On Adaptively Secure Multiparty Computation with a Short CRS

[SCN'16]

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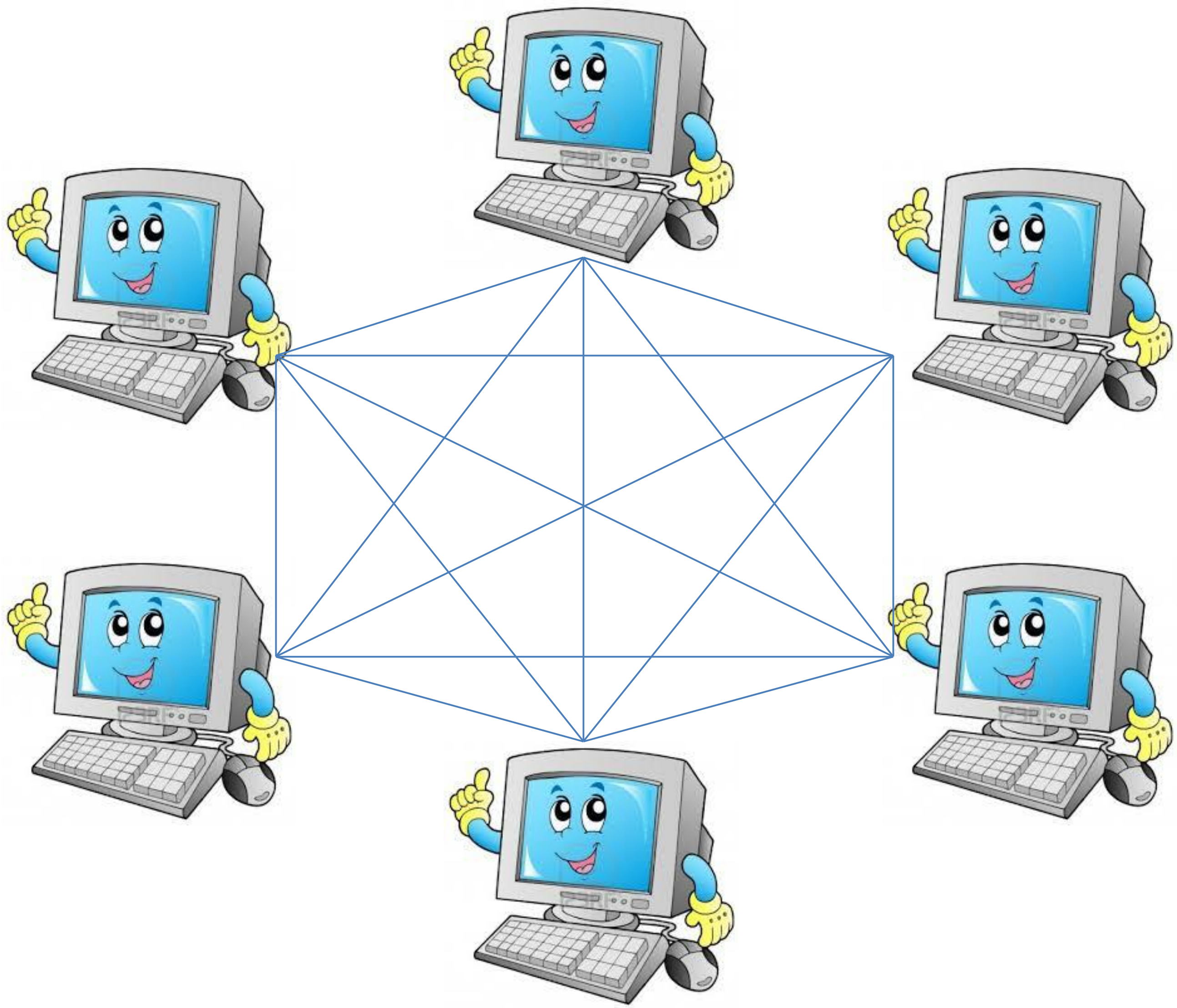
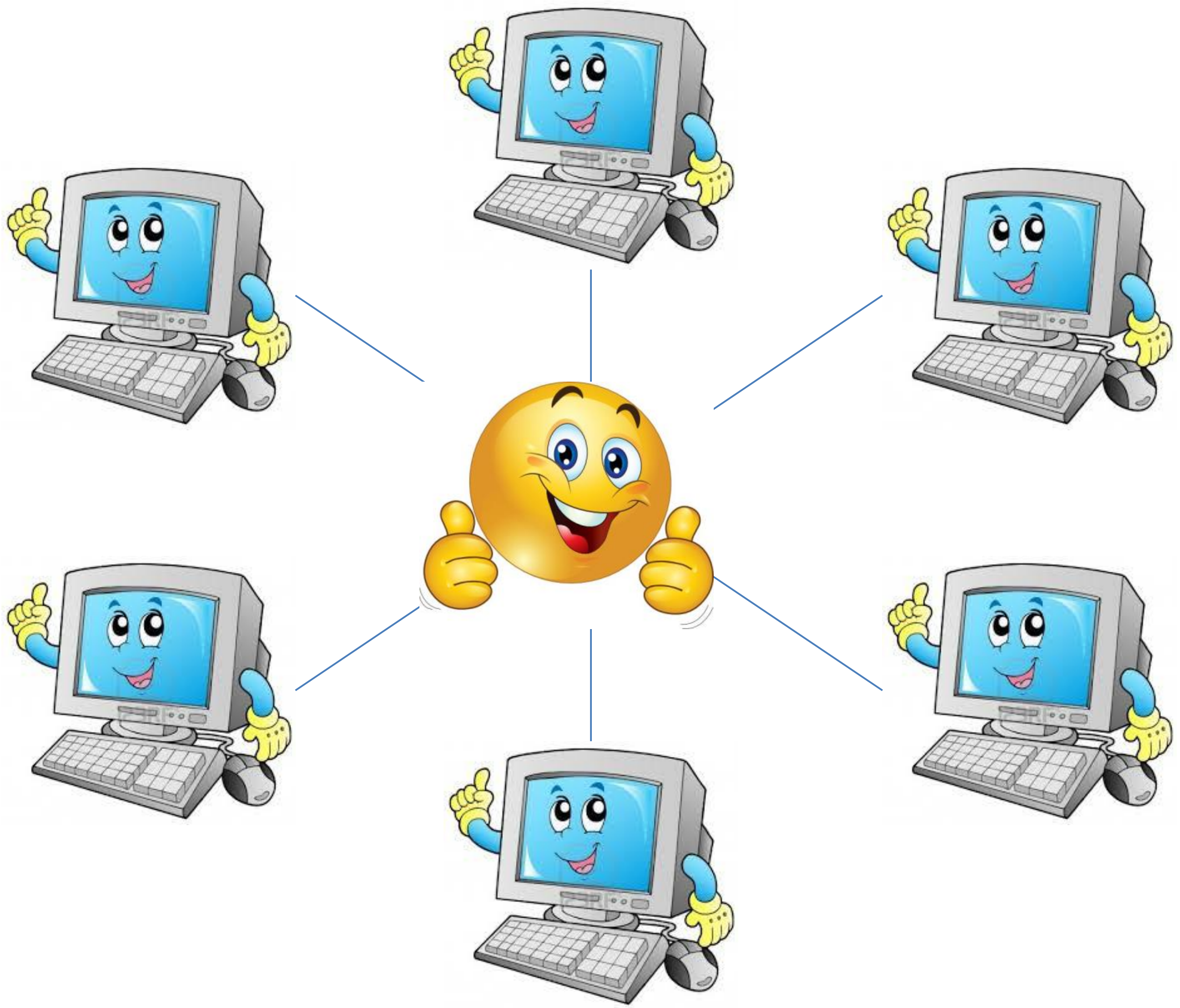
Chris Peikert (University of Michigan)

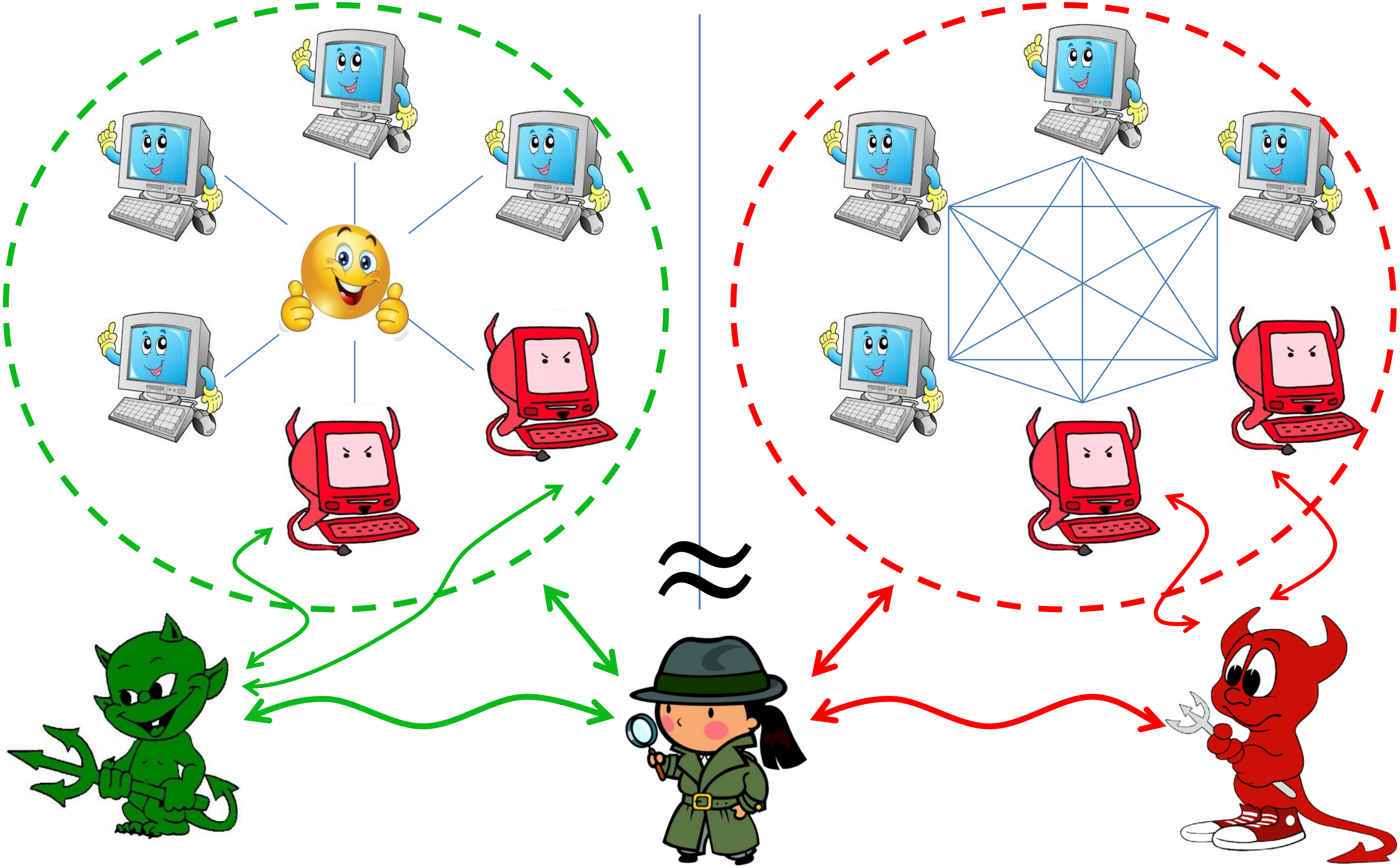
Secure Multiparty Computation (MPC)



Ideal World/"Functionality"



Simulation-Based Security



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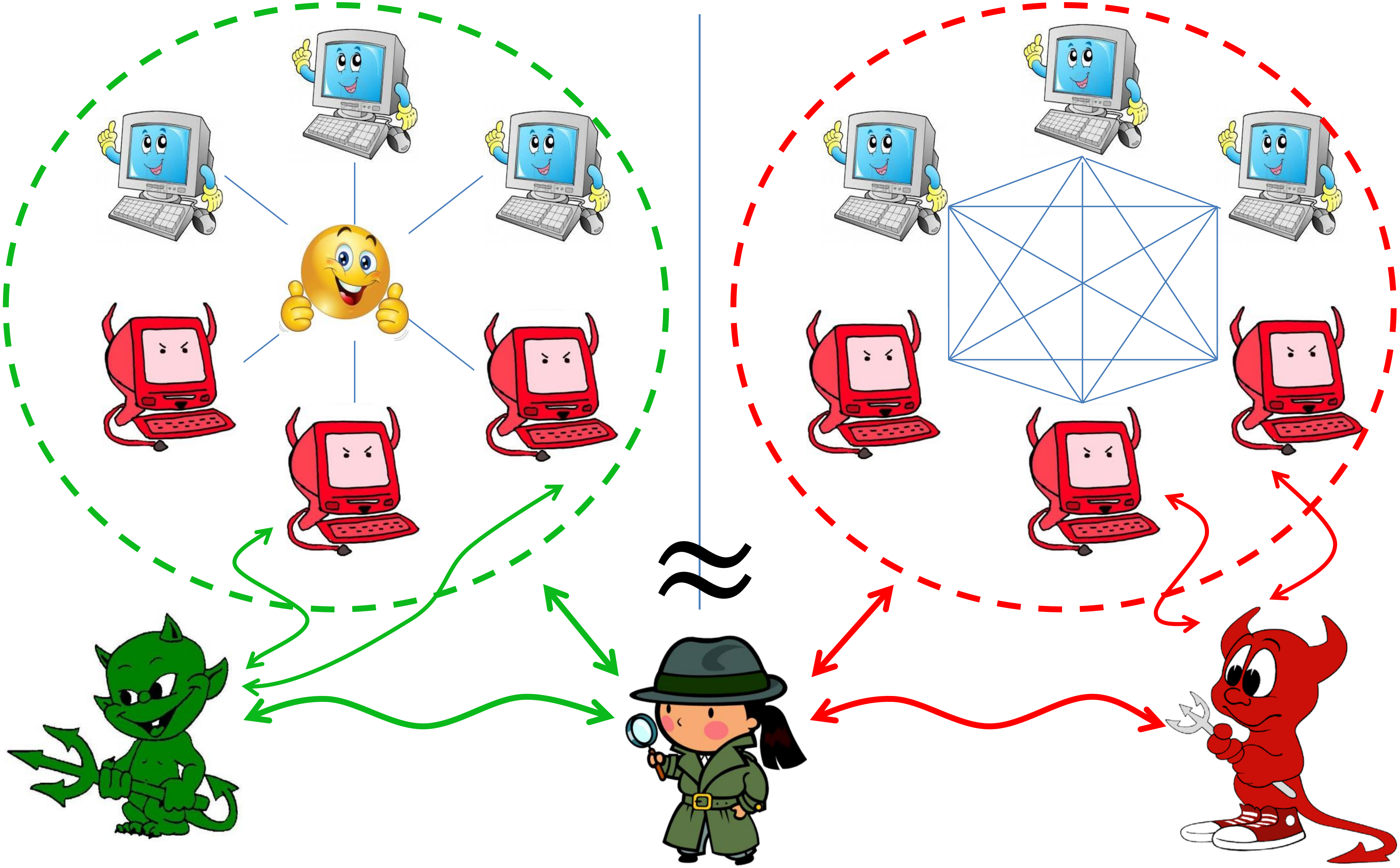

