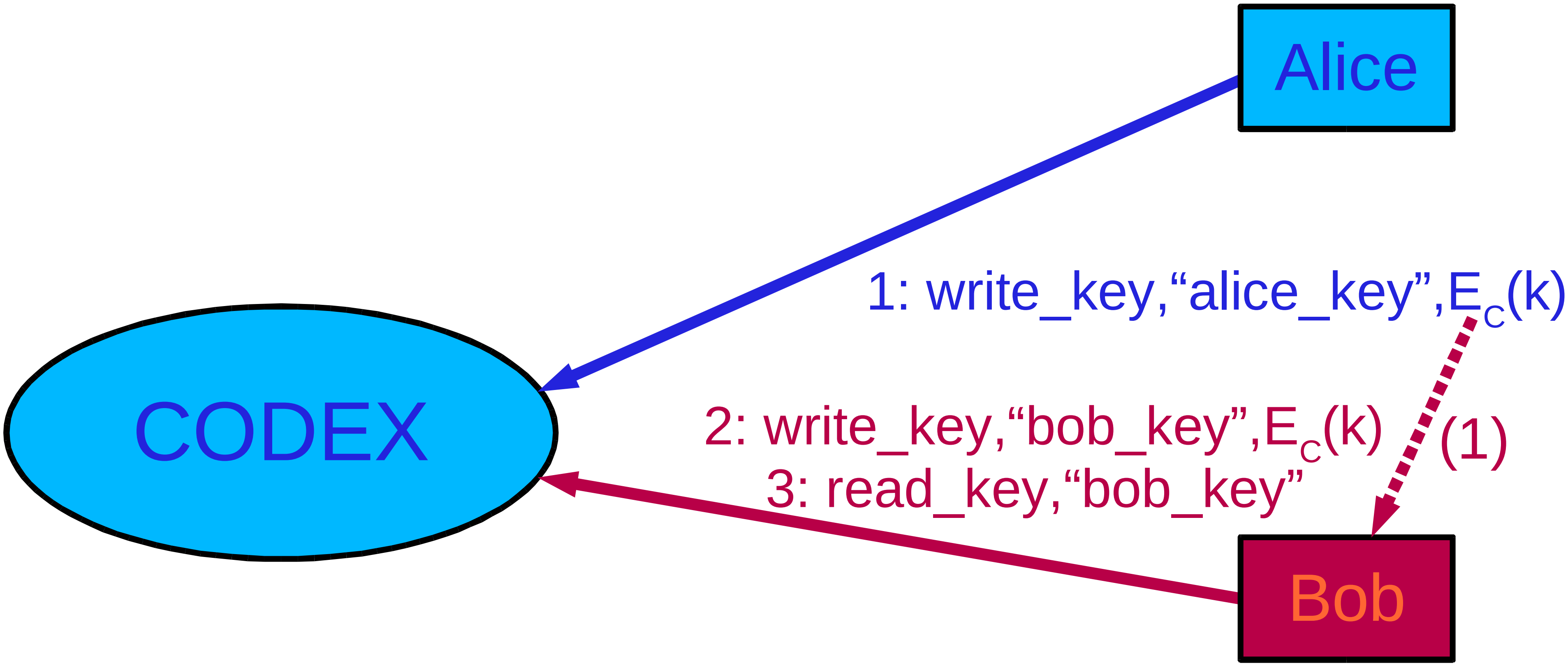
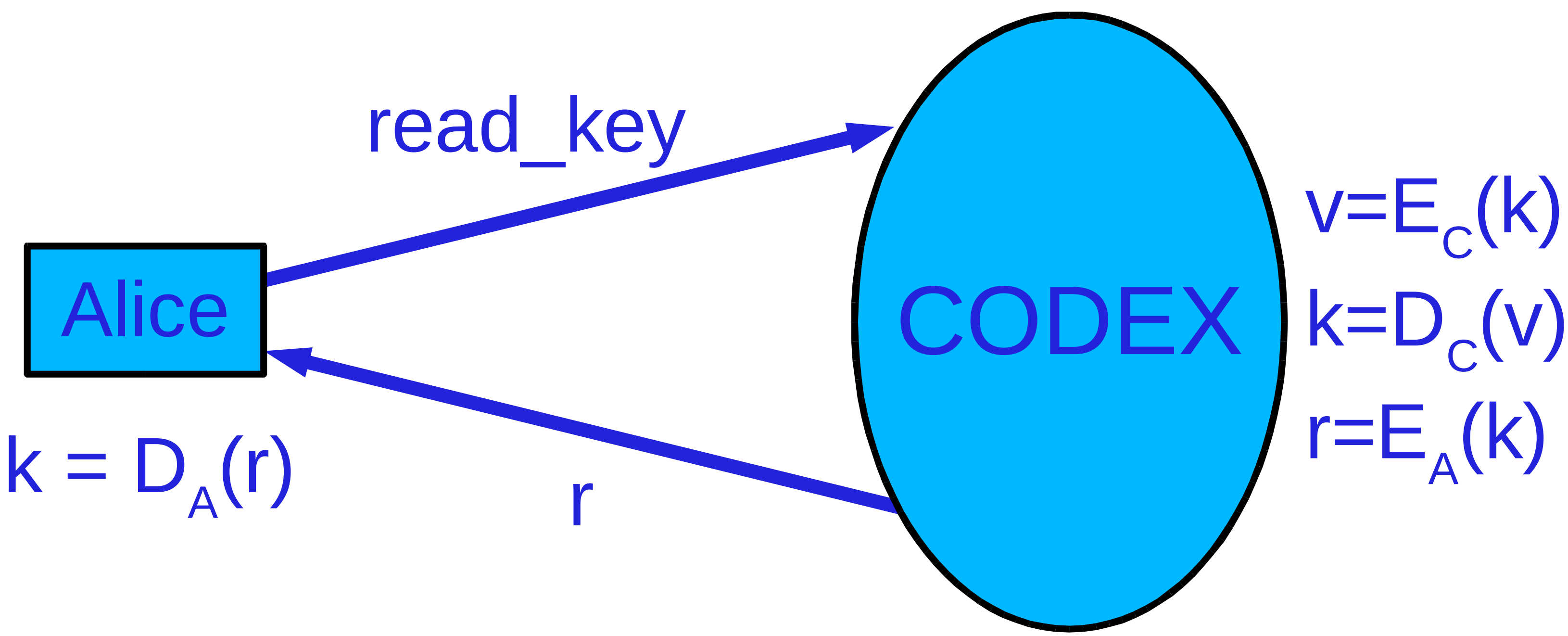



non-interactive, non-reusable ZKP that k known

(eg, Schnorr signature on ciphertext)

