Universal Composition with Responsive Environments

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Simulation-Based Security

Definition of simulatability (basic idea):

$$\boxed{\mathcal{P}} \leq \boxed{\mathcal{F}}$$

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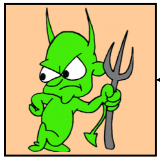
$\forall$  $\longleftrightarrow$ $\mathcal{P}$ $\quad\exists$  $\longleftrightarrow$ $\mathcal{F}$

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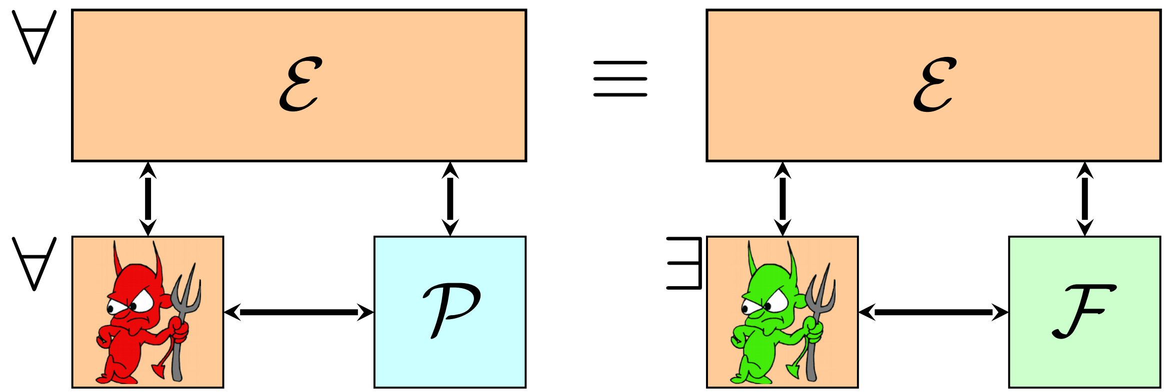

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e.g., some real-world protocol
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can now be used in more complex protocols

Models for Simulation-Based Security

- UC model [Canetti 2001]
- IITM model [Küsters 2006]
- GNUC model [Hofheinz, Shoup 2011]
- ...

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Our solution:

Responsive Environments

Urgent Requests

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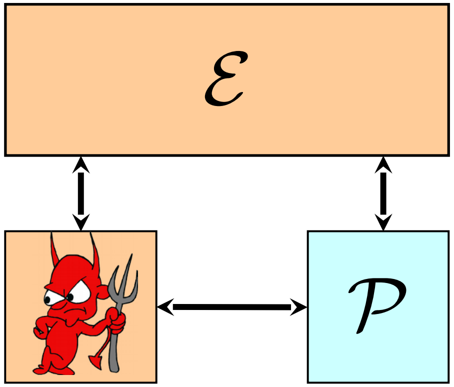

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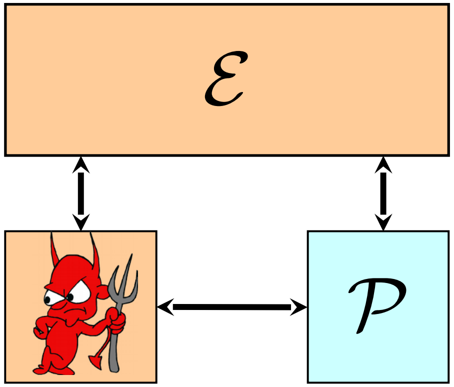

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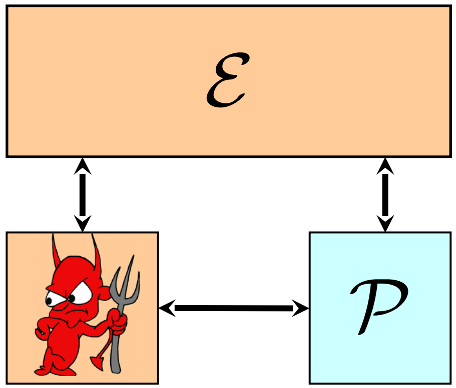

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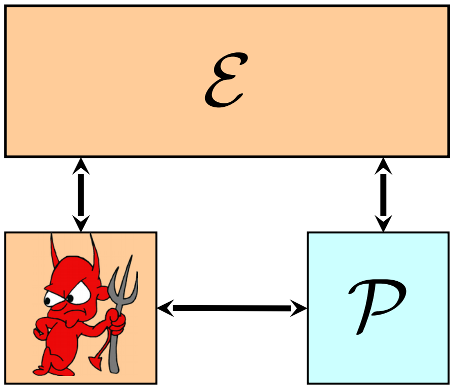

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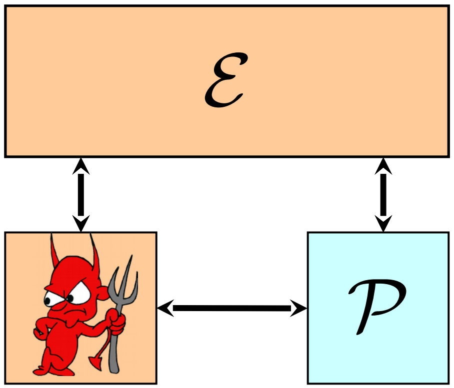

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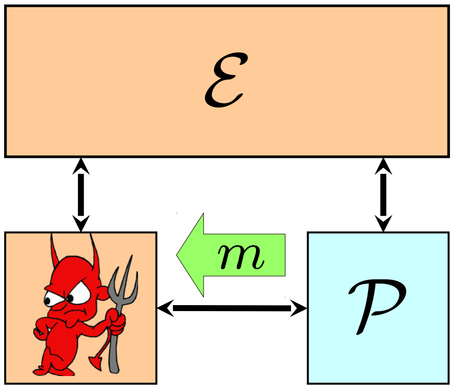
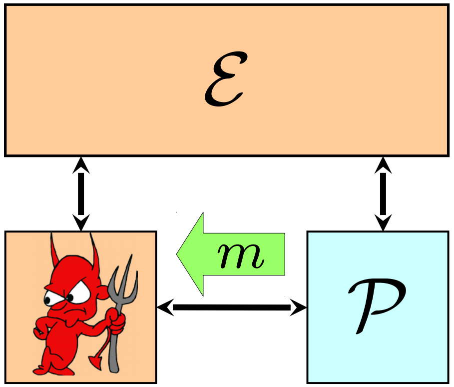
$\Rightarrow$ Send a message m (urgent request)