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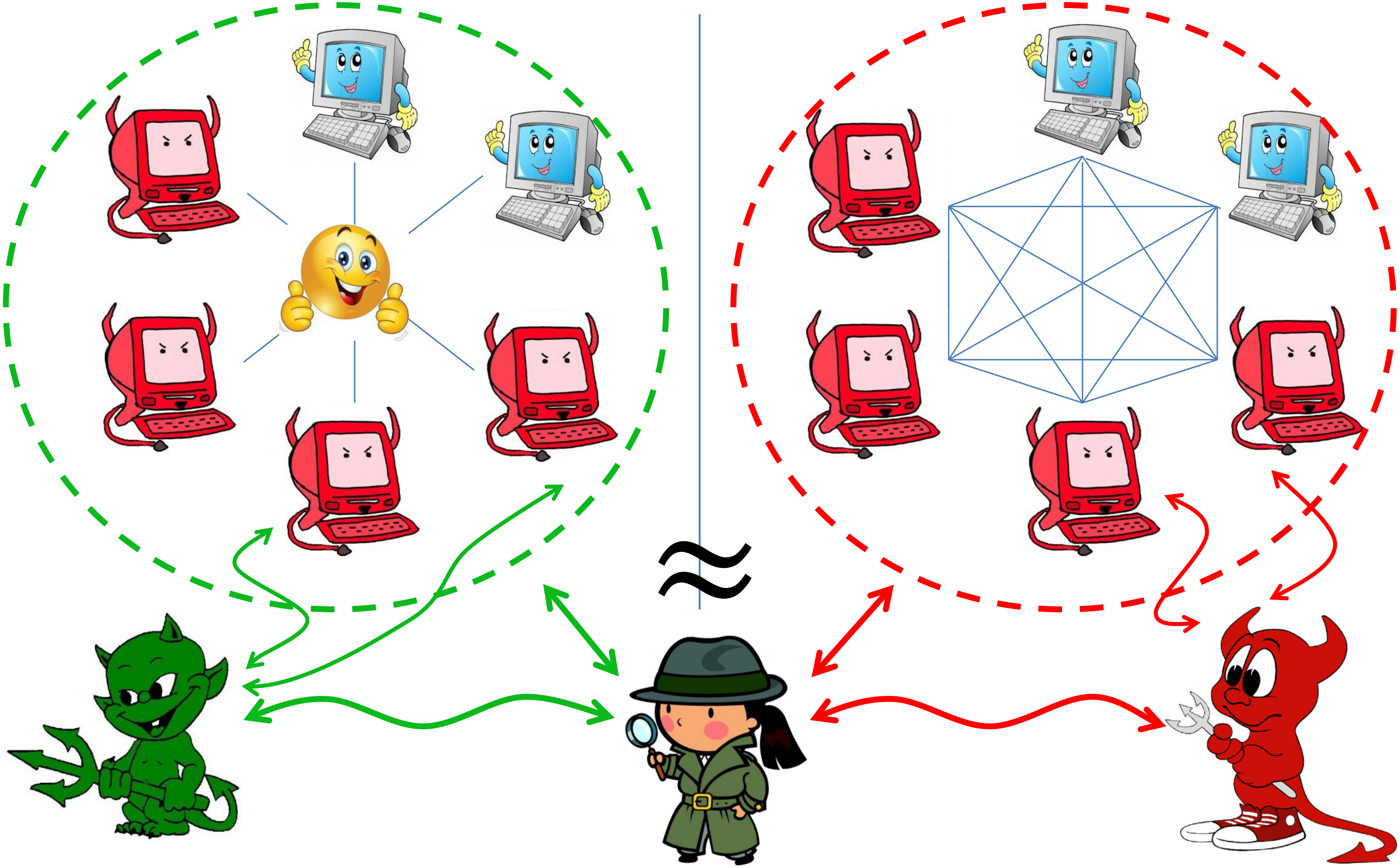

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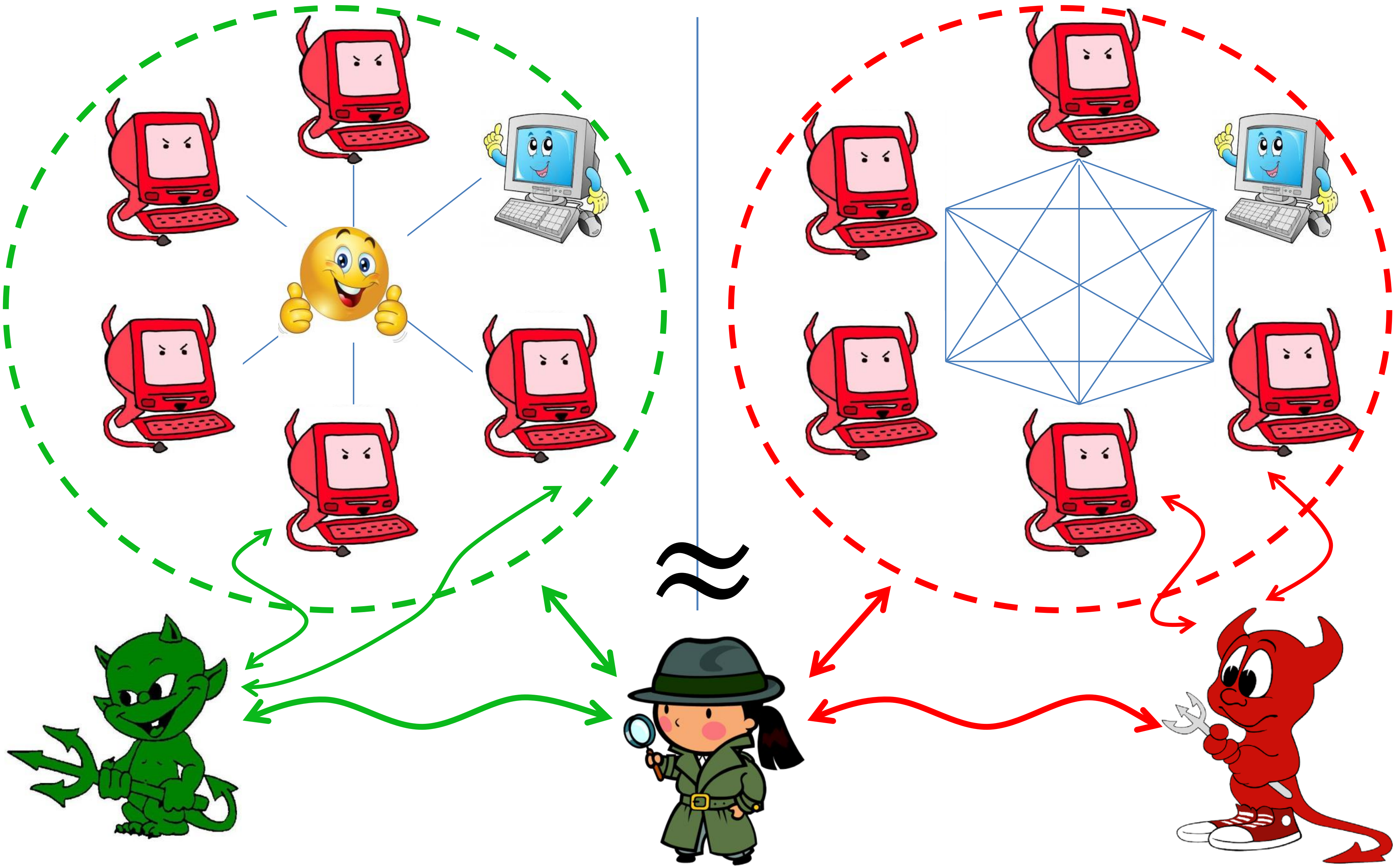

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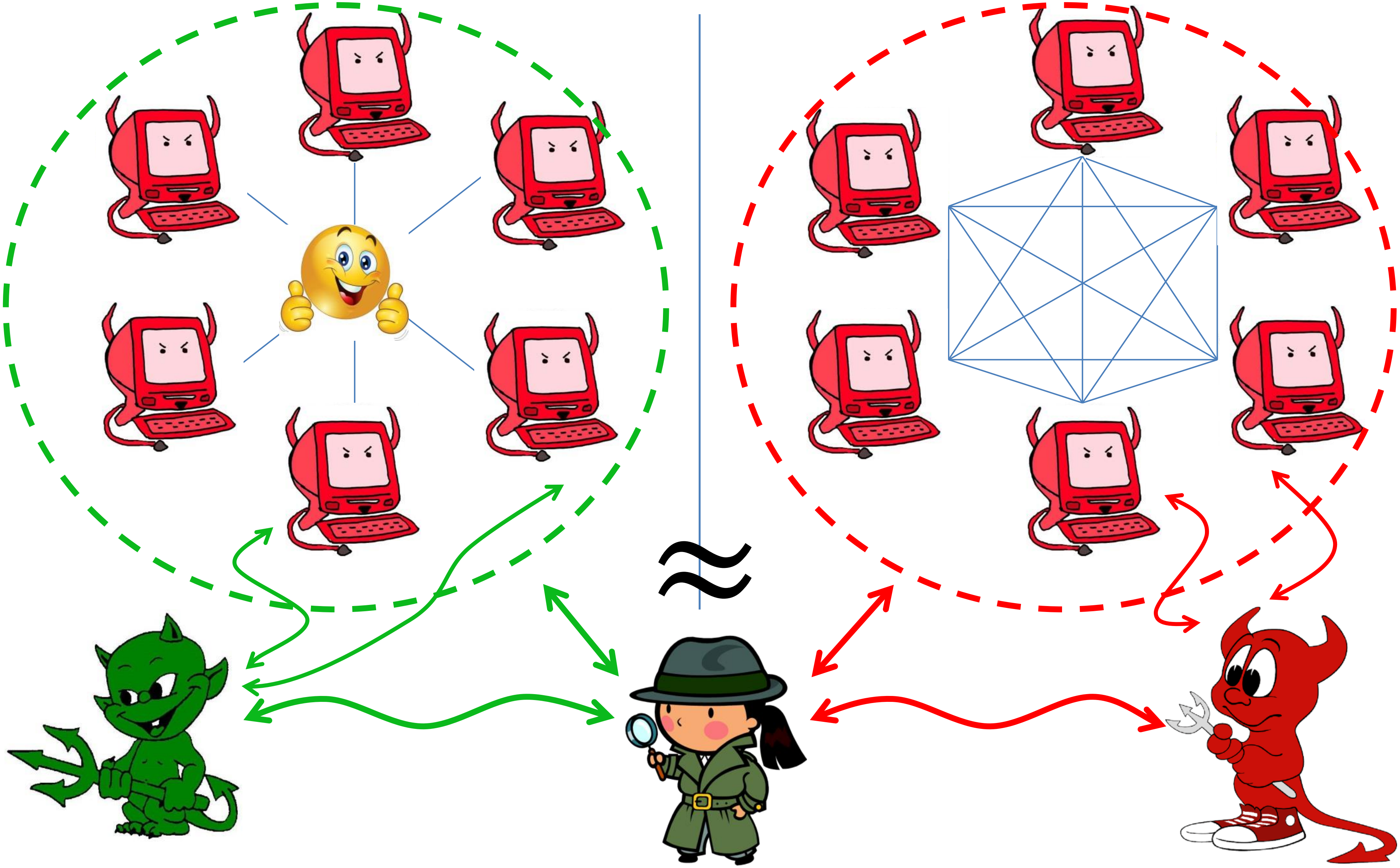
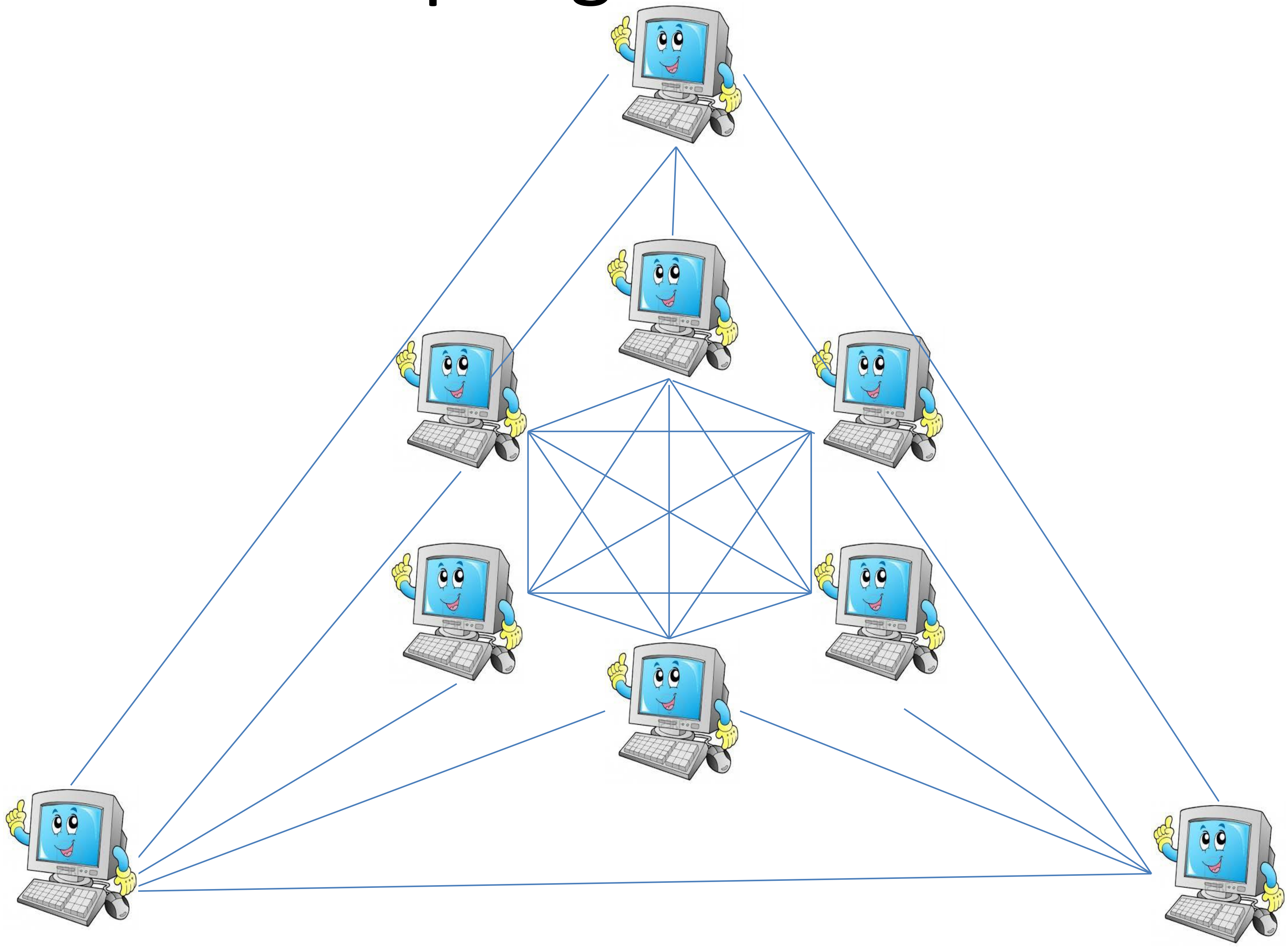


Corrupting All Parties



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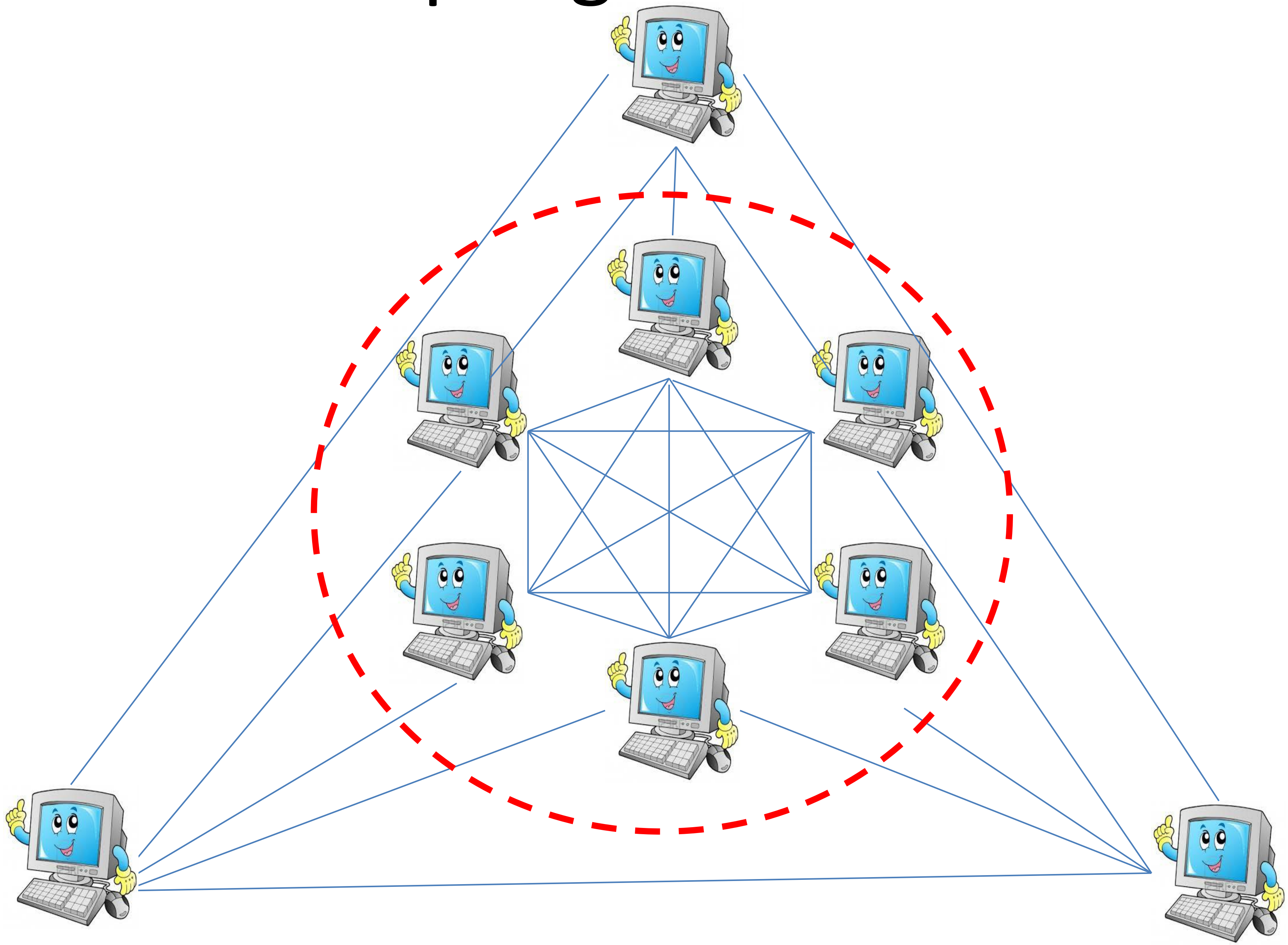