# Protecting Secrets During Decryption



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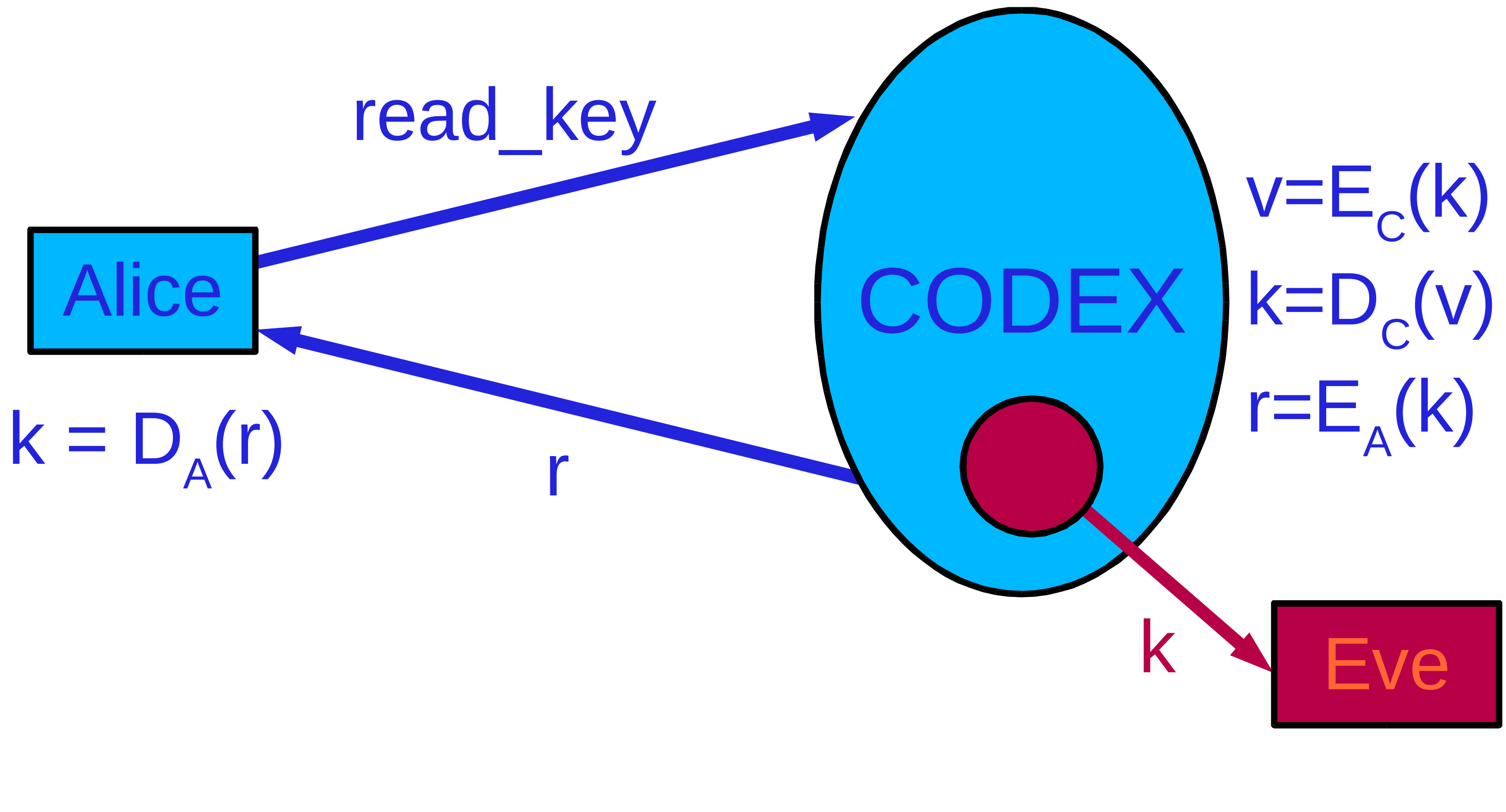

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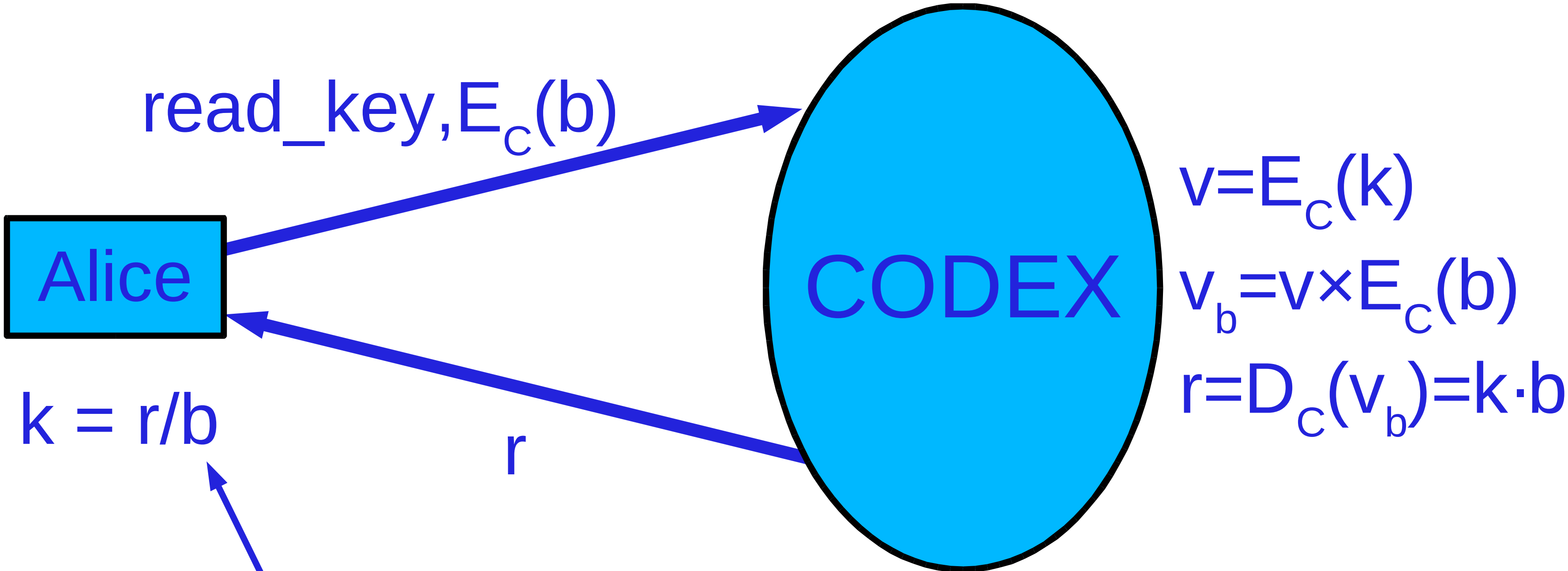


known only to Alice

blind decryption

[Chaum83]