Non-Responsiveness Problem

Urgent requests do not model real network traffic



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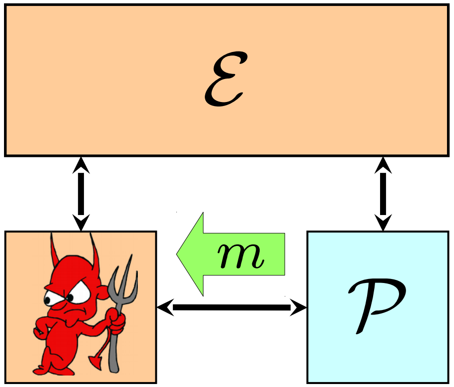

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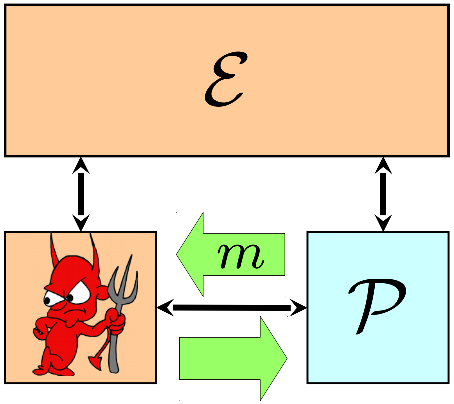

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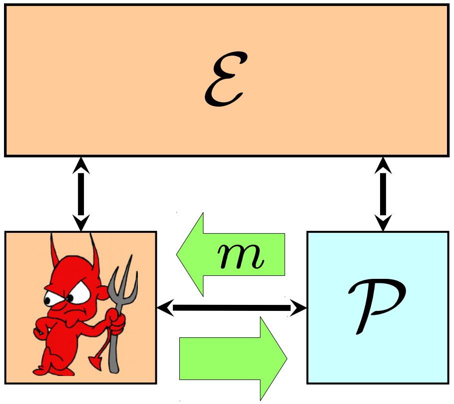

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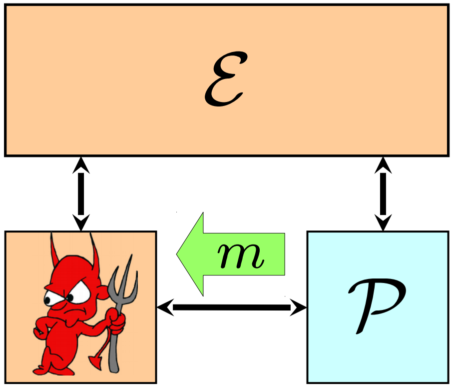

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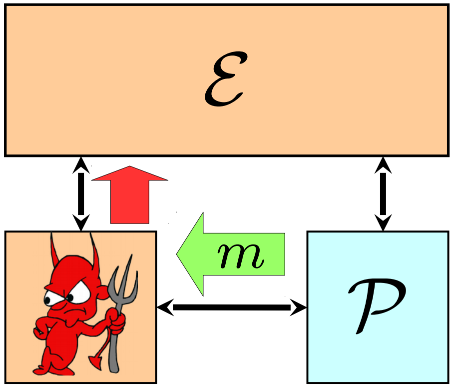

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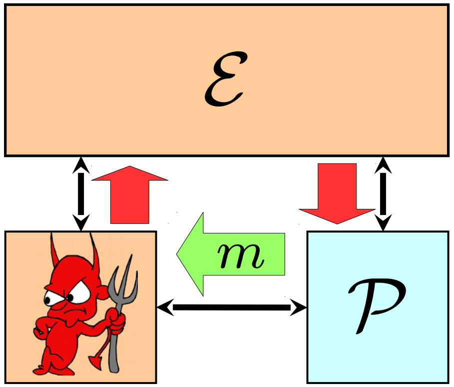

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However, adversary can:

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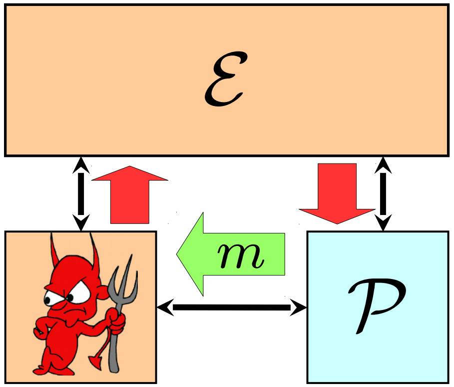

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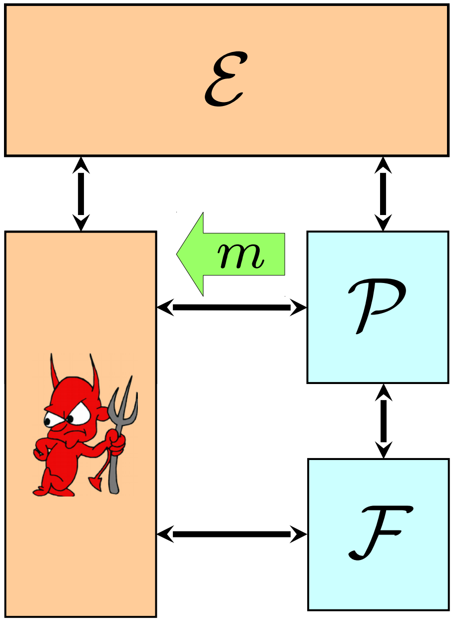