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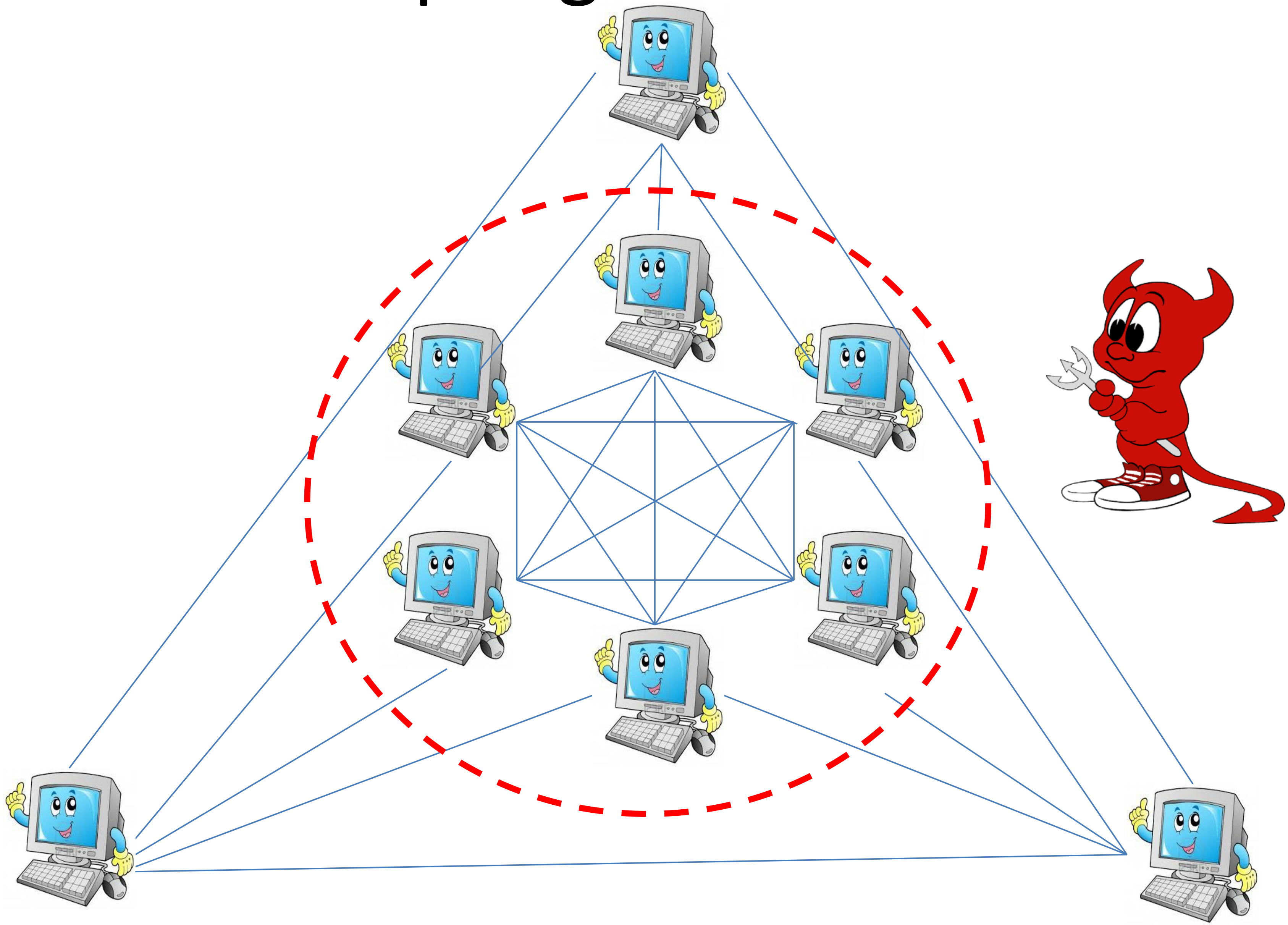

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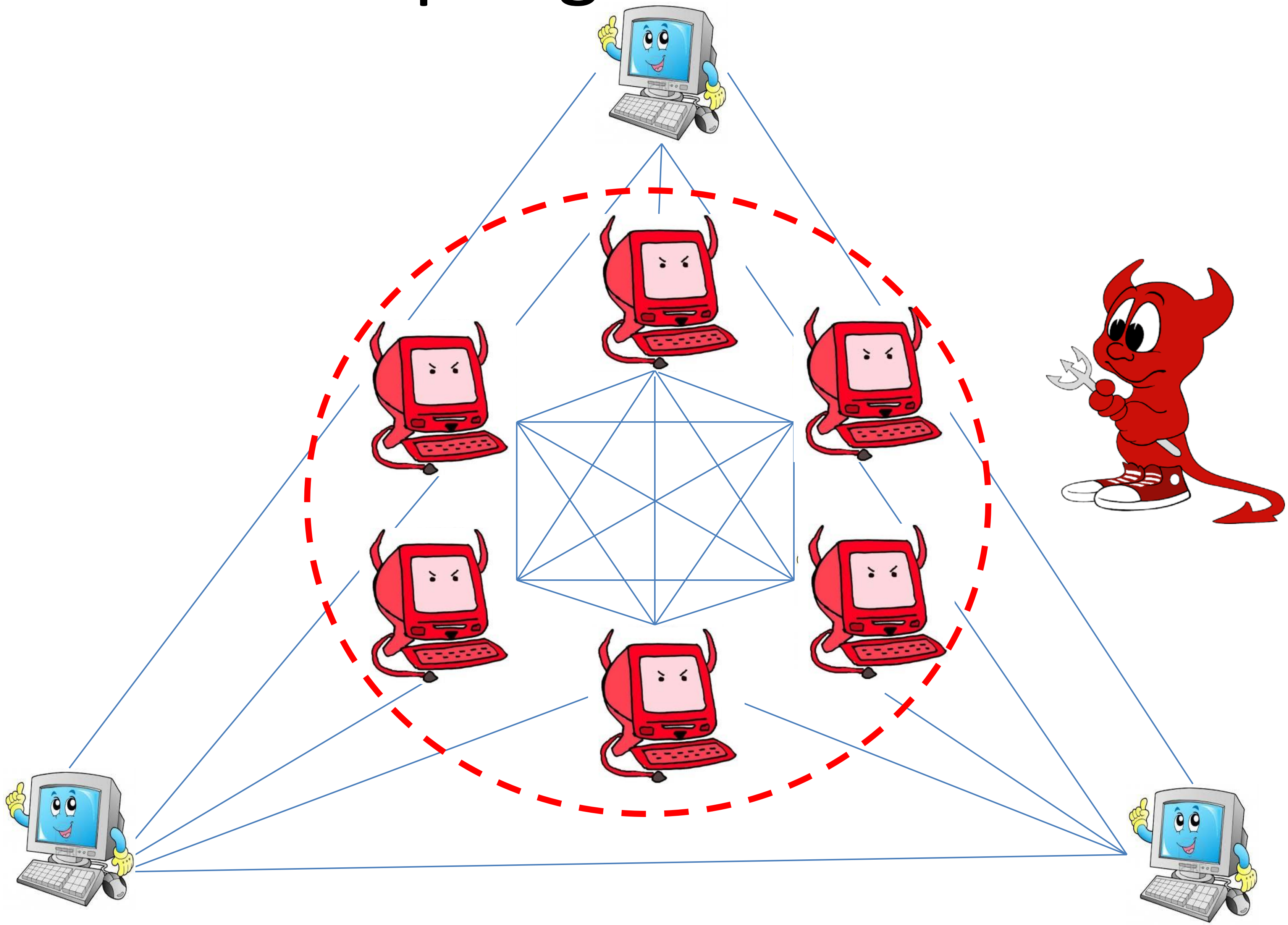


Modeling Adaptive Security

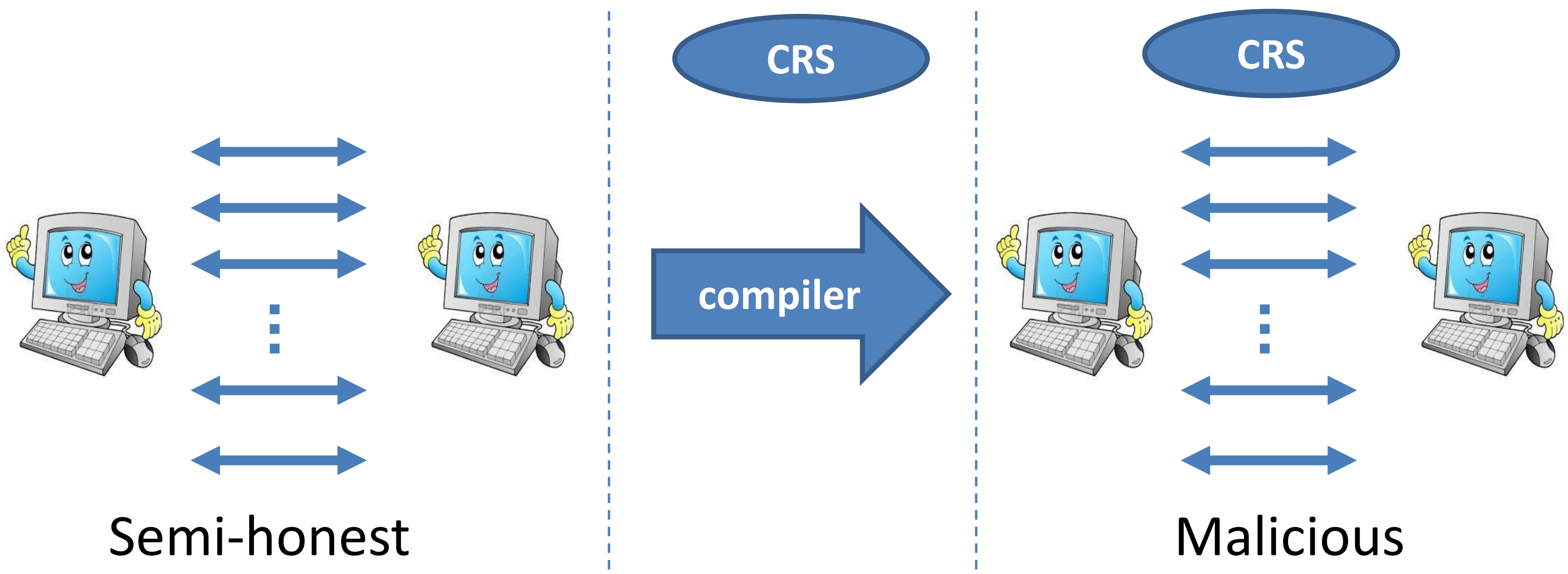
Modular Composition [Canetti'00]	Universal Composition [Canetti'01]
Sequential composition	Concurrent composition
Synchronous protocols	Asynchronous protocols
(Mostly) non-interactive environment	Interactive environment
Inputs are given statically before the computation	Inputs are given dynamically during the computation

Feasibility Result [CLOS'02]

1. Semi-honest protocol in the plain model
   – Round complexity is $O(d)$

d= depth of the circuit

2. Semi-honest to malicious compiler in CRS model
   – Round complexity blows up by constant factor
3. Malicious protocol in CRS model
   – Round complexity is $O(d)$



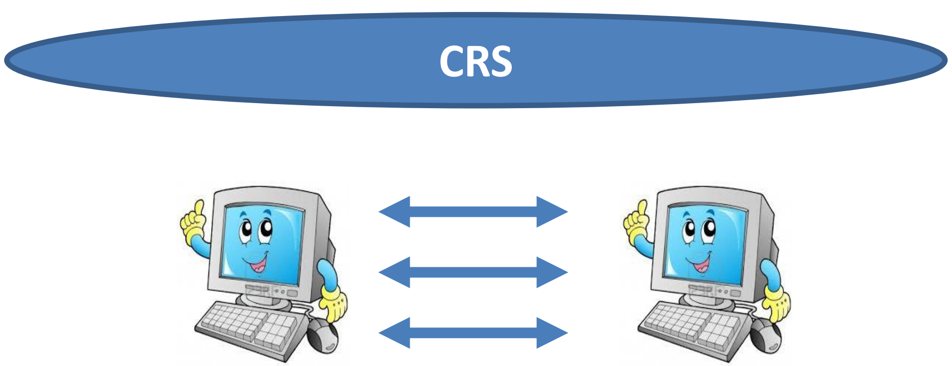
Constant-Round Protocols

Constant-round adaptive MPC [CGP’15] [DKR’15] [GP’15]

– In the CRS model, also for the semi-honest case
– CRS contains obfuscated program that gets the circuit as input
  ⇒ The size of the CRS grows with the size of the circuit

Constant-round in RAM model [CP’16]

– The size of the CRS grows with the size of the inputs



Protocols with Short CRS

Semi-honest setting

- No CRS (plain model)

Malicious setting

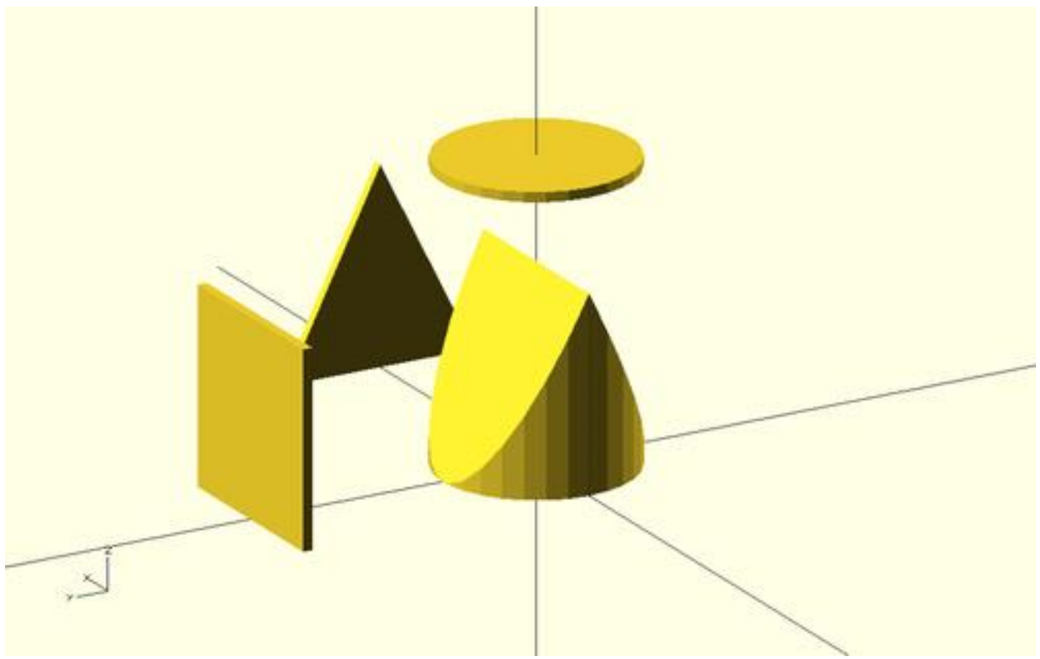
- CRS independent of the circuit
  (depends only on security parameter)