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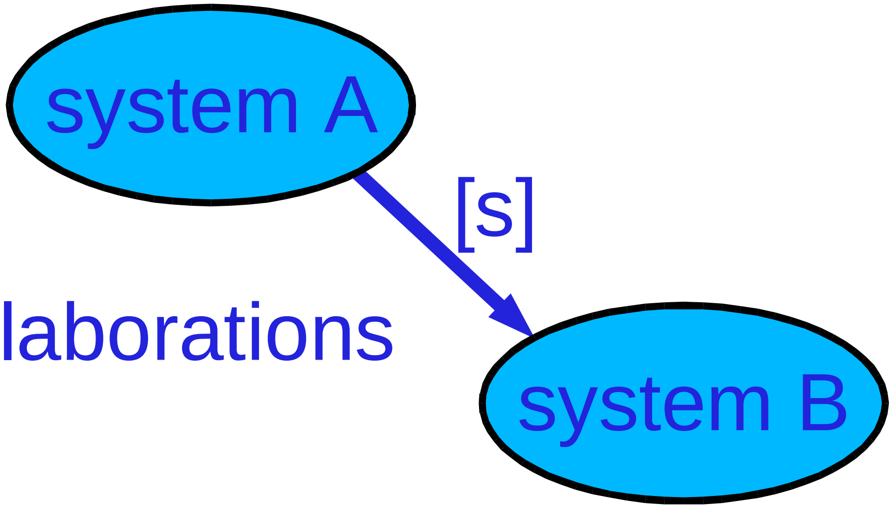
# Composing Systems with Distributed Trust




- business/military collaborations
- exploiting locality
- “trusted” hosts in peer-to-peer

each system employs distributed trust

transparent vs. non-transparent

# Tradeoffs: Non-Transparent vs. Transparent

non-transparent:

simple data propagation (secure links)

clients need public keys of all servers

exposes fault tolerance structure

# Tradeoffs: Non-Transparent vs. Transparent

transparent:

one public key

looks like single server

threshold signatures (extra communications)

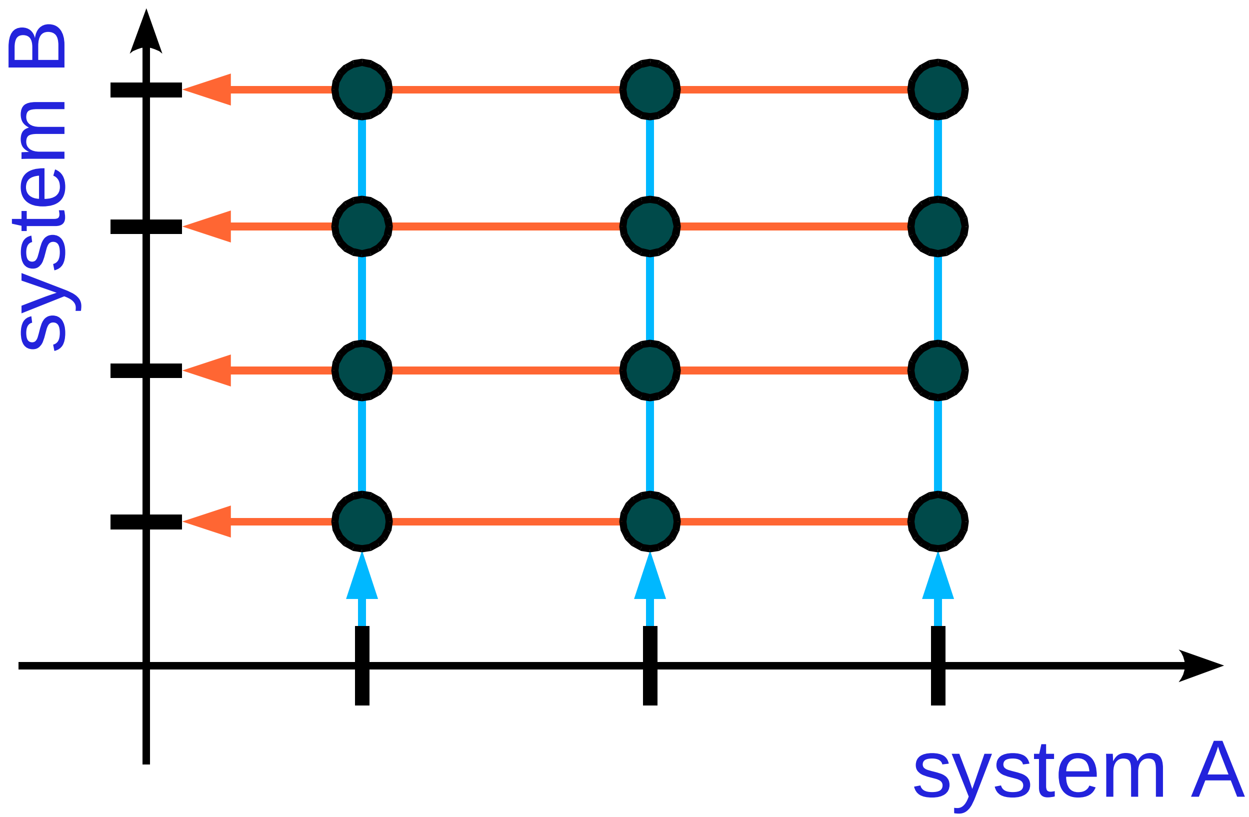
compromised delegates

transferring secrets more complicated

# Non-Transparent System Composition

data $\rightarrow$ shared secrets

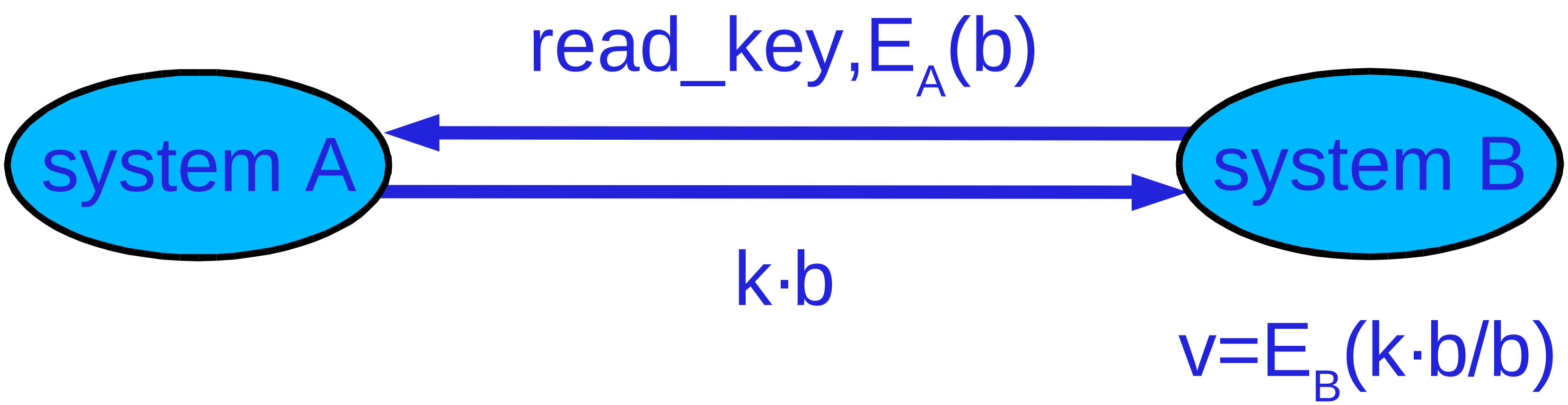
redistribution similar to PSS [DJ97,WWW02]