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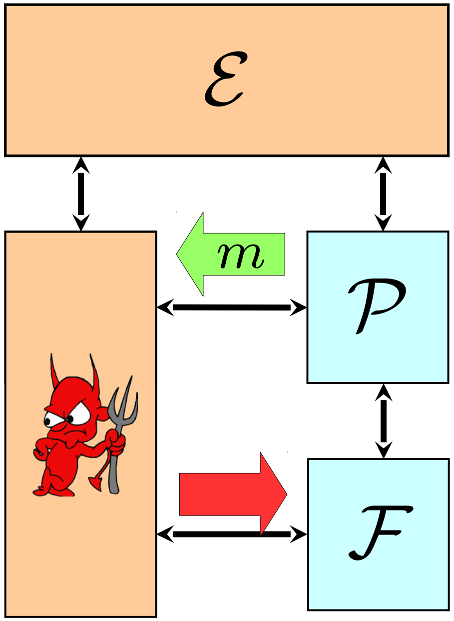

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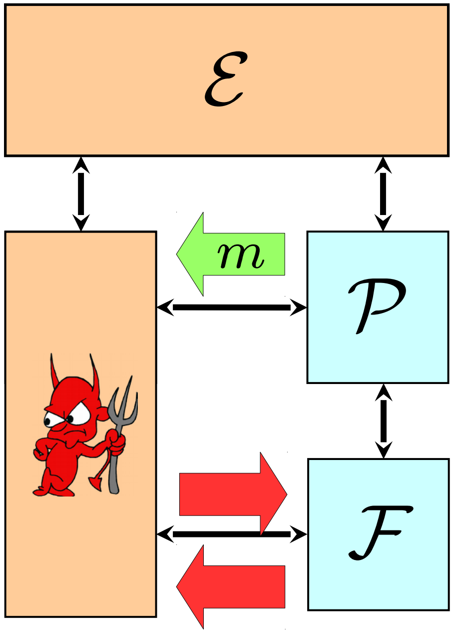

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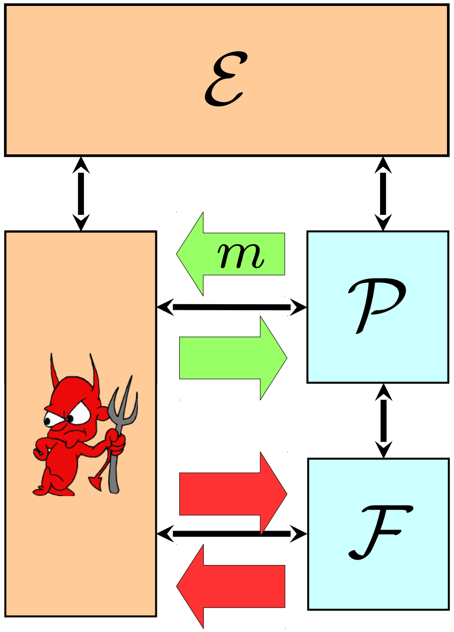

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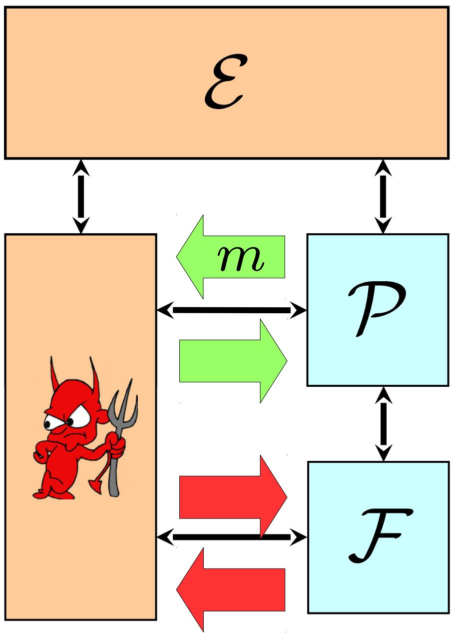

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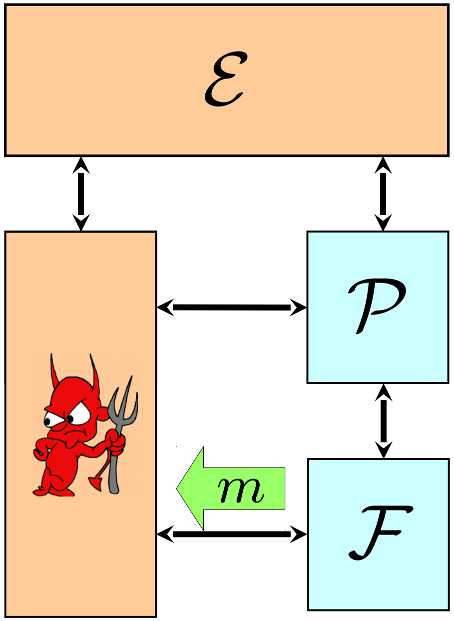

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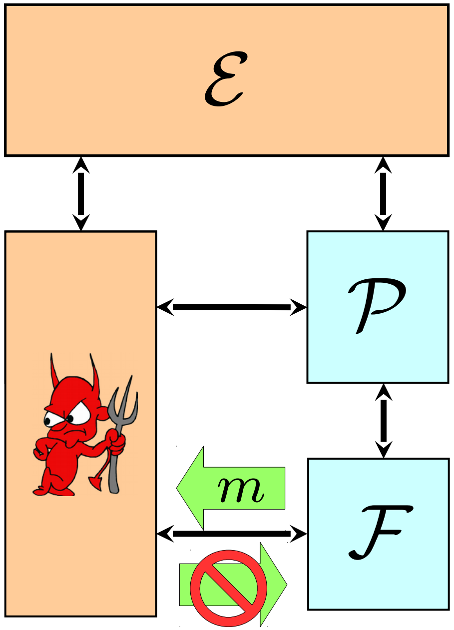