Can use [CLOS'02] compiler

Outline

1. Non-Interactive NCE in UC framework
2. Protocols with round complexity independent of circuit
3. Constant-round protocols for class of functions

Non-Interactive
Non-Committing Encryption



Non-Interactive
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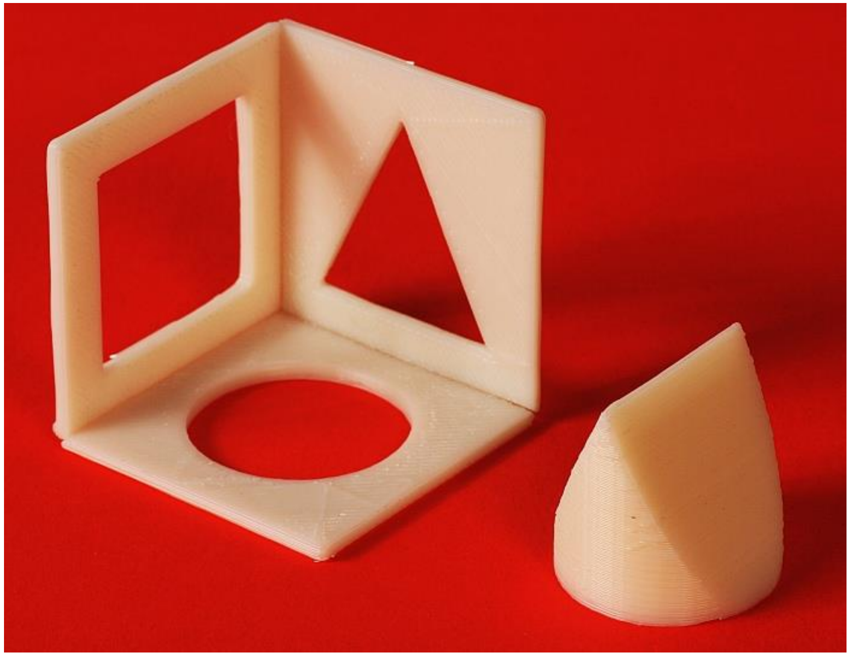
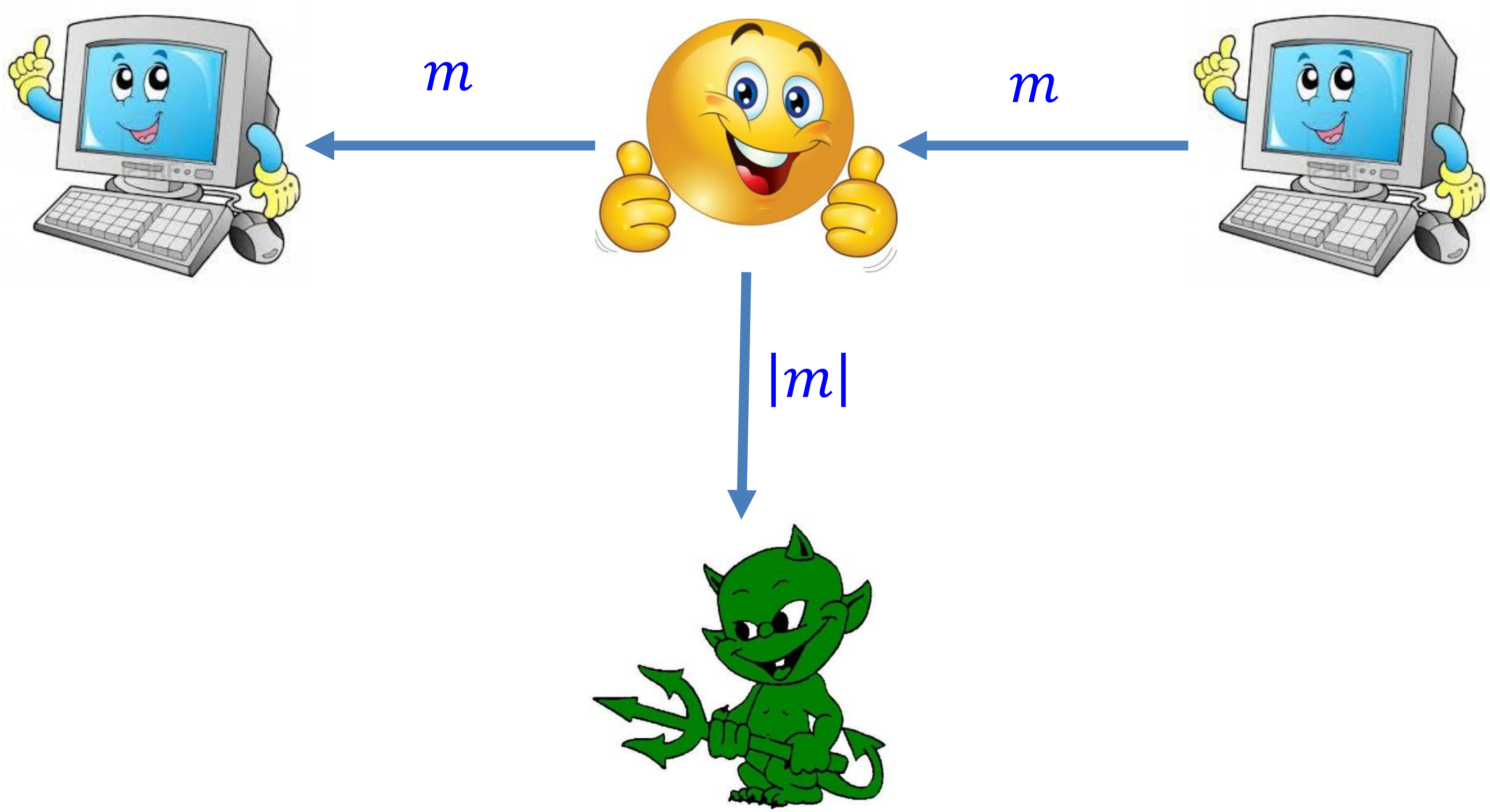


Secure Message Transmission (SMT)



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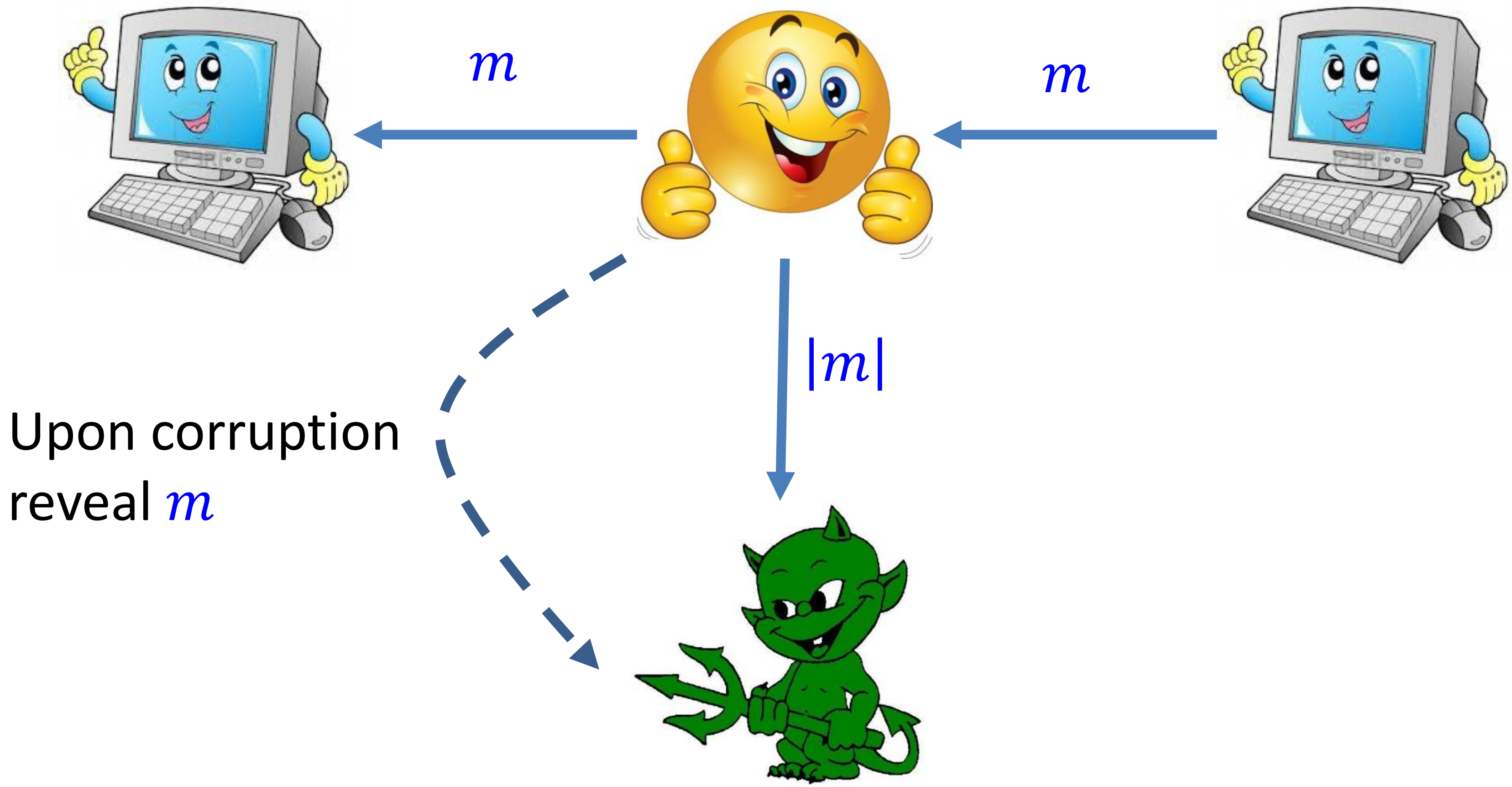
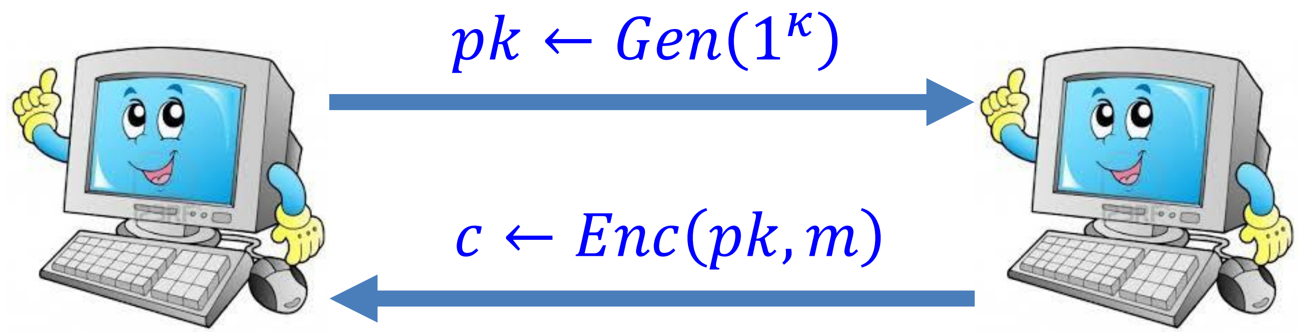


Statically Secure Protocol



- Use public-key encryption (PKE)
- Simulation:
  - Both parties are honest, encrypt 0
  - One party corrupted, $\mathcal{S}$ learns m and encrypts m

PKE can be defined as a non-interactive (2-round) protocol statically realizes $\mathcal{F}_{SMT}$

Adaptive Corruptions

- Using PKE simulation fails when parties start honest
- [CFGN'96] defined Non-Committing Encryption (NCE) as n-party protocol that adaptively realizes $\mathcal{F}_{SMT}$
- [DN'00] defined strong NCE as 2-party protocol that adaptively realizes $\mathcal{F}_{SMT}$ (in [Canetti'00])
- Both definitions and constructions are interactive
- Can define non-interactive NCE as 2-round protocol
- [CLOS'02] provided a simpler definition

Non-Interactive NCE

Definition: A PKE scheme (Gen, Enc, Dec) with algorithm Sim is non-interactive NCE if $\forall m \in \{0,1\}$ the distributions are comp. indistinguishable

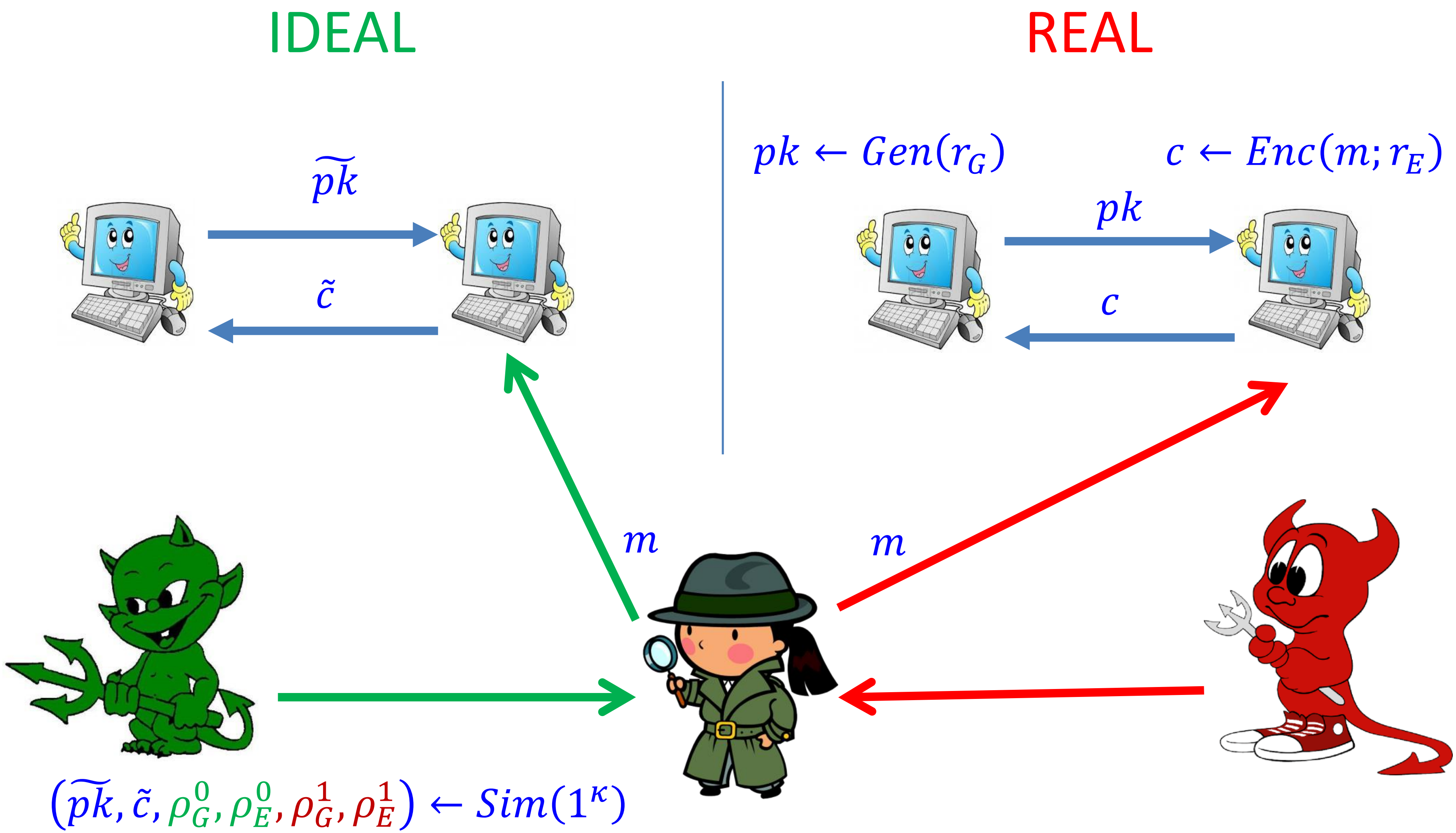
- Honest view of encryption of m

$$\{pk, c, r_G, r_E \mid pk = Gen(1^\kappa; r_G), c = Enc(pk, m; r_E)\}$$

- Simulated encryption explained for m

$$\left\{\widetilde{pk}, \tilde{c}, \rho_G^m, \rho_E^m \mid \left(\widetilde{pk}, \tilde{c}, \rho_G^0, \rho_E^0, \rho_G^1, \rho_E^1\right) \leftarrow Sim(1^\kappa)\right\}$$