# Transparent System Composition

data $\rightarrow$ public-key encrypted

redistribution via blinding, re-encryption



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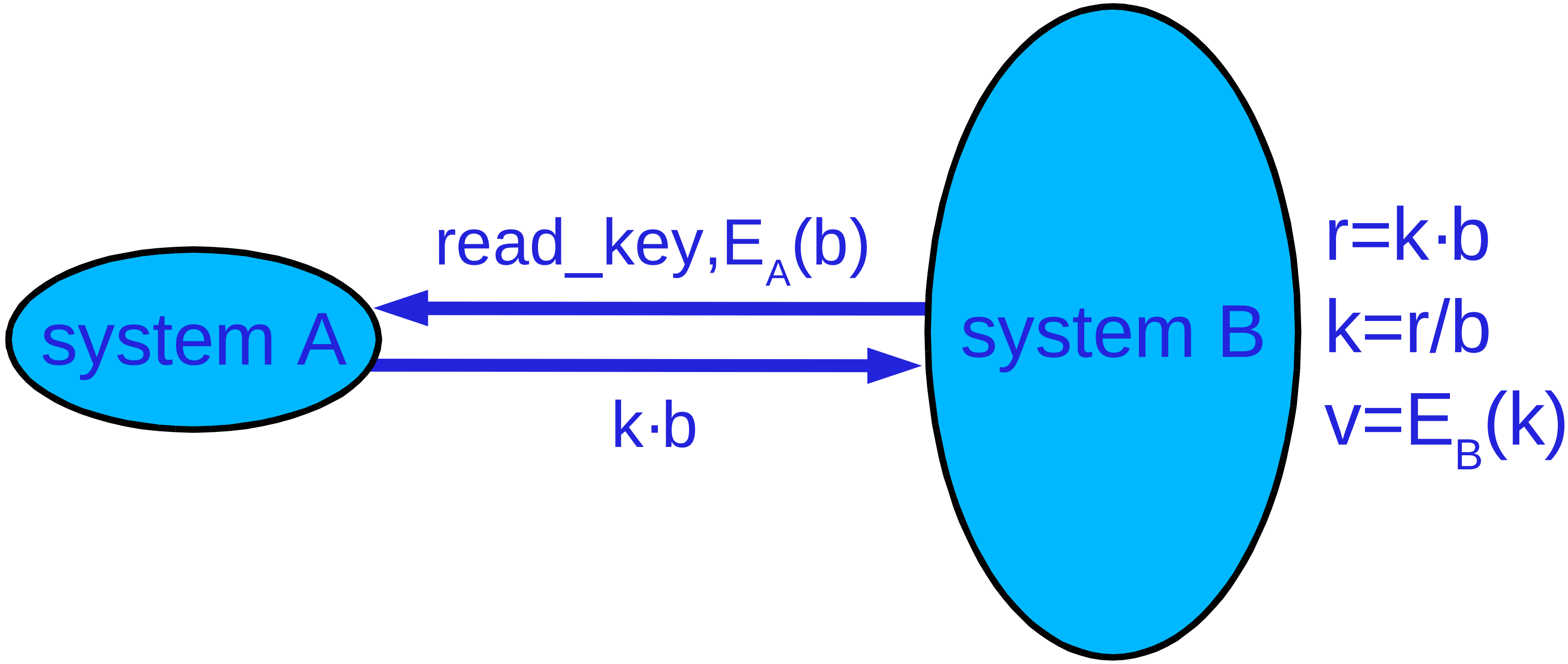
# Protecting Secrets During Unblinding



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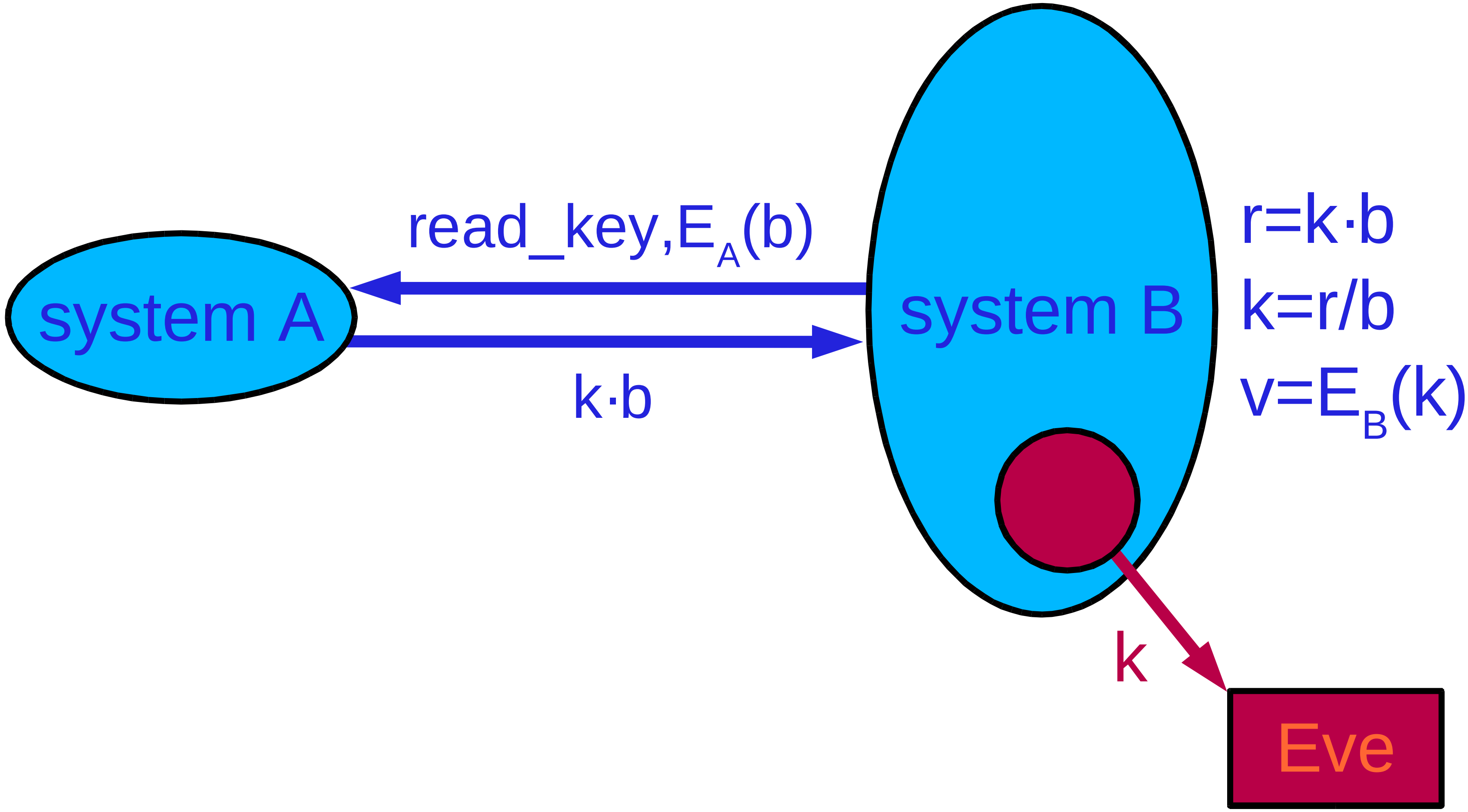