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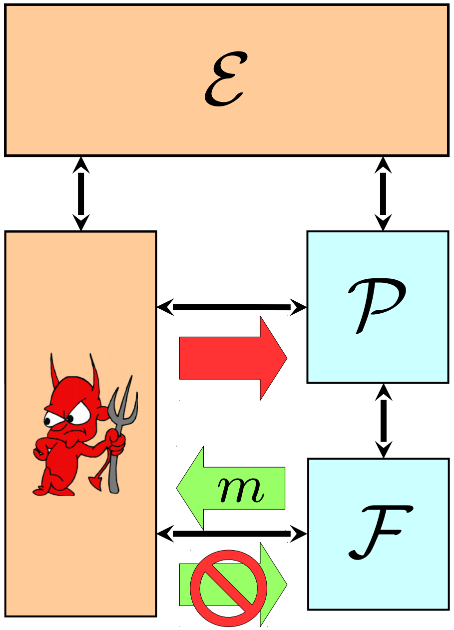

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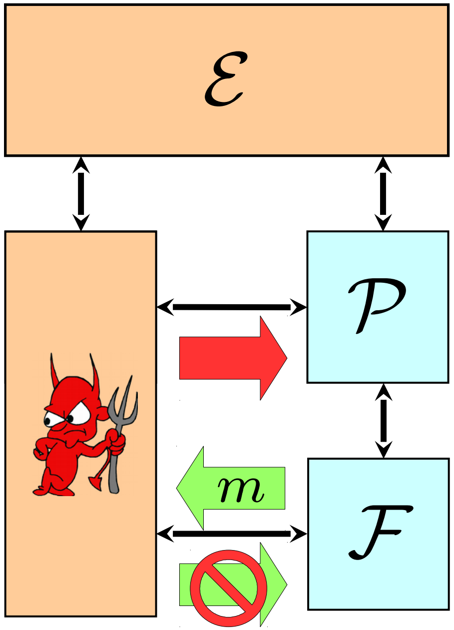
Protocol designers have to deal with unintended adversarial behavior:



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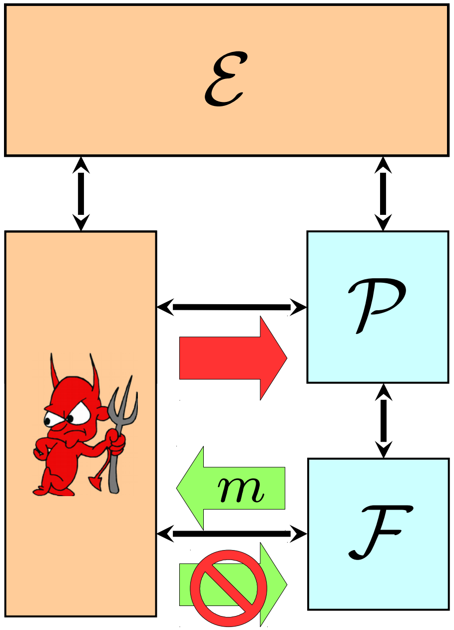

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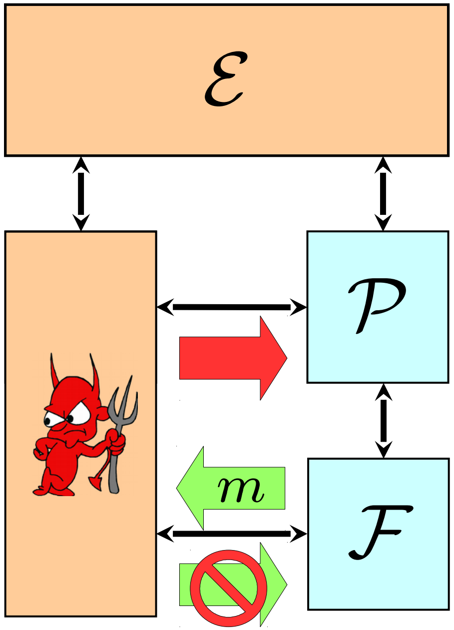

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Protocol designers have to deal with unintended adversarial behavior:

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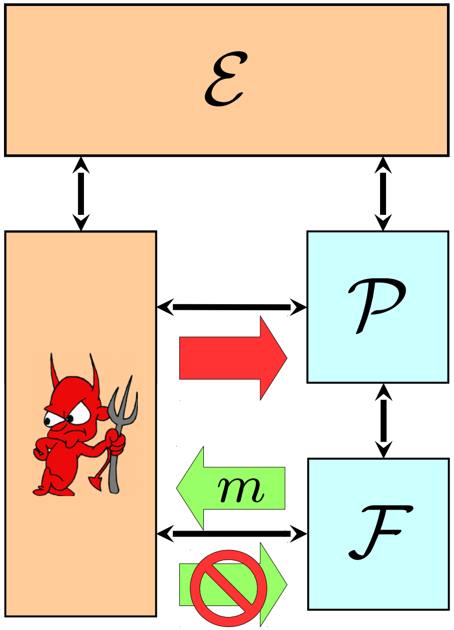

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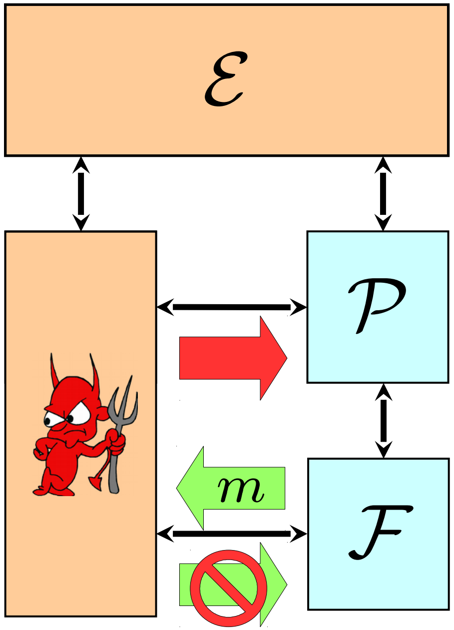