Non-Interactive NCE (2)



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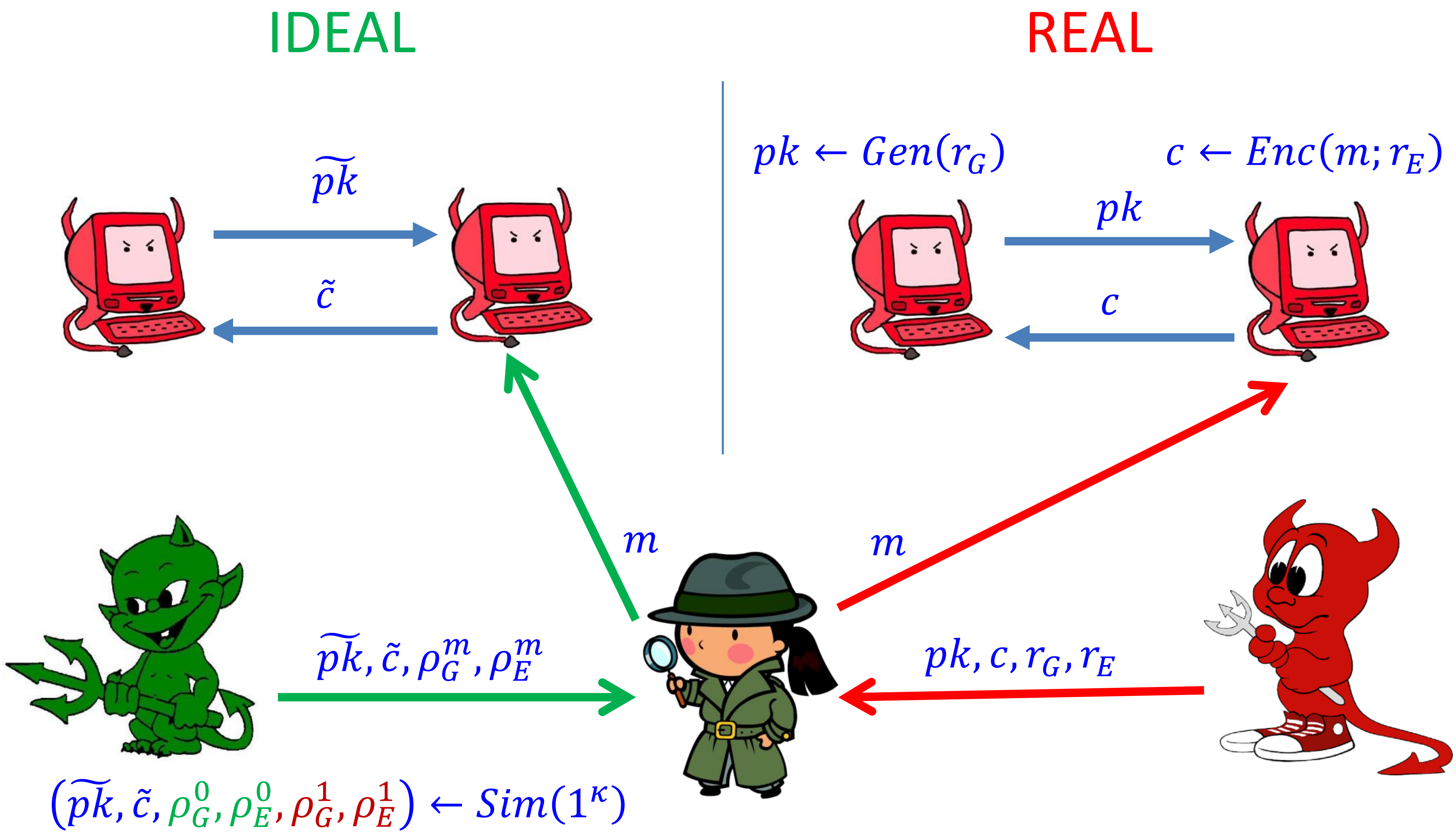
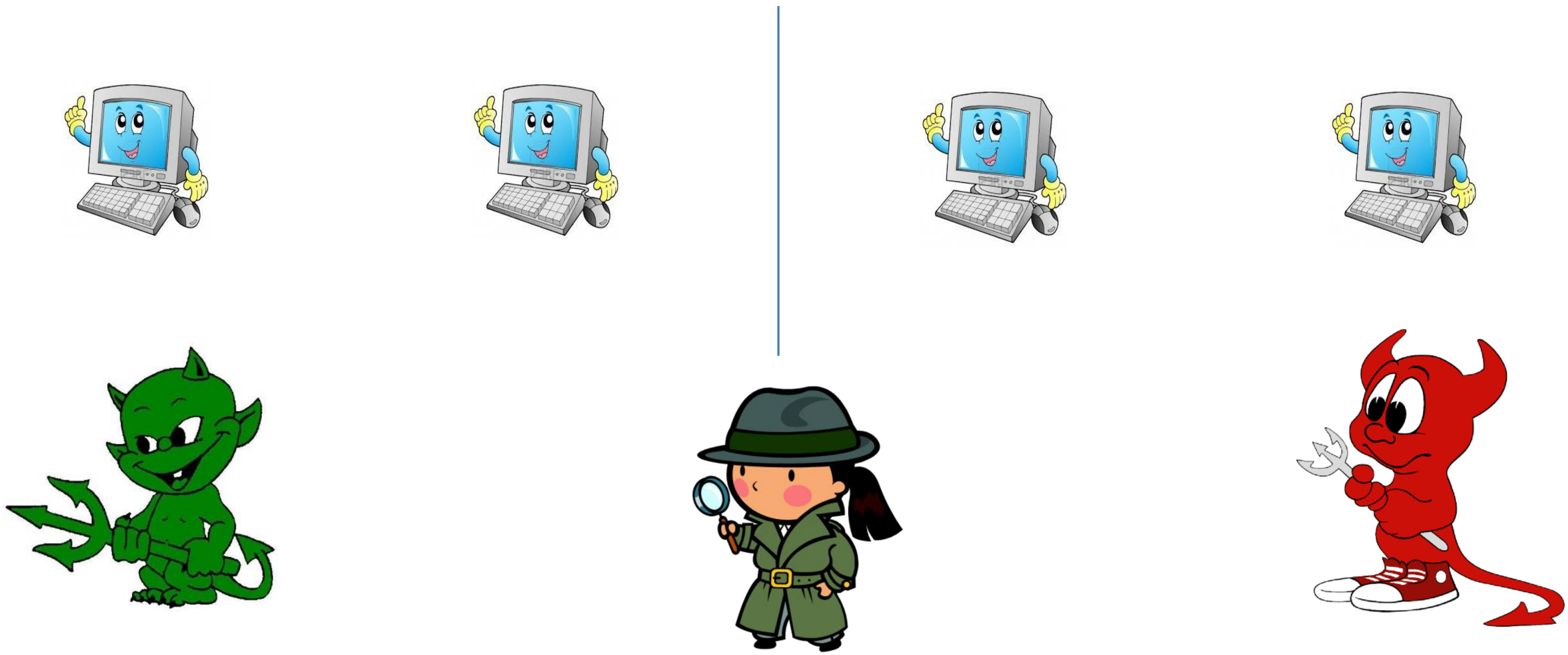


Problem

- Simulation is valid if inputs are given before the computation begins (as in modular composition)
- In UC inputs are dynamically generated
- Need to simulate corruptions before inputs are given



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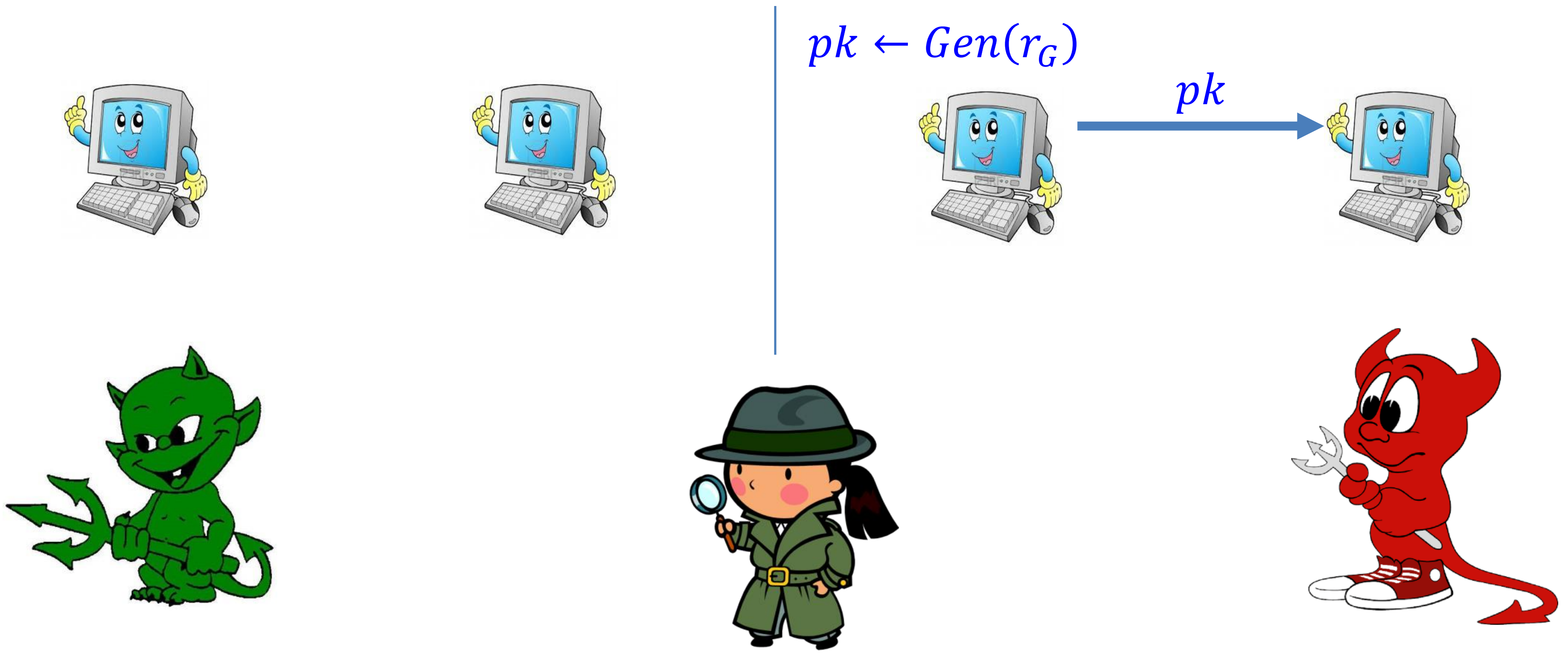

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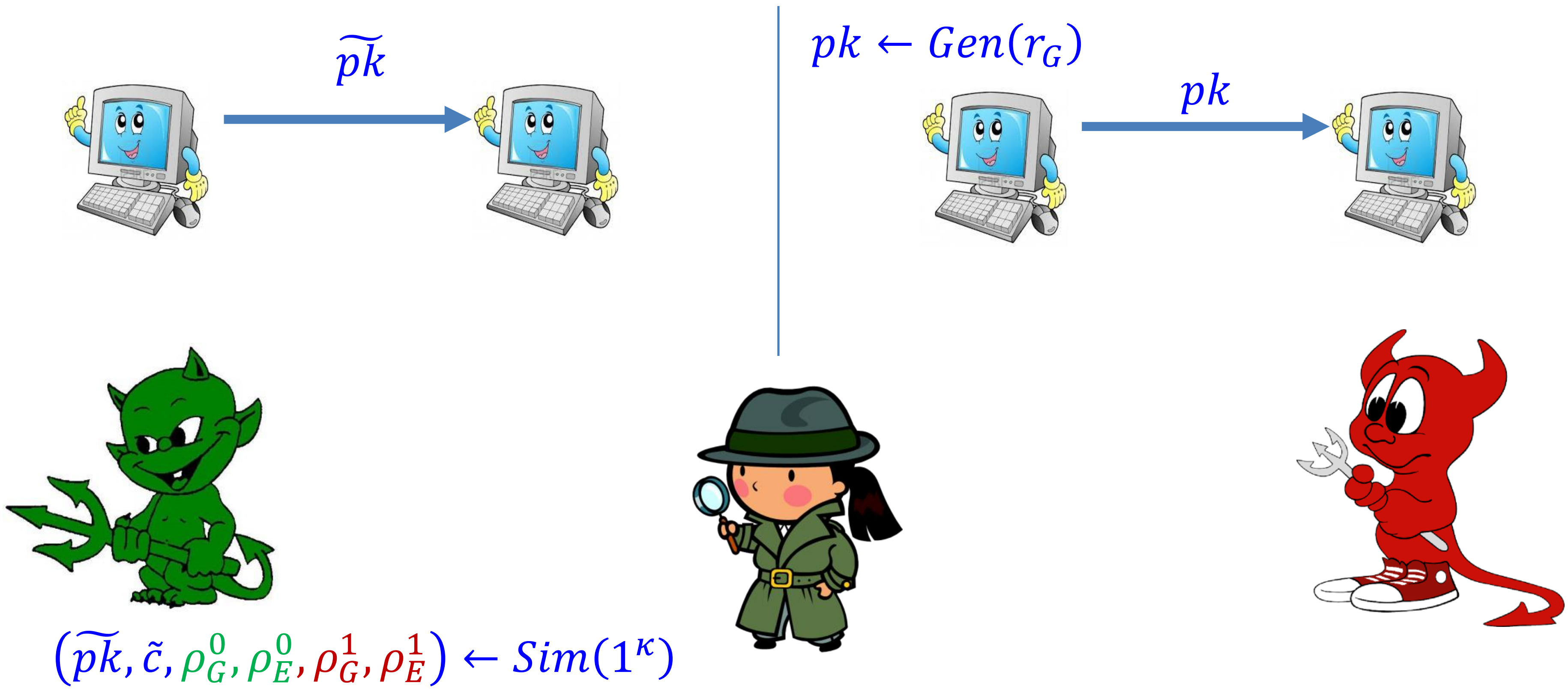