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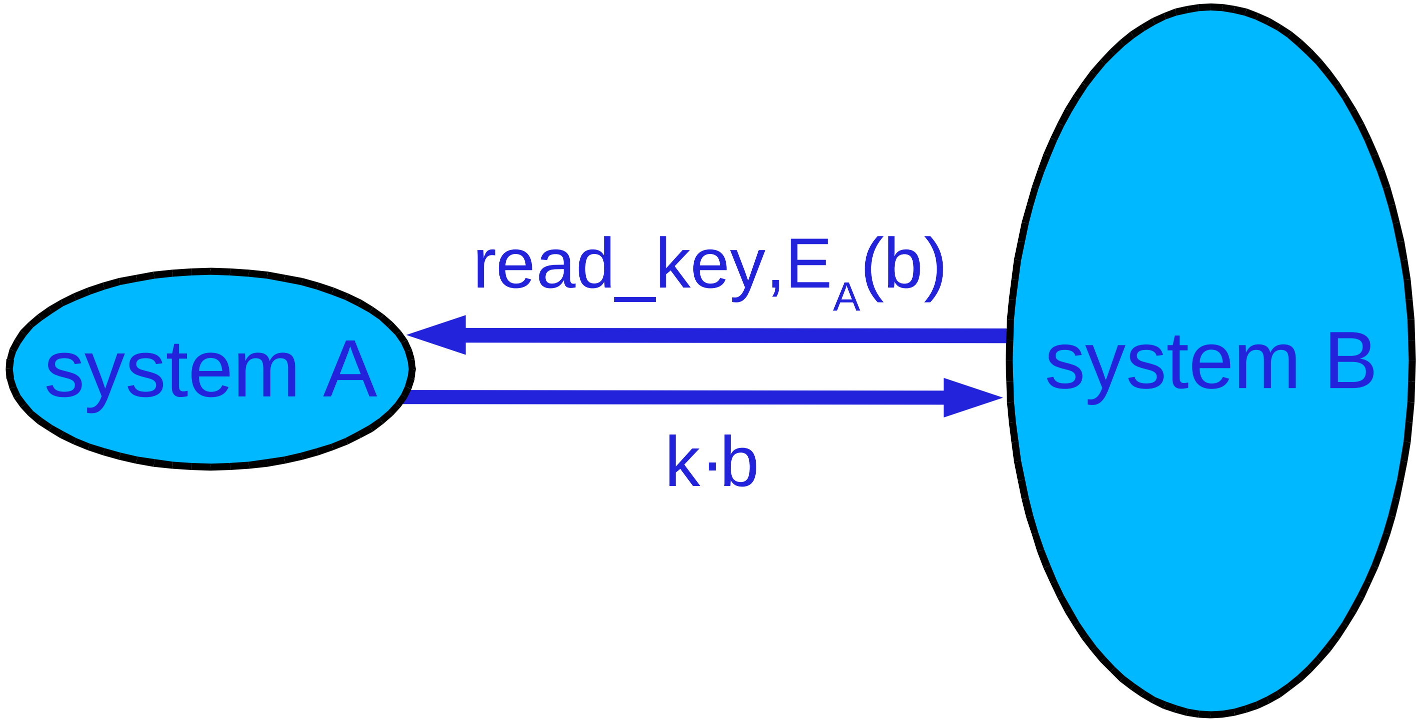



$r = k \cdot b$

$v = r \otimes \underbrace{E_B(b^{-1})}_{E_B(k)}$

distributed blinding

many cryptosystems $\Rightarrow$ simple to compute $E_B(b^{-1})$ from $E_B(b)$

# Distributed Blinding

goal: Generate ciphertexts $c_A = E_A(b)$, $c_B = E_B(b)$

requirements:

- consistency
- confidentiality
- randomness

solution: construct $c_A$ and $c_B$ simultaneously from encrypted partial blinding factors $b_i \rightarrow E_A(b_i), E_B(b_i)$

$b = \prod_i b_i \Rightarrow c_A = \prod_i E_A(b_i)$, $c_B = \prod_i E_B(b_i)$

# Maintaining Consistency of b

faulty processor:

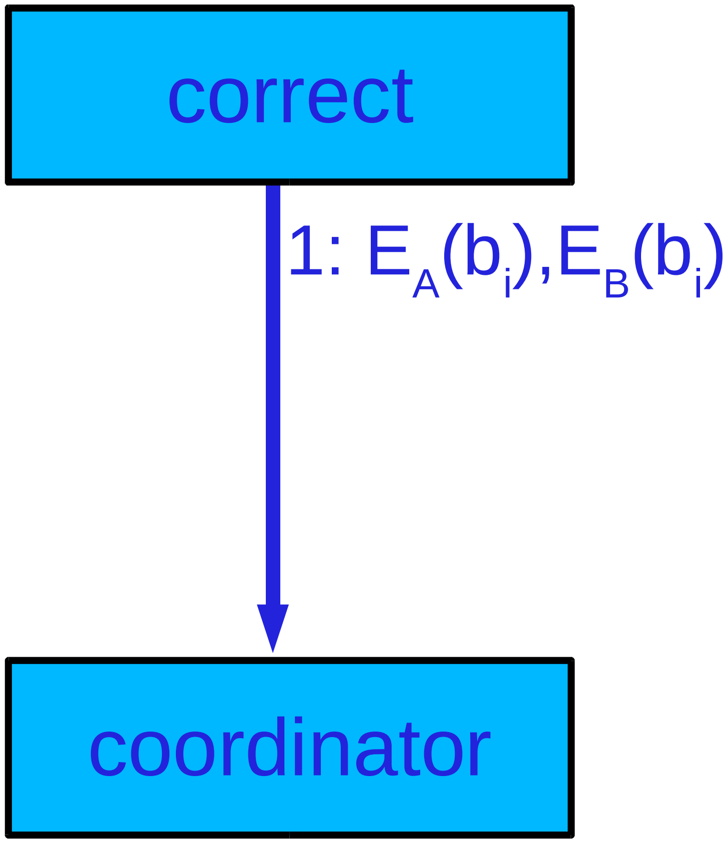
$E_A(b_i)$, $E_B(b_i')$ inconsistent ($b_i \neq b_i'$)