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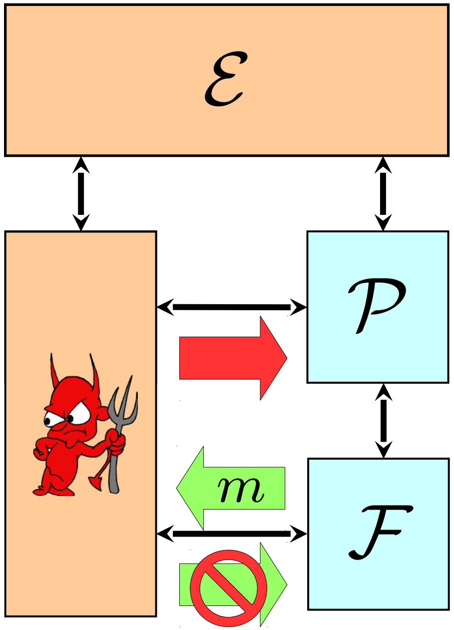

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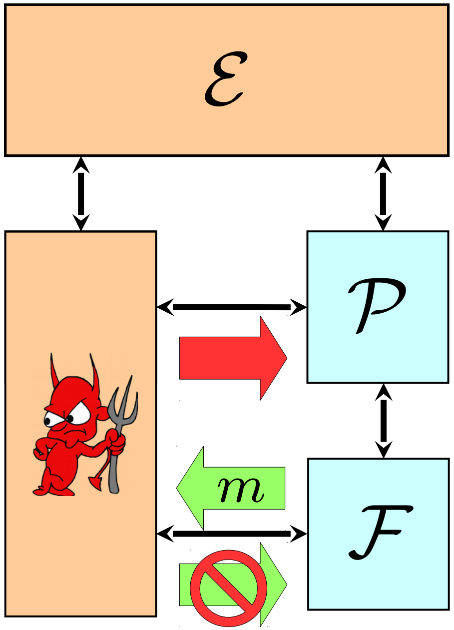

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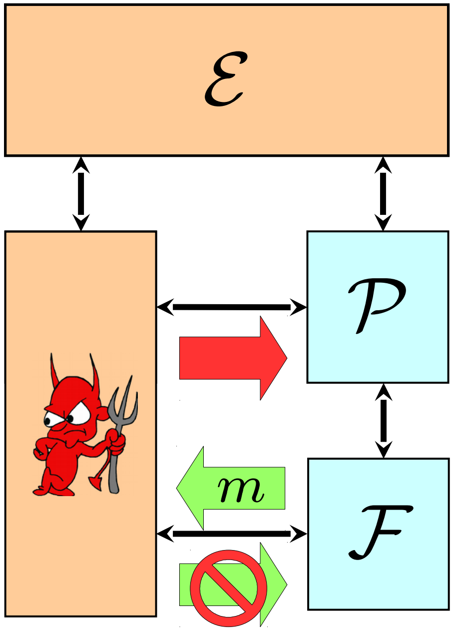
  - * Hard to reuse functionalities



Examples from the literature

$\mathcal{F}_{\text{NIKE}}$ from [Freire, Hesse, Hofheinz, 2014]

Upon input $(\texttt{init}, P_i, P_j)$ from P_i [...] consider two cases:

- Corrupted session mode: if there exists $(\{P_i, P_j\}, K_{i,j})$ in Λ_{keys}, set $key = K_{i,j}$. Else, **send $(\texttt{init}, P_i, P_j)$ to the adversary. After receiving $(\{P_i, P_j\}, K_{i,j})$ from the adversary**, set $key = K_{i,j}$ and add $(\{P_i, P_j\}, K_{i,j})$ to Λ_{keys}.
- Honest session mode: [...]

Return (P_i, P_j, key) to P_i.

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Lack of expressivity:

Functionality meant to model *non-interactive* key exchange, but is actually interactive

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$\mathcal{F}_{\text{sok}}$ from [Chase, Lysyanskaya, 2006]

Upon receiving a value $(\texttt{Setup}, sid)$ from any party P, verify that $sid = (M_L, sid')$ for some sid'. If not, then ignore the request. Else, if this is the first time that $(\texttt{Setup}, sid)$ was received, **hand $(\texttt{Setup}, sid)$ to the adversary; upon receiving** $(\texttt{Algorithms}, sid, \text{Verify}, \text{Sign}, \text{Simsign}, \text{Extract})$ **from the adversary**, store these algorithms. Output the stored $(\text{Algorithms}, sid, \text{Sign}, \text{Verify})$ to P.

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Problems in proofs:

Functionality might not receive algorithms,
which is problematic for realizations based on $\mathcal{F}_{\text{sok}}$

Examples from the literature

$\mathcal{F}_{\text{D-Cert}}$ from [Zhao, Zhang, Qin, Feng, 2014]

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Unintended state changes and behavior:

Adversary can corrupt signer of a signature during verification
$\Rightarrow$ Possible to accept invalid signatures

Examples from the literature

Realization of $\mathcal{F}_{\text{D-Cert}}$ from [Zhao, Zhang, Qin, Feng, 2014]

Signature Protocol: When activated with input $(\texttt{Sign}, sid, m)$, Party S does:

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S **sends** $(\texttt{Sign}, (U, s), m)$ **to** $\mathcal{F}_{\text{SIG}}$**. Upon receiving** $(\texttt{Signature}, (U, s), m, \sigma)$ **from** $\mathcal{F}_{\text{SIG}}$, S outputs $(\texttt{Signature}, sid, m, \sigma)$.