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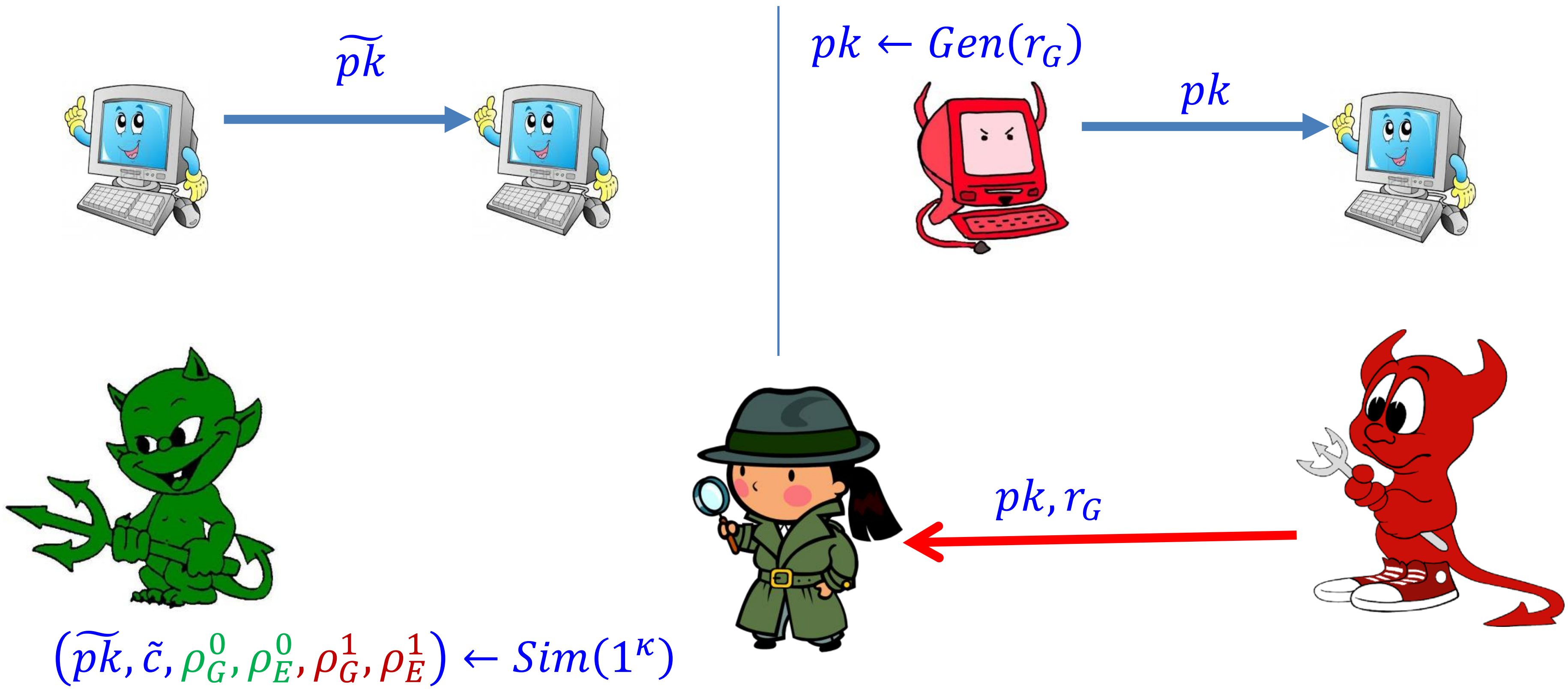

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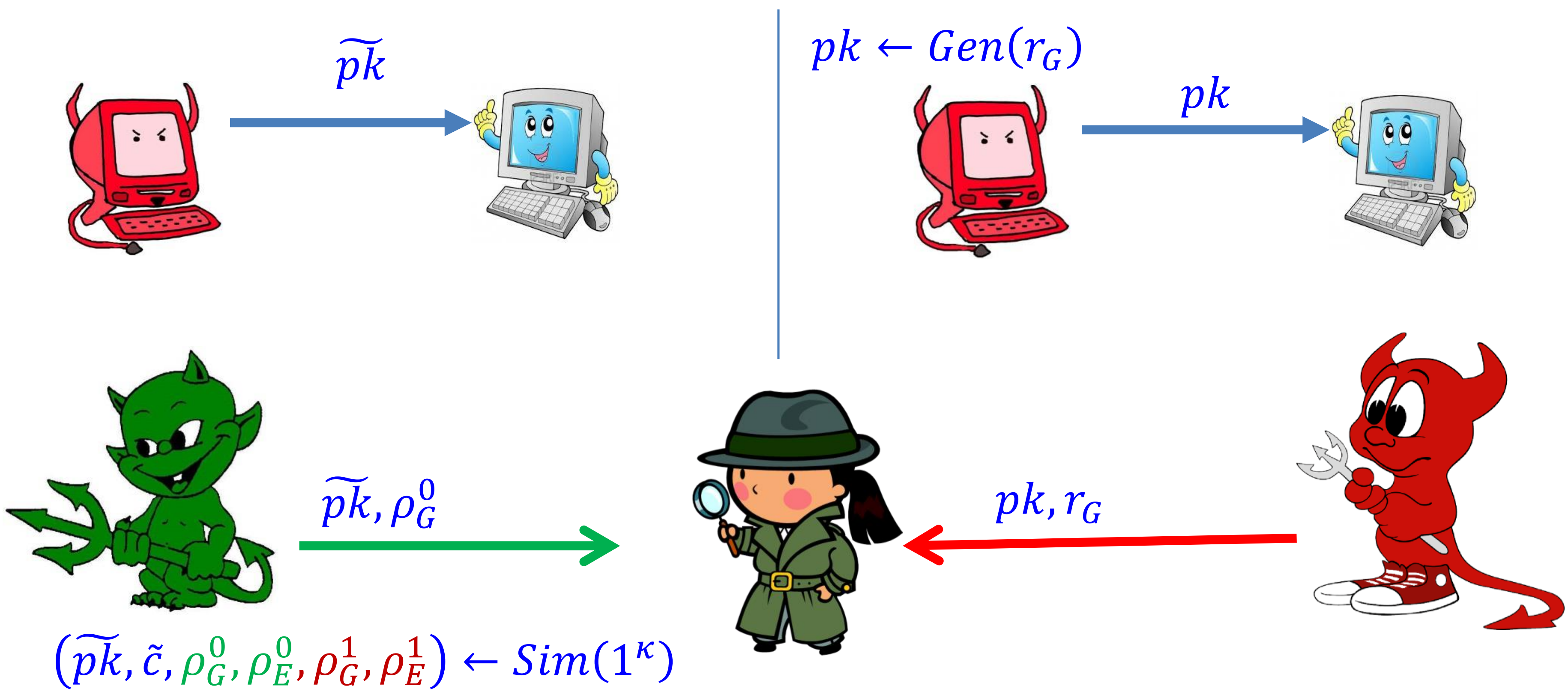

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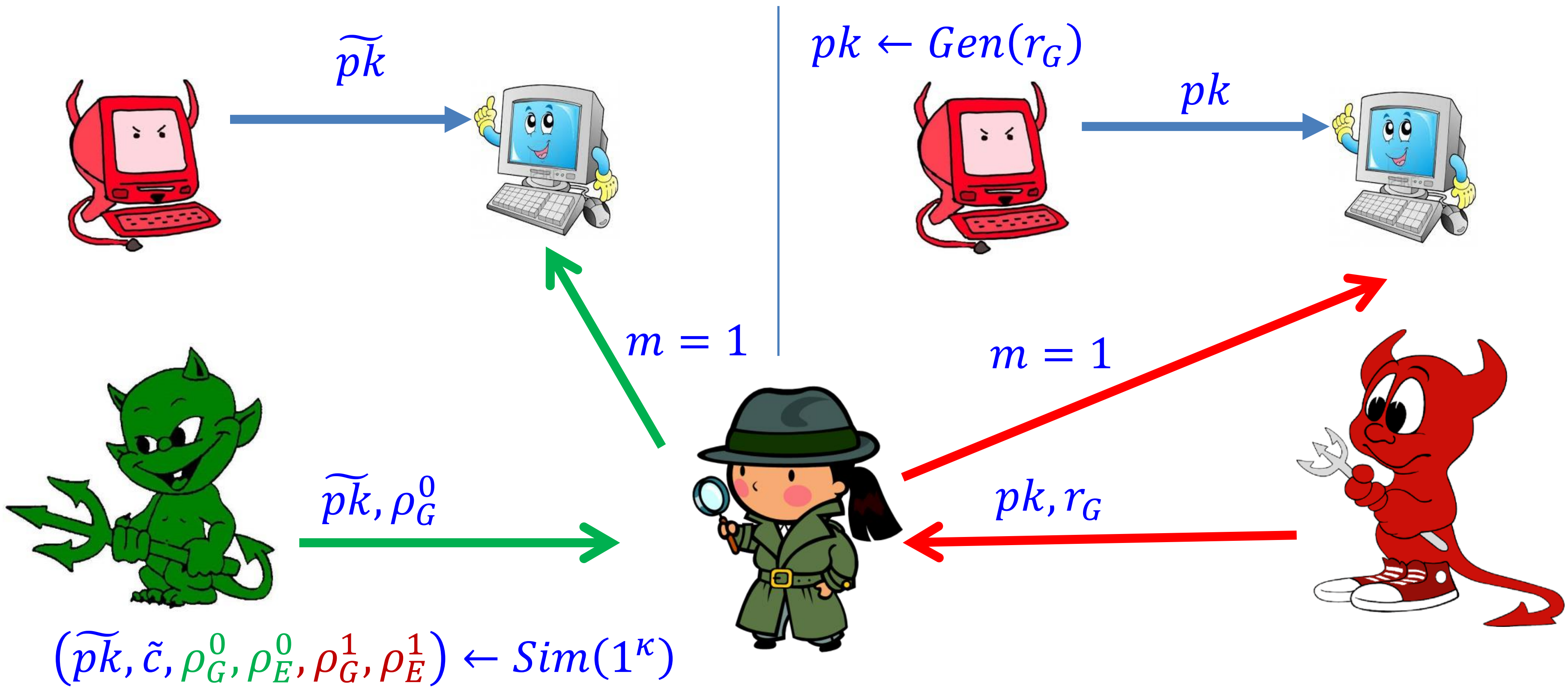

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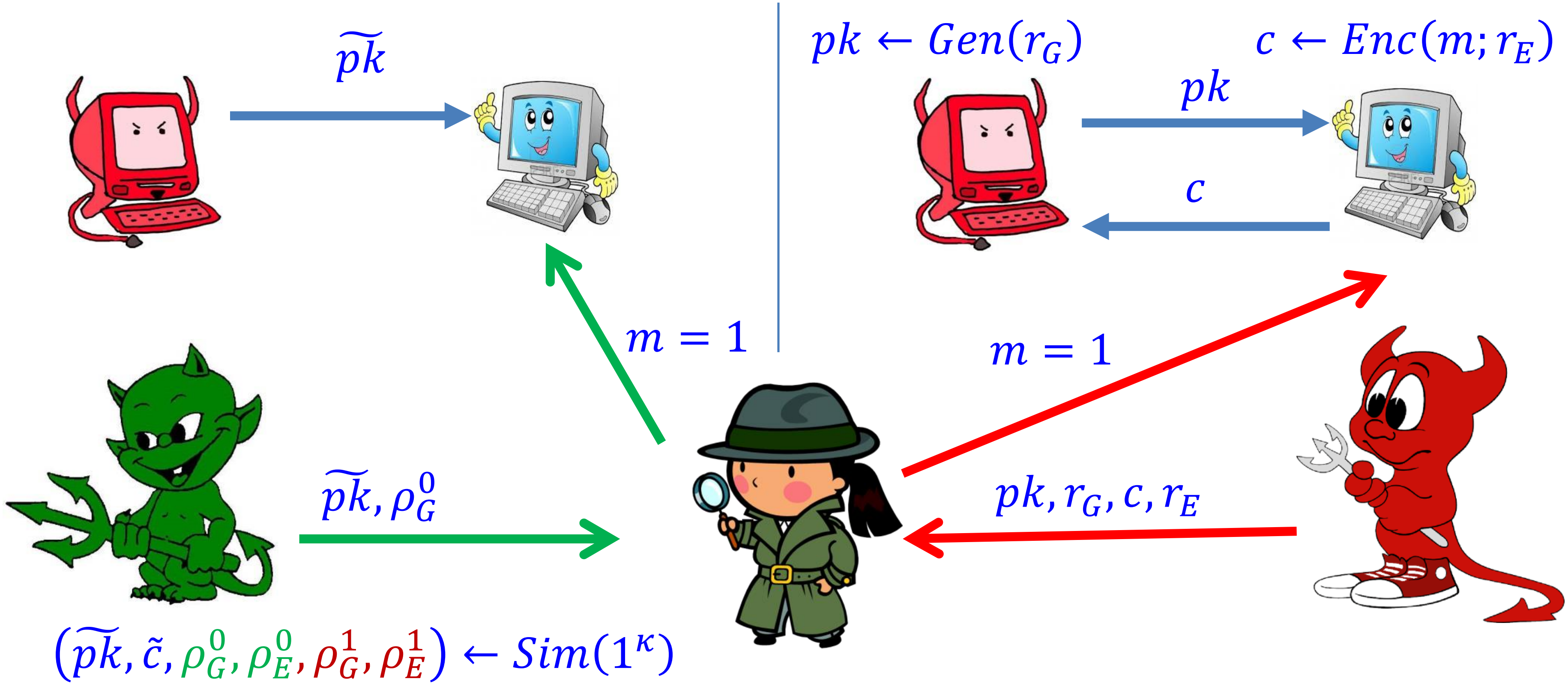
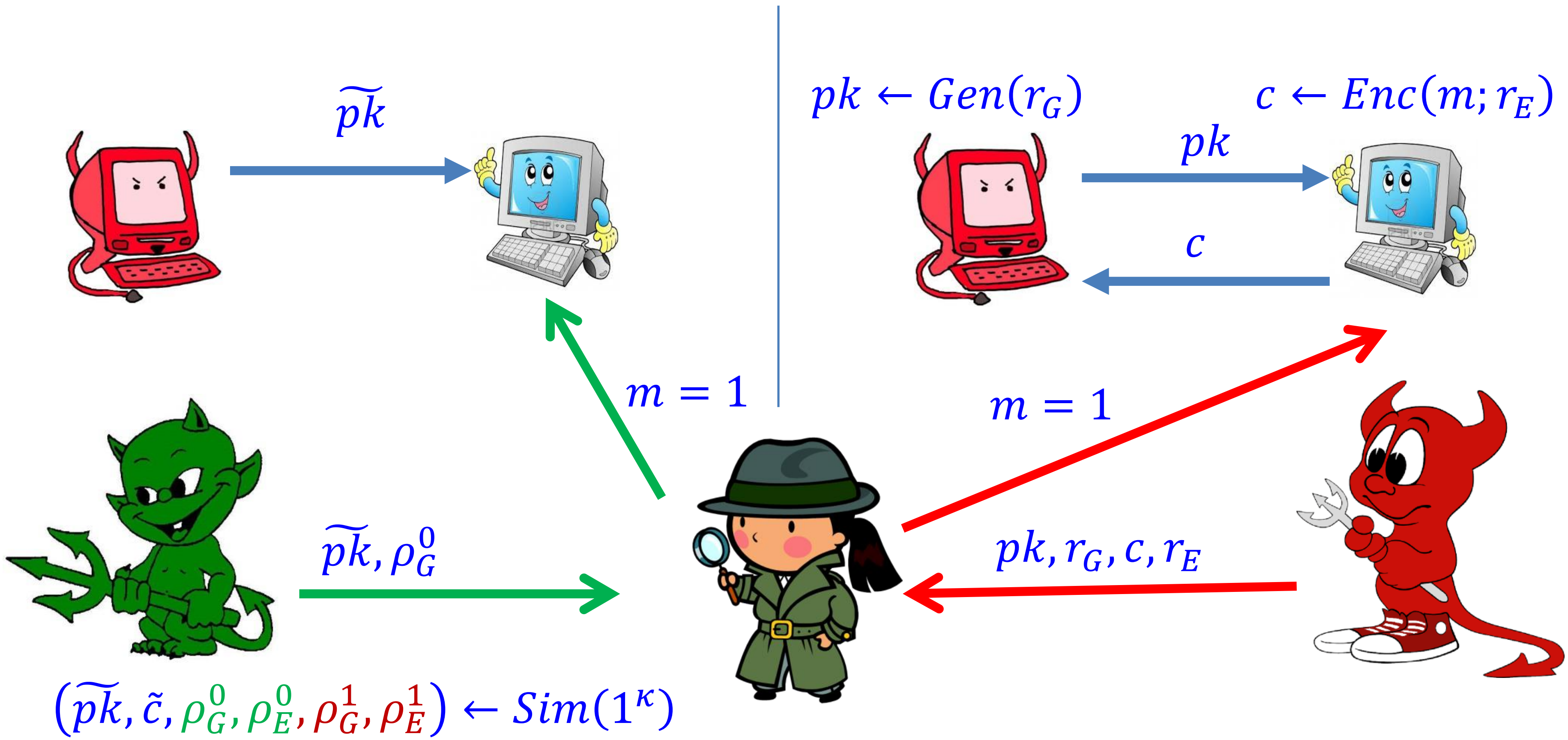