proof of correctness

translation certificates [Jakobsson99]

self-verifying contributions

# Maintaining Confidentiality and Randomness of b



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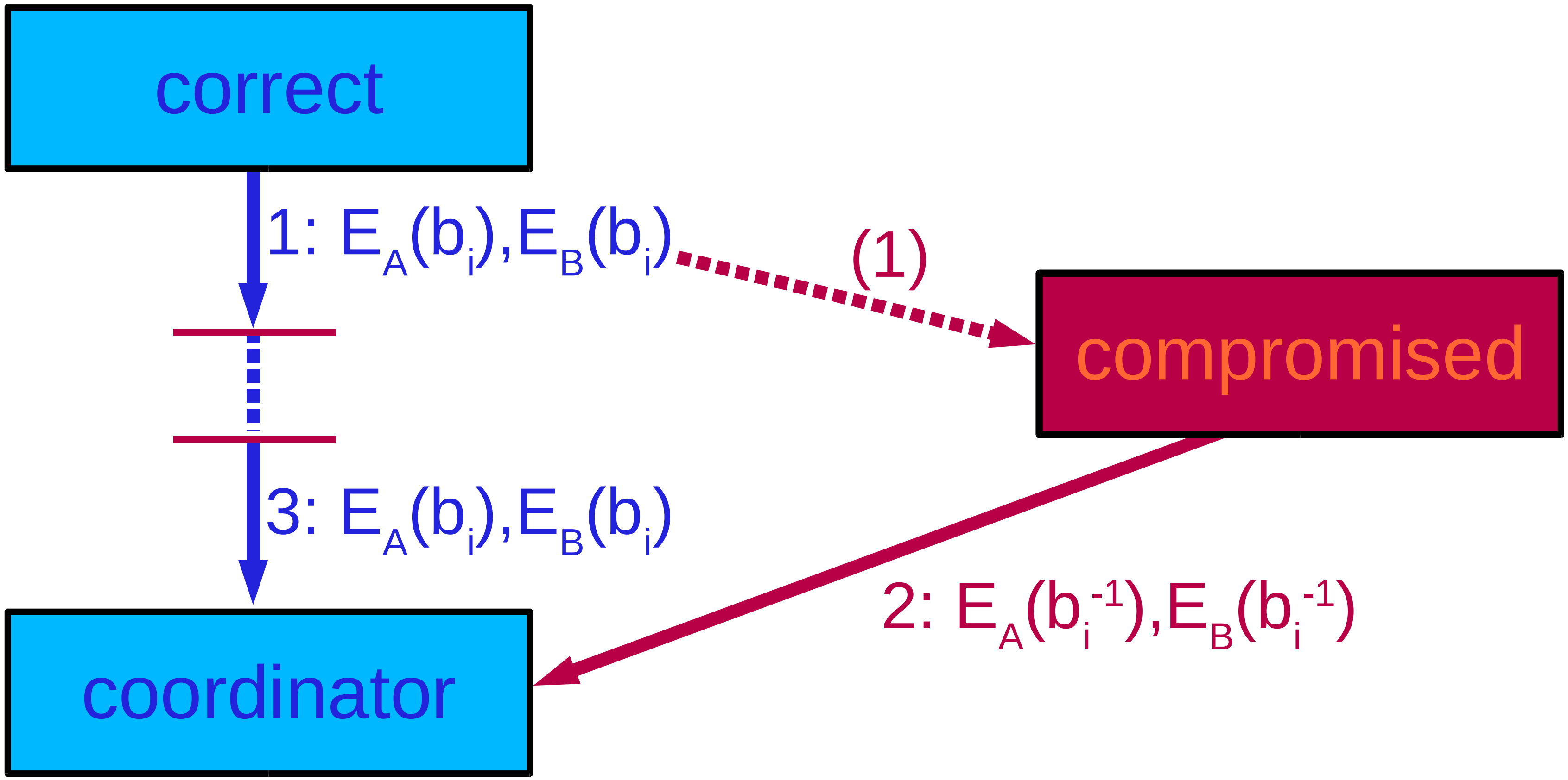