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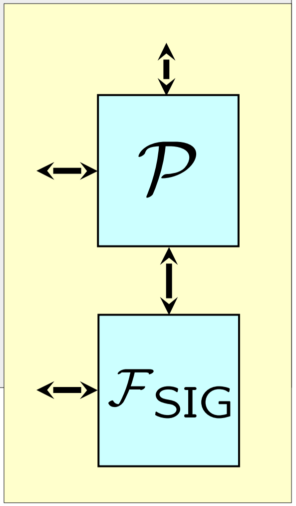

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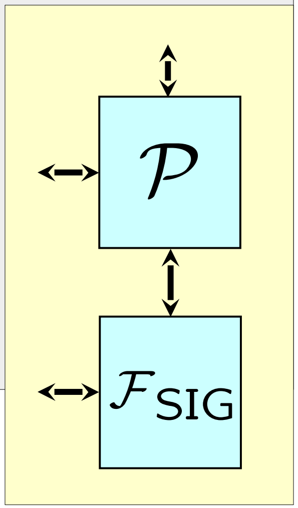

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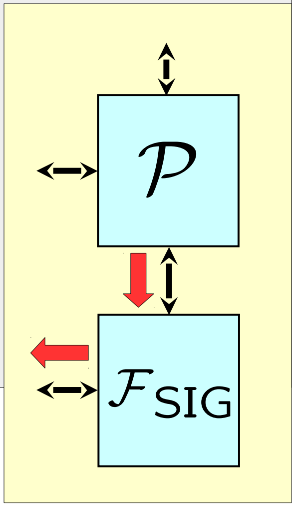

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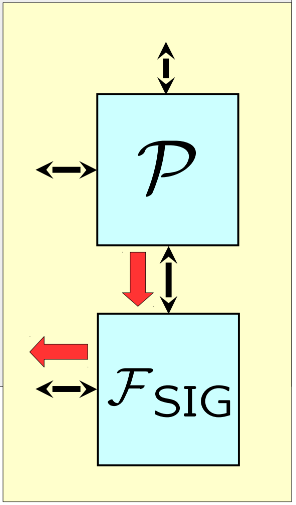

Problem propagates to higher level protocols:

Adversary is activated when calling a subroutine which models a local task.

The behavior of $\mathcal{P}$ in this case is undefined.

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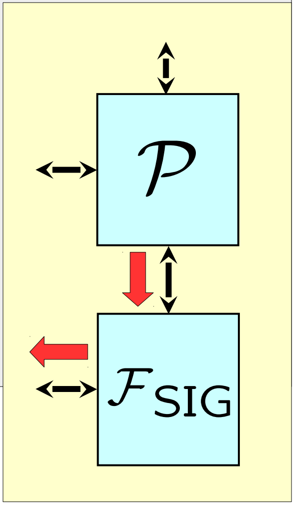

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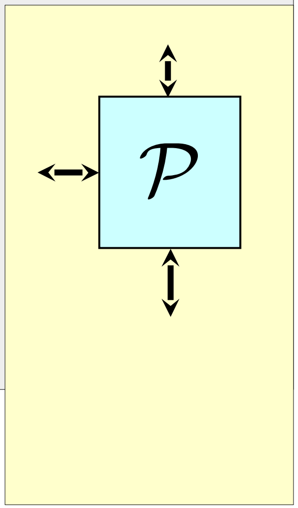

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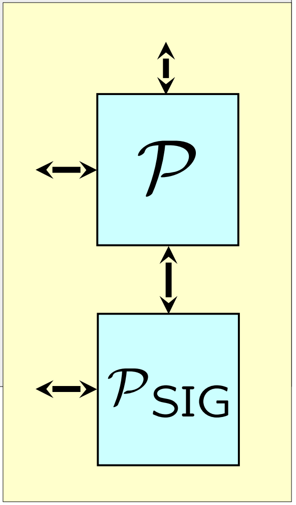

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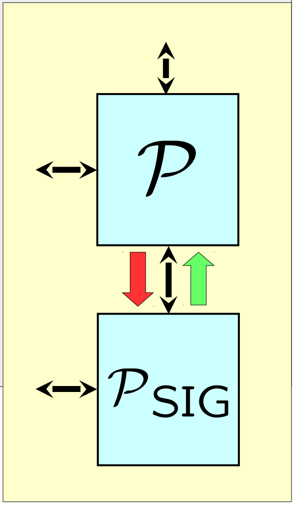

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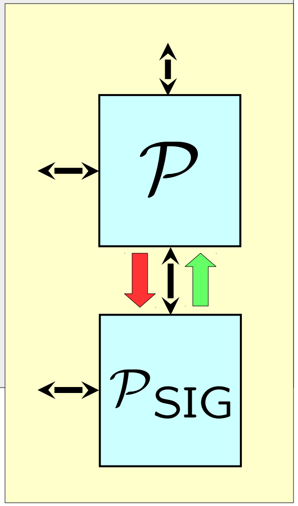

Idealization cannot express properties of realization:

Unlike $\mathcal{F}_{\text{SIG}}$, realization $\mathcal{P}_{\text{SIG}}$ is indeed local.

Problems from previous slides do not exist when using $\mathcal{P}_{\text{SIG}}$.