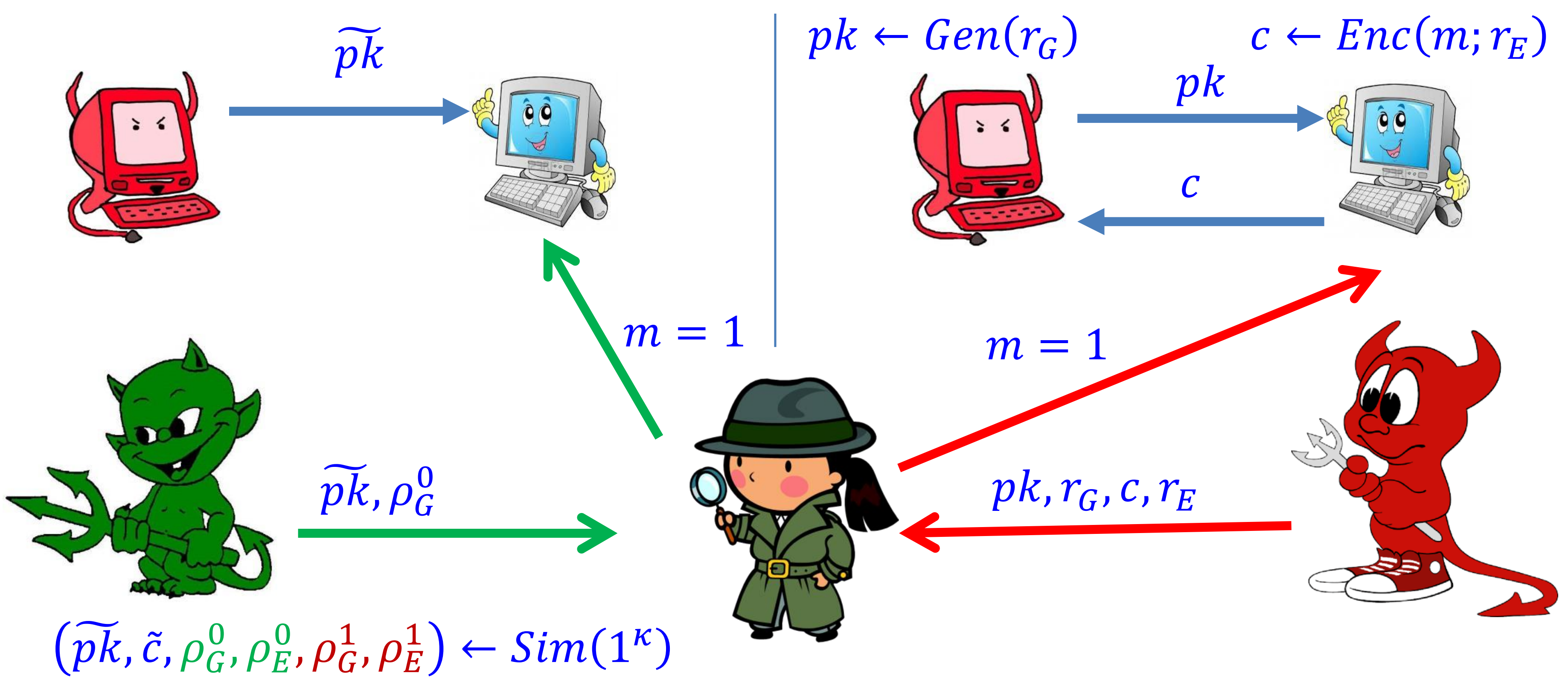
Problem

- Once $\widetilde{pk}, \rho_G^0$ (or ρ_G^1) are fixed, $\tilde{c}$ is committing
- $\tilde{c}$ won't decrypt to random m with noticeable prob.



Adjust the Simulation

- Simulation of c only after sender activated with m
- $\mathcal{S}$ learns m from ideal functionality (receiver corrupt)
- $\mathcal{S}$ encrypts $c \leftarrow Enc(\widetilde{pk}, m; r_E)$



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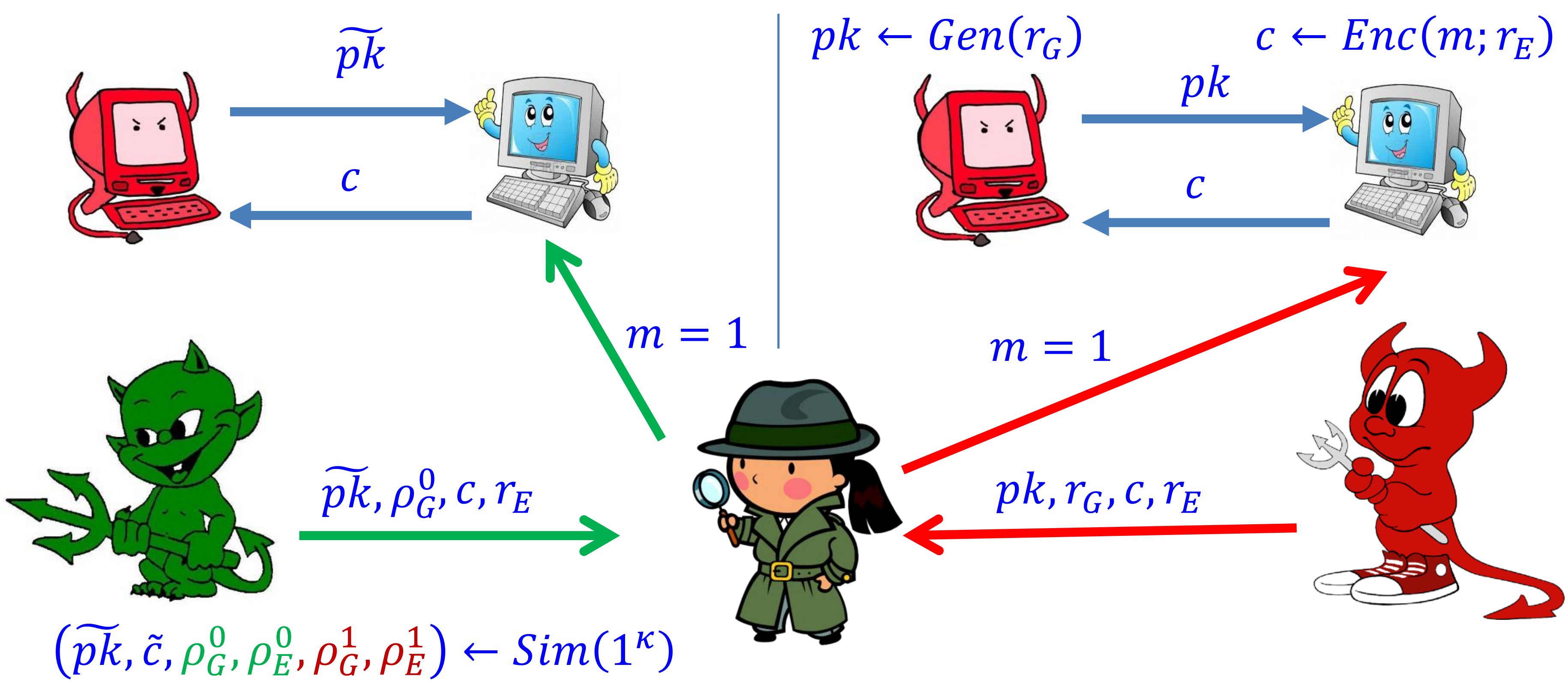
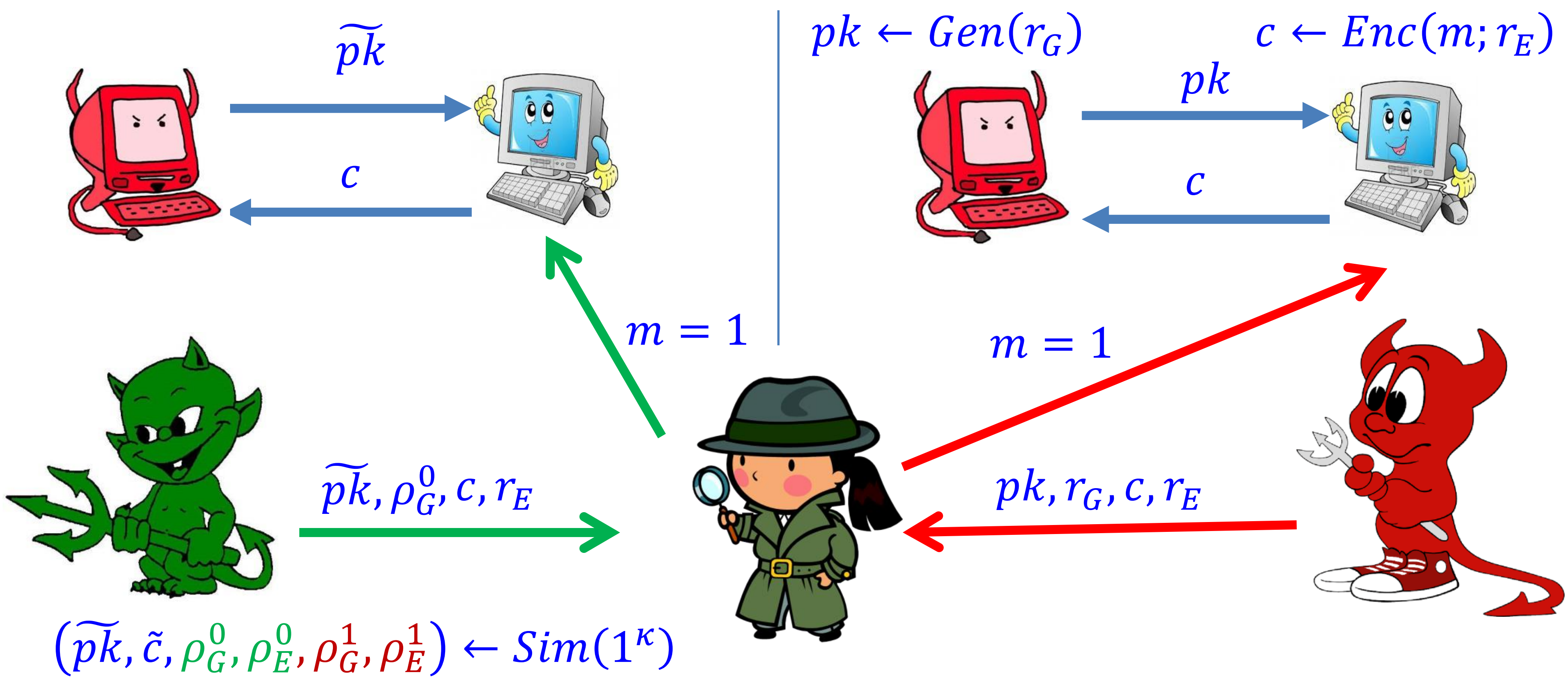


Adjust the Simulation (2)

- We show how to combine committing and non-committing ciphertexts in simulation

Thm: If non-interactive NCE exists, then $\mathcal{F}_{SMT}$ can be adaptively UC realized in 2 rounds



Application: Oblivious Transfer (OT)

Augmented NCE:

– Oblivious sampling of public keys $pk \leftarrow OGen(1^\kappa)$

– Invertible sampling

$$\{pk, r \mid pk = OGen(1^\kappa; r)\} \sim \{pk, OGen^{-1}(pk) \mid pk \leftarrow Gen(1^\kappa)\}$$

Adaptive OT [CLOS'02]

m_0, m_1

$pk_c \leftarrow Gen(1^\kappa)$

$pk_{1-c} \leftarrow OGen(1^\kappa)$

c

$c_0 \leftarrow Enc(pk_0, m_0)$

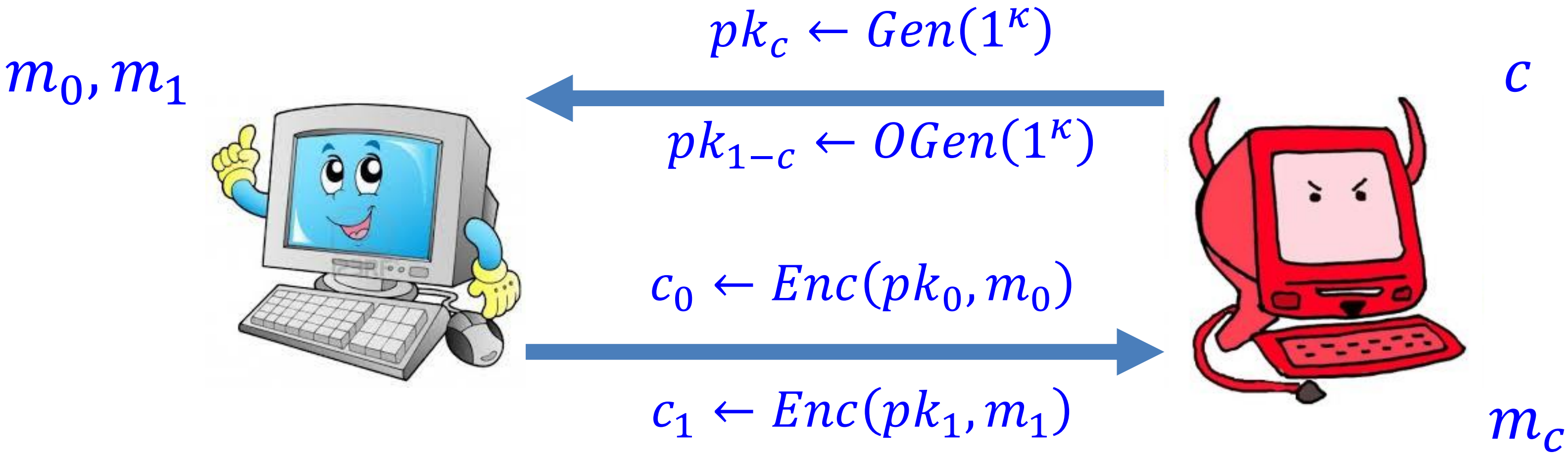
$c_1 \leftarrow Enc(pk_1, m_1)$

m_c

Simulation (semi-honest)

- $\mathcal{S}$ simulate using $\left(\widetilde{pk}_0, \tilde{c}_0, \rho_{0,G}^0, \rho_{0,E}^0, \rho_{0,G}^1, \rho_{0,E}^1\right) \leftarrow Sim(1^\kappa)$ $\left(\widetilde{pk}_1, \tilde{c}_1, \rho_{1,G}^0, \rho_{1,E}^0, \rho_{1,G}^1, \rho_{1,E}^1\right) \leftarrow Sim(1^\kappa)$

Adaptive OT [CLOS'02]



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- Upon receiver corruption, $\mathcal{S}$ learns c, m_c and provides randomness $\rho^{m_c}_{c,G}$

Adaptive OT [CLOS'02]

m_0, m_1

$pk_c \leftarrow Gen(1^\kappa)$

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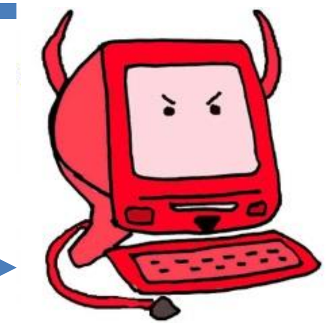

c

m_c

Simulation (semi-honest)

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- Upon receiver corruption, $\mathcal{S}$ learns c, m_c and provides randomness $\rho^{m_c}_{c,G}$

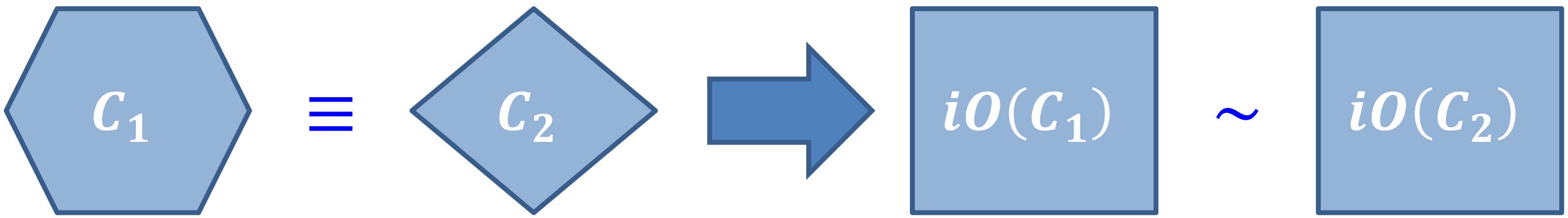
See the paper for details

input & output

Round Complexity Independent of C

"Your proposal is written with clarity and conviction. Send it up to legal for obfuscation."