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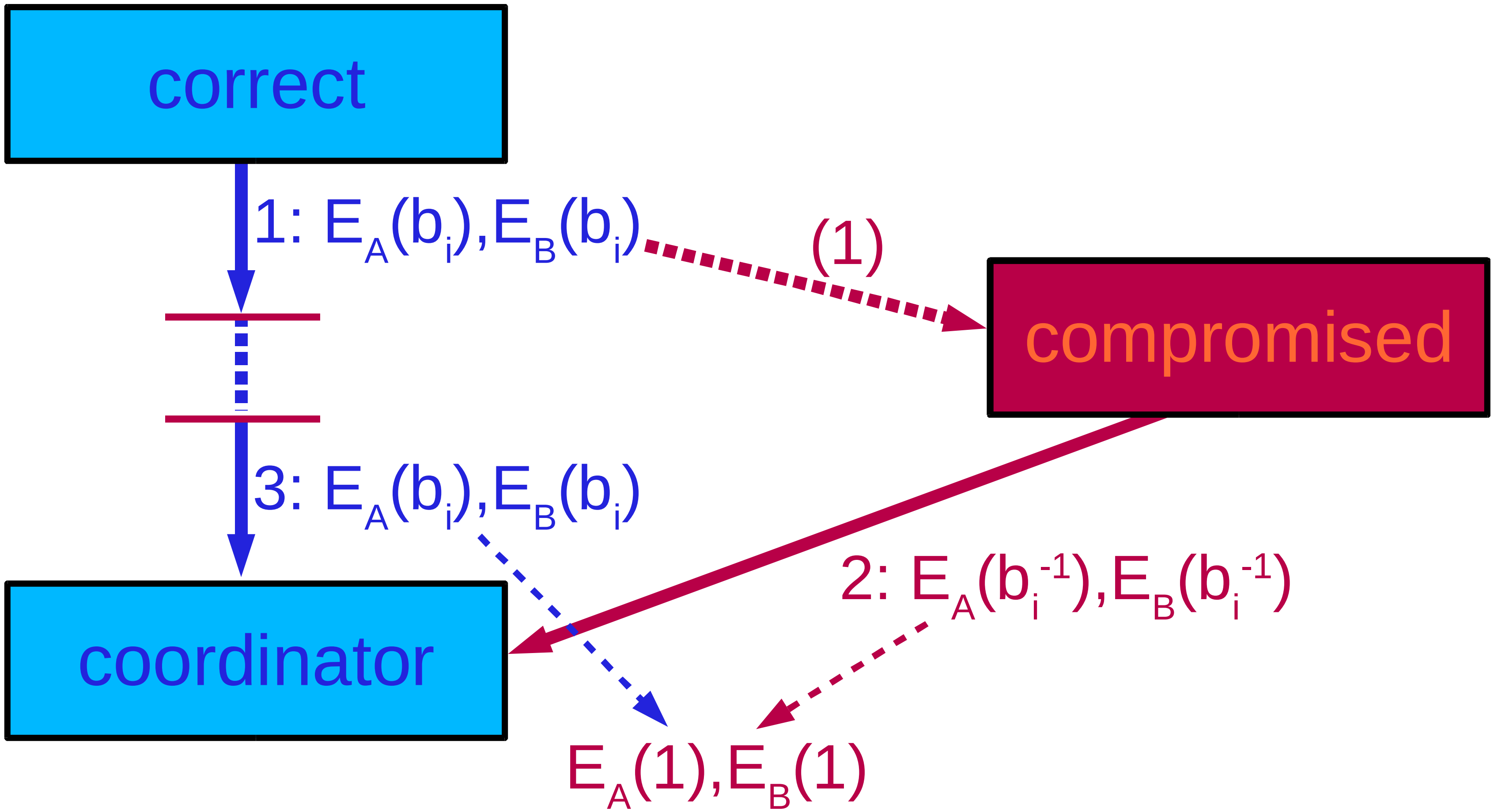
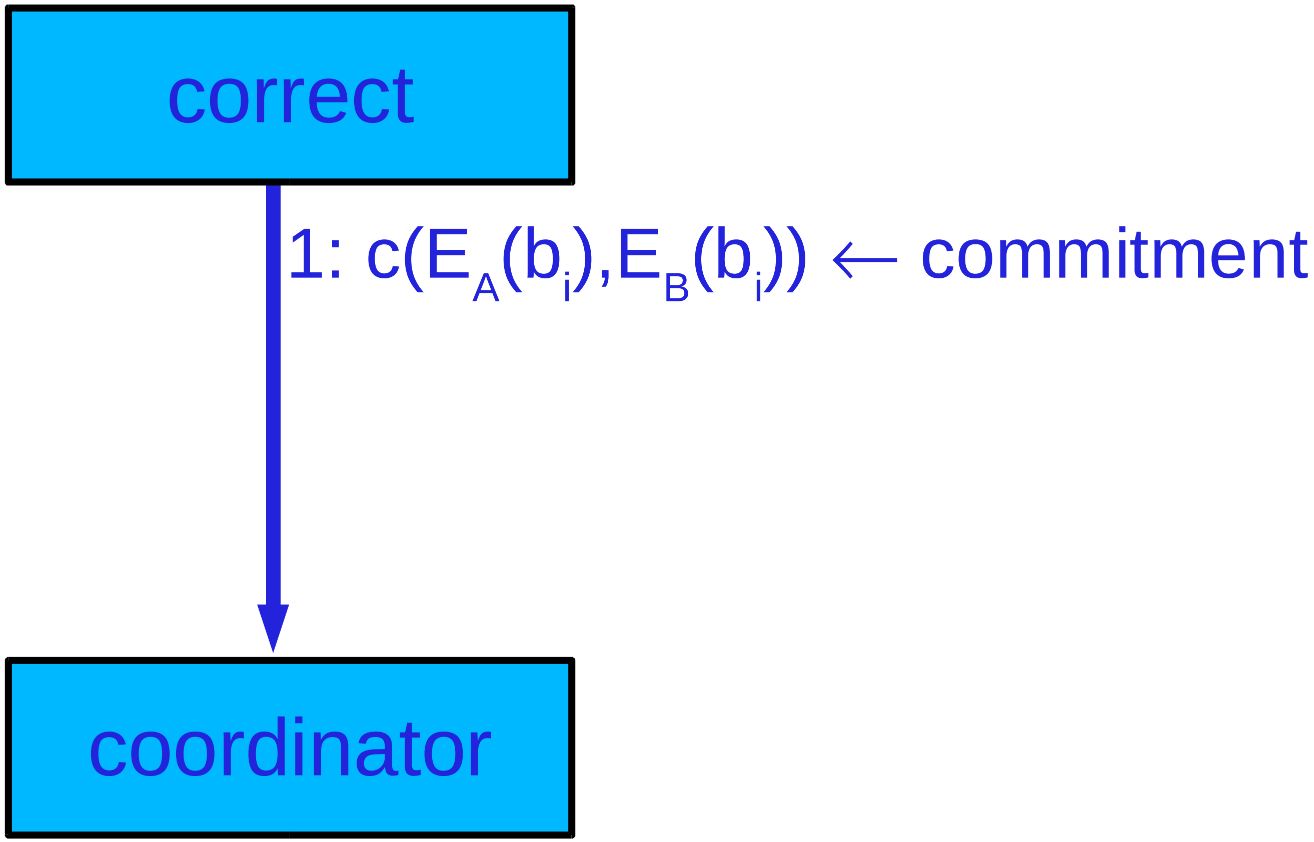