Dealing with the Non-Responsiveness Problem

Workarounds for full specifications:

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- Blocking requests while waiting for adversary

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However:

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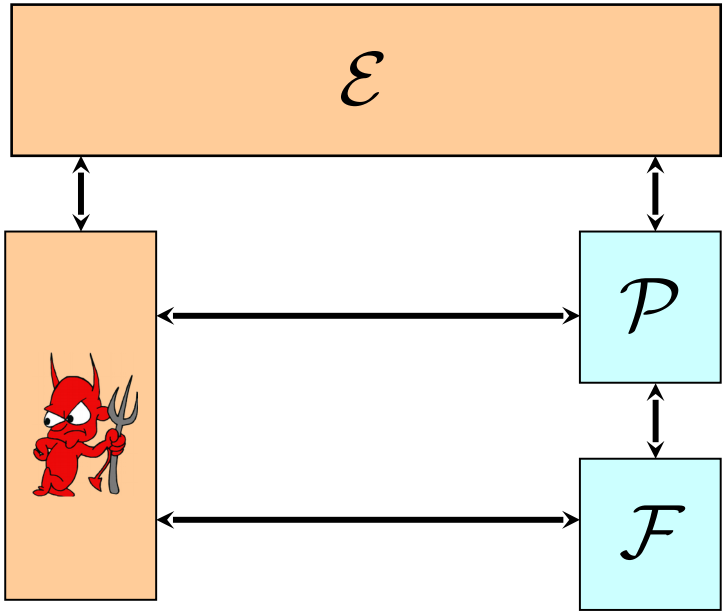
Also:

Does not address unintended state changes or limited expressivity

Our Solution

We introduce responsive environments and responsive adversaries



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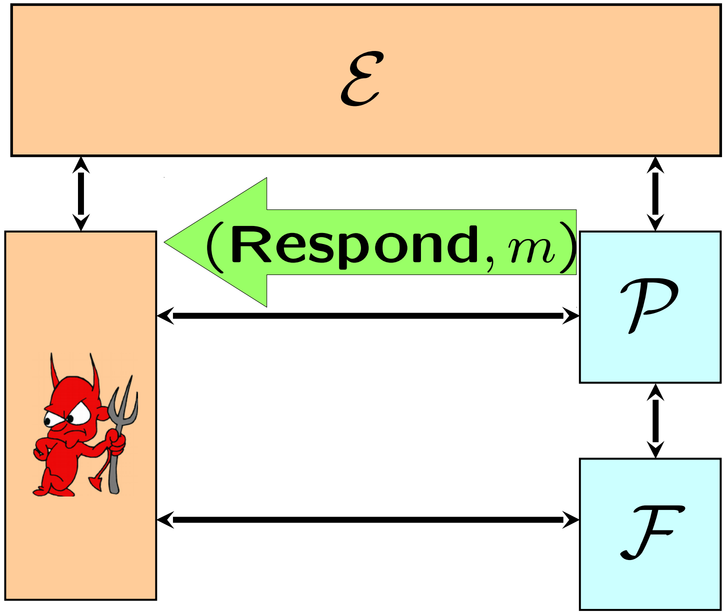

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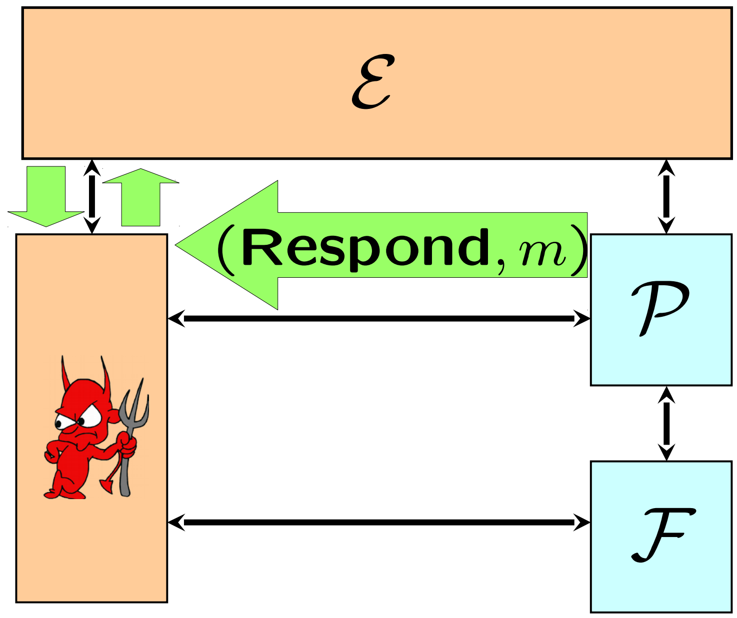

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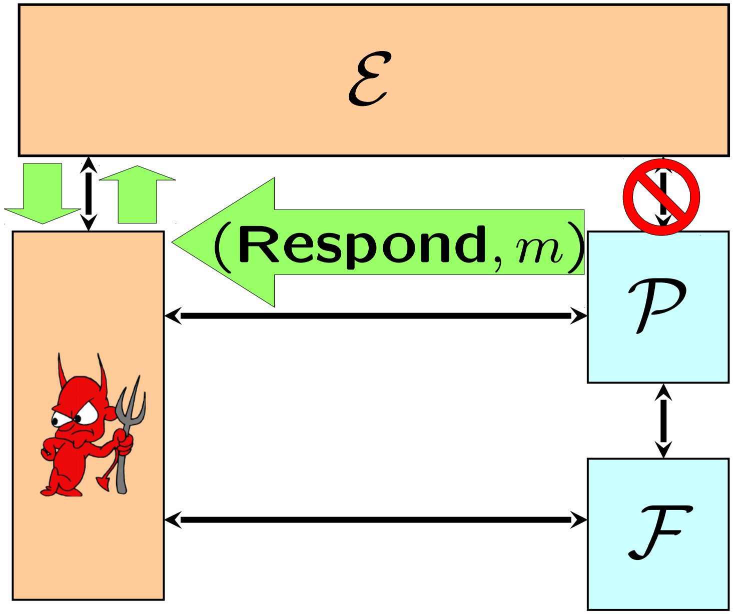

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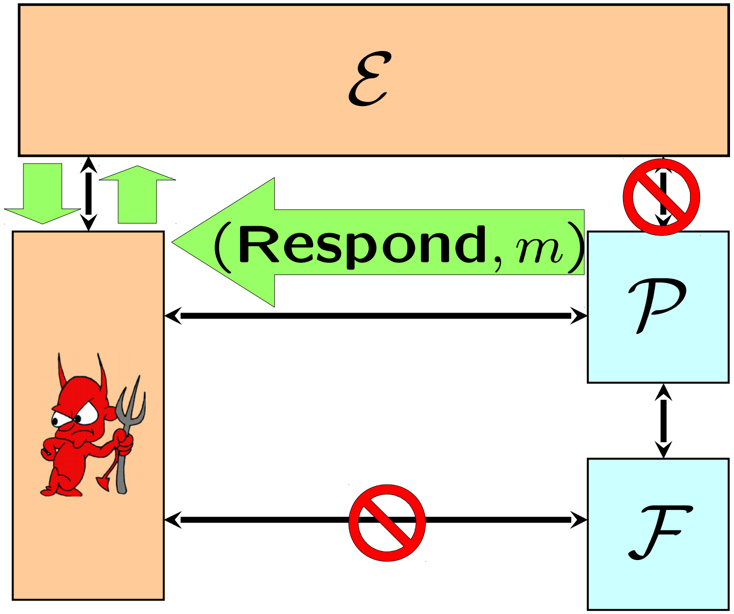

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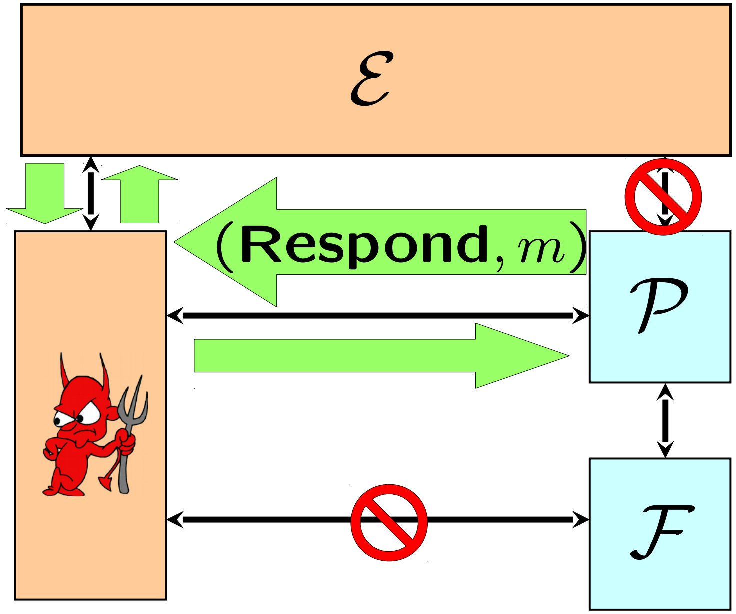


Non-Responsiveness Problem

Urgent requests do not model real network traffic

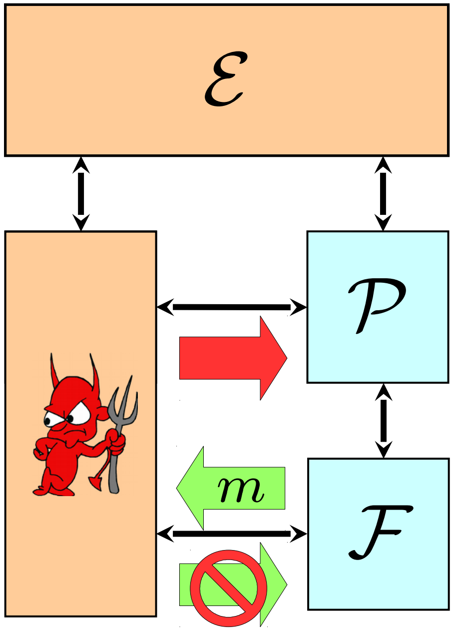
$\Rightarrow$ Real adversary cannot use them to mount attacks

$\Rightarrow$ Natural to expect adversary in model to answer immediately

Non-Responsiveness Problem

However, adversary can:

- Activate protocol in unexpected way
- Activate and change state of other parts of the protocol
- Block parts of the protocol



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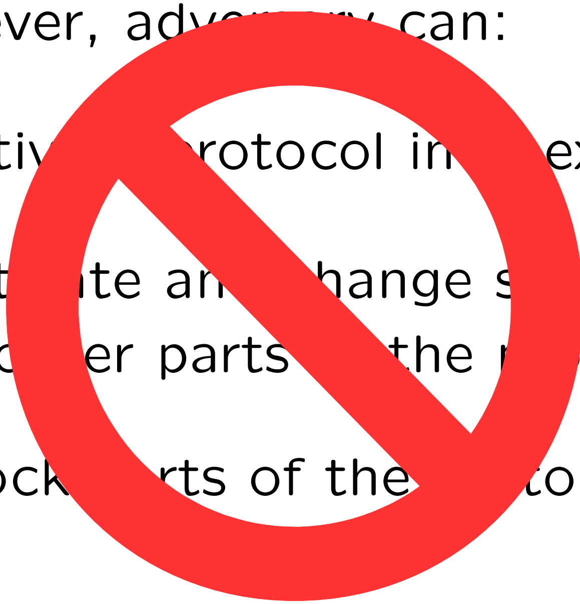

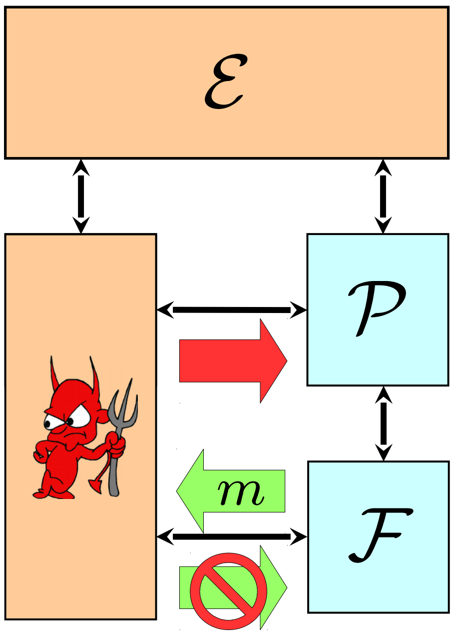

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