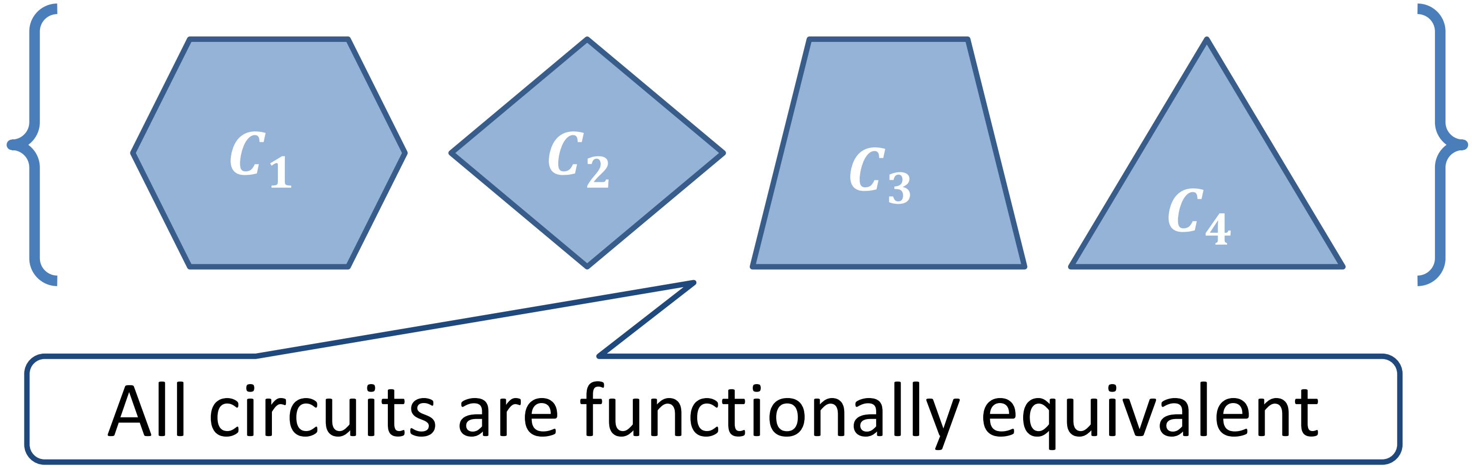
Indistinguishability Obfuscation (iO)



Candidate construction [GGHRSW'13]

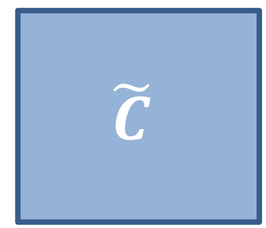
Nice property: the depth of the obfuscation circuit is independent of the circuit to obfuscate

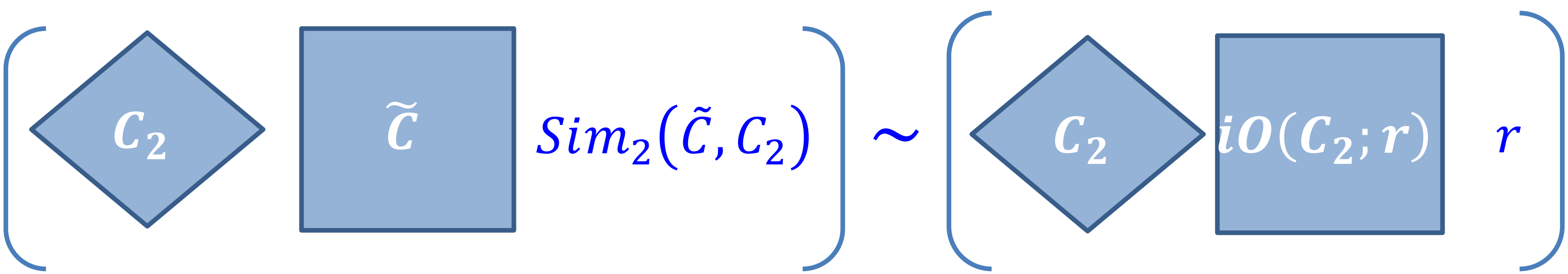
Non-Committing iO

$\Gamma =$ 

<u>Def</u>: (iO, Sim_1, Sim_2) is non-committing iO for Γ if

- Sim_1 generates canonical obf. circuit $\tilde{C}$ for Γ
- Given any $C \in \Gamma$, Sim_2 can explain $\tilde{C}$ as $iO(C)$





Non-Committing iO (2)

Bad news:

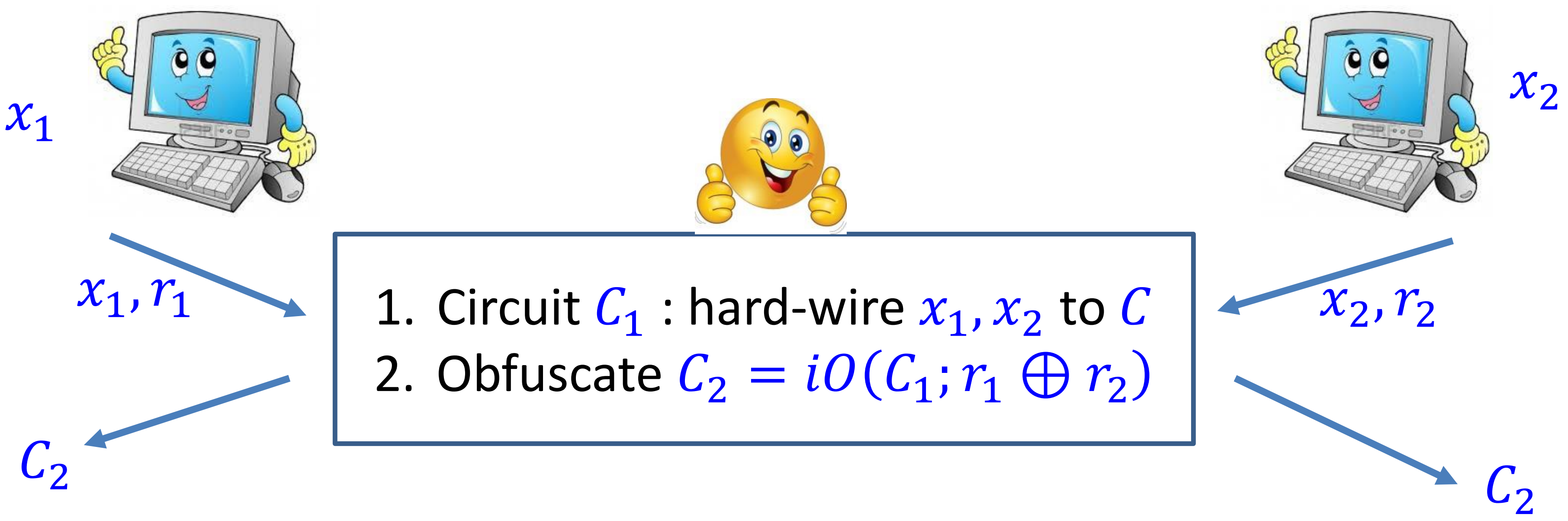
If NCiO for circuits exists
$\Rightarrow$ poly-time solution to circuit equivalence (co-NP)
$\Rightarrow$ polynomial hierarchy collapses

Good news:

Circuit equivalence is easy for constant circuits
(no input wires)

Thm: If NCiO for constant circuits exists
then $\exists$ adaptive SFE protocol with short CRS
whose round complexity is independent of C

Protocol Idea



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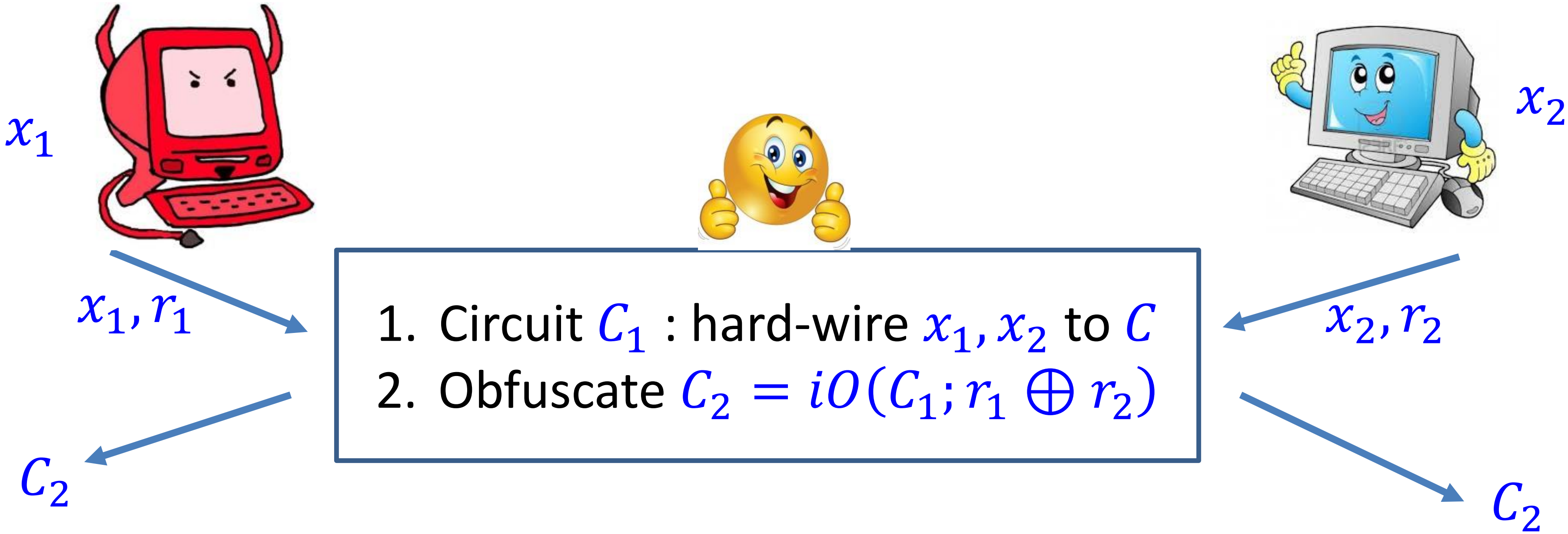

Simulation idea

1st corruption: learn x_1, y and randomly sample r_1

Compute $\tilde{C} \leftarrow Sim_1$ obfuscated constant circuit with output y

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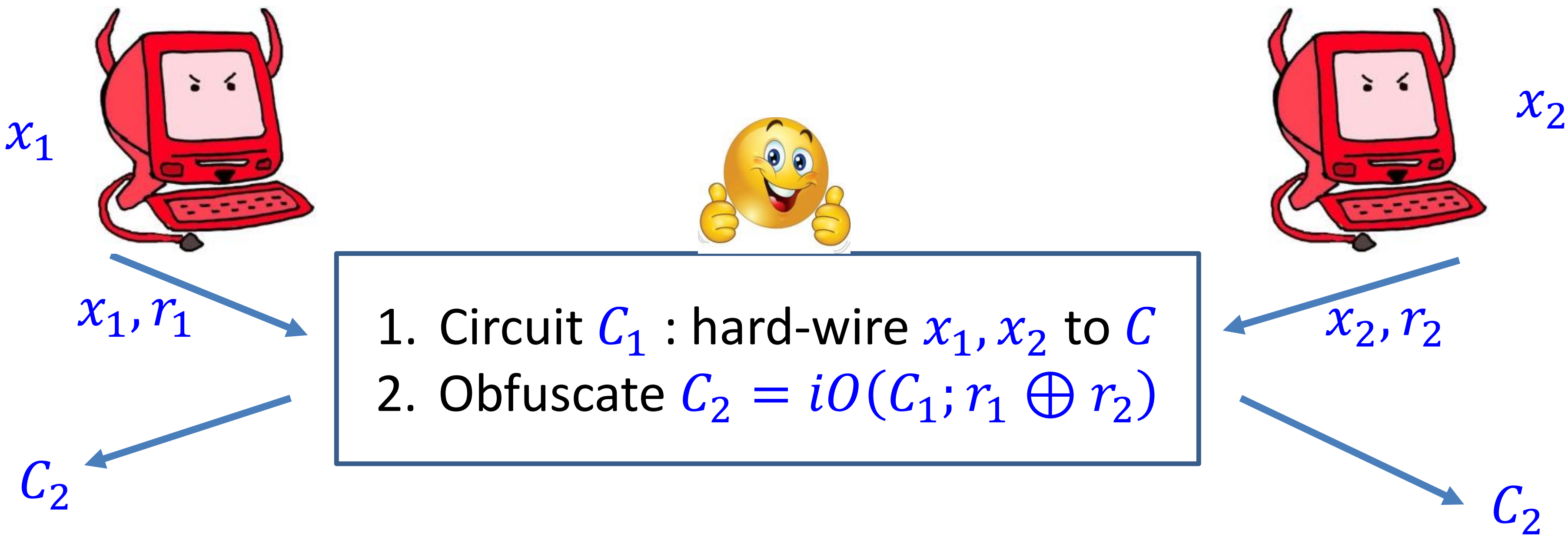
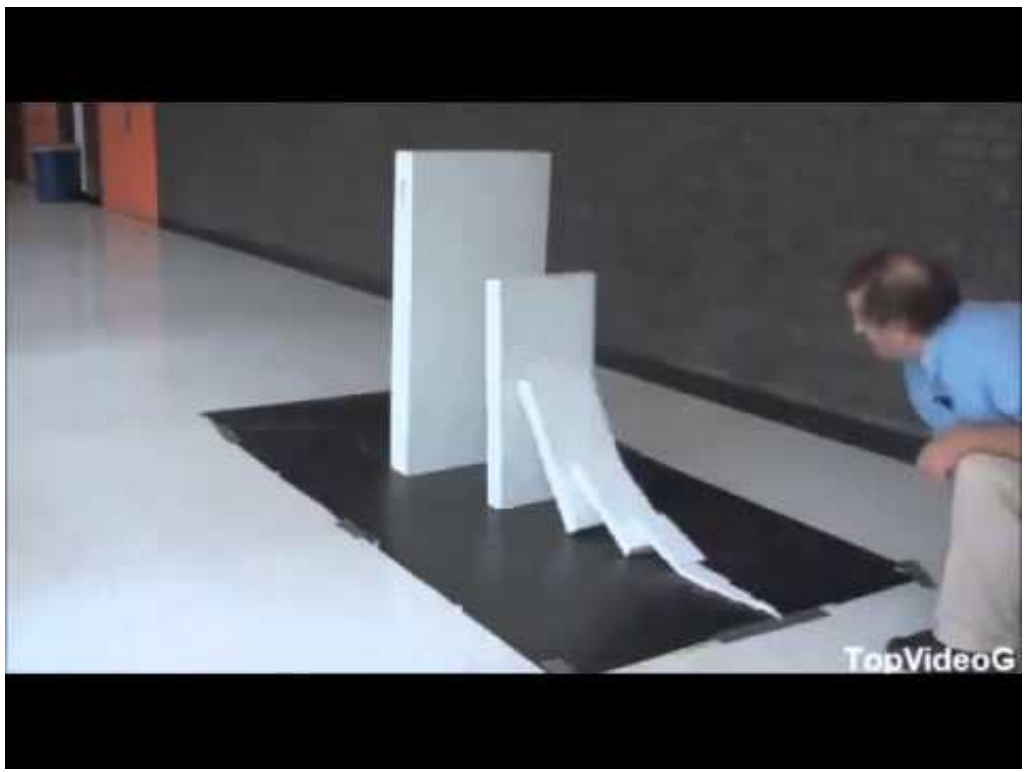


Simulation idea

1st corruption: learn x_1, y and randomly sample r_1
Compute $\tilde{C} \leftarrow Sim_1$ obfuscated constant circuit with output y

2nd corruption: learn x_2, y and compute C_1 (using C, x_1, x_2)
Compute $r \leftarrow Sim_2(\tilde{C}, C_1)$ and set $r_2 = r \oplus r_1$

Constant Round for One-Sided Poly-Size Domain



Constant-Round Protocol

Thm: Assume adaptively secure OT exist

- f is deterministic 2-party functionality
- $x_1 \in D \subset \{0,1\}^n, |D| = poly(n)$
- $x_2 \in \{0,1\}^n$

Then f can be adaptively realized with short CRS in constant number of rounds

Optimistic view: feasibility result

Pessimistic view: to rule out constant-round protocols in general, consider super-poly domain or randomized functions

Summary

1. How to simulate non-interactive NCE in UC
2. NCiO is complete for round complexity ind. of circuit
3. Constant-round protocols for class of functions

Open questions:

- Does NCiO for constant circuits exist?
- Find more functions that have constant-round protocols with short CRS

Grazie