$b_i$ confidential, b neither confidential nor random

# Maintaining Confidentiality and Randomness of b



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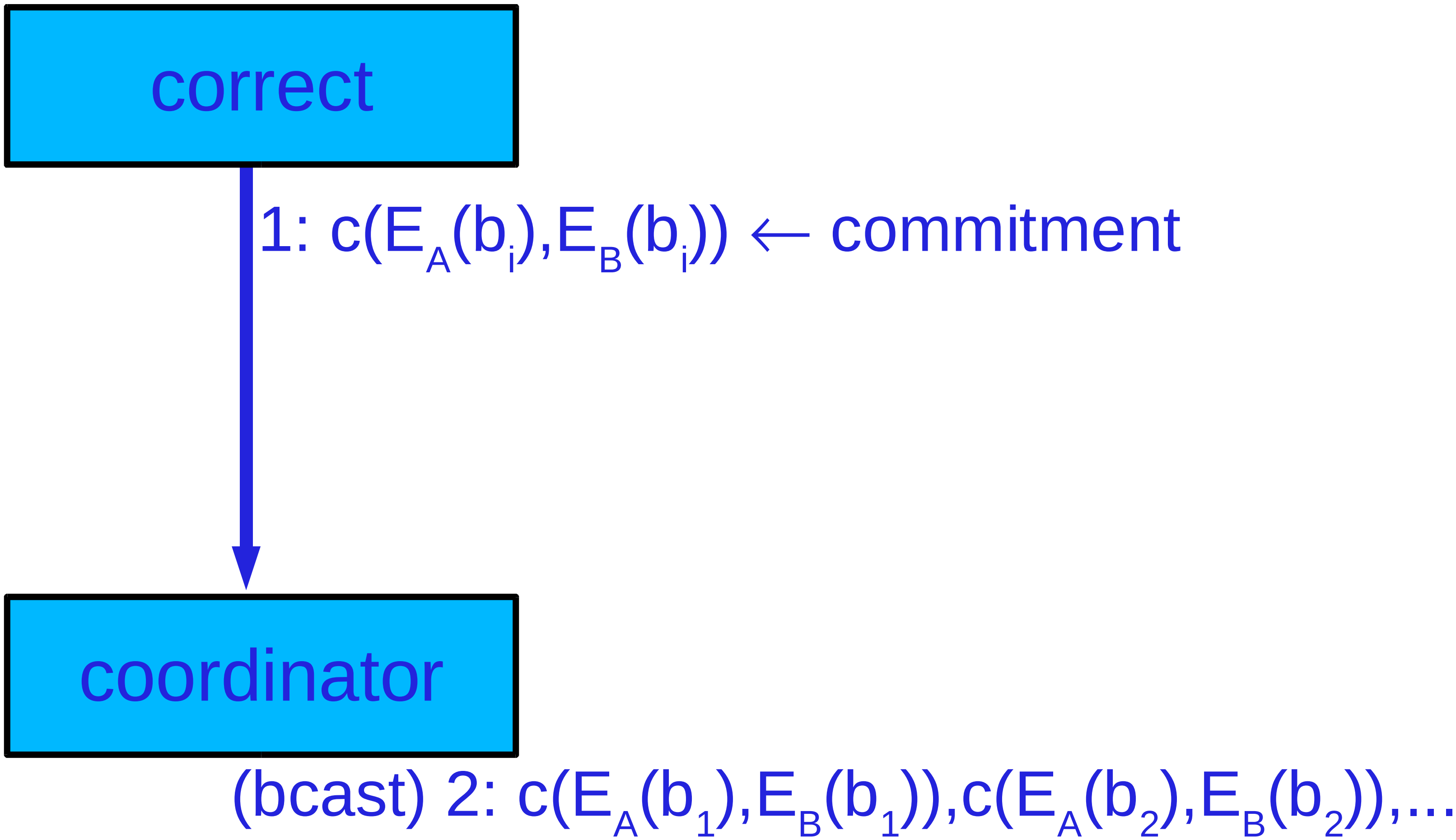

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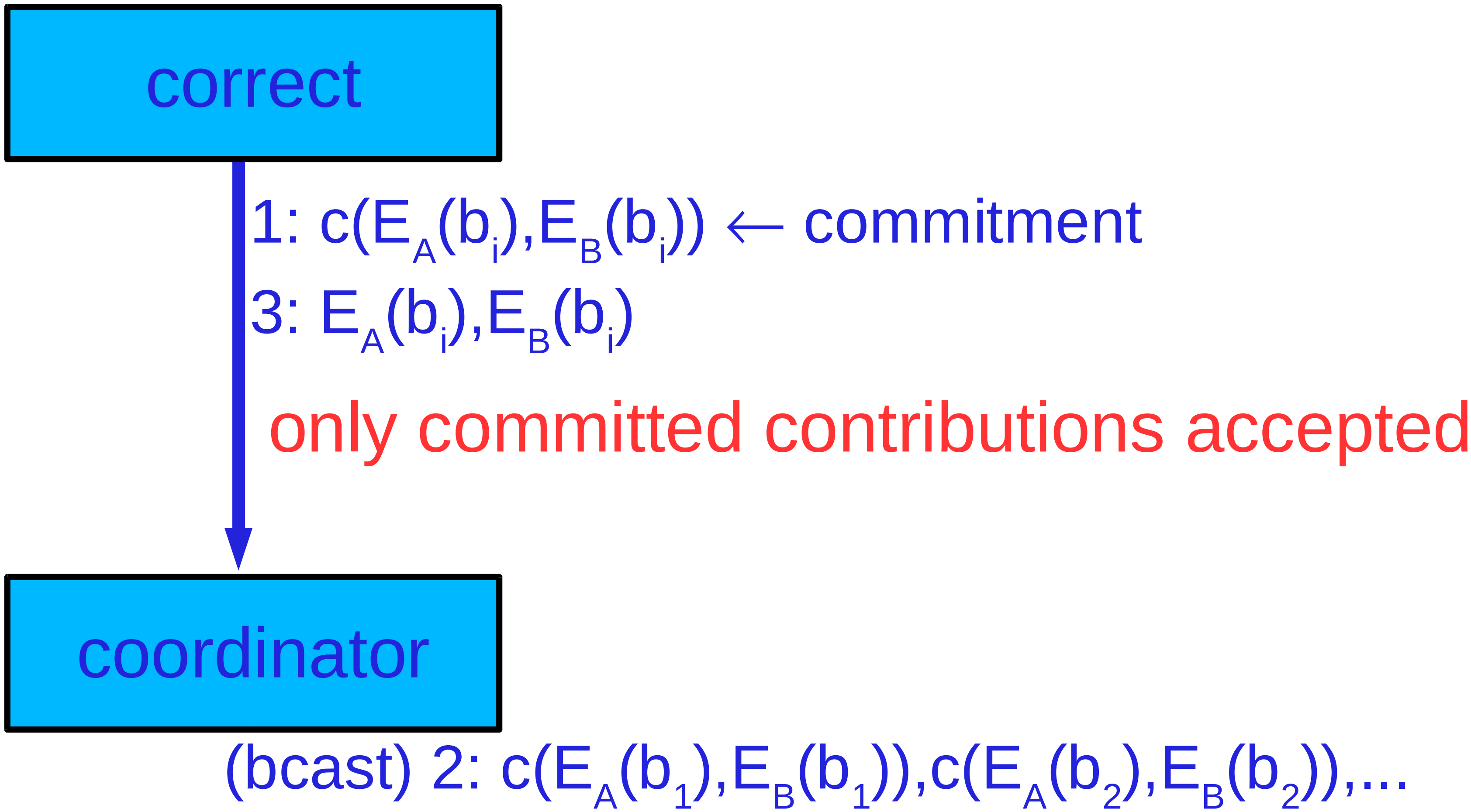

# Summary

trustworthiness is important
network, individual processors not trustworthy

contributions:

- CODEX key distribution service
  (implementation in progress)
- distributed blinding for composing systems
  (protocol developed, working on proof
  of security properties)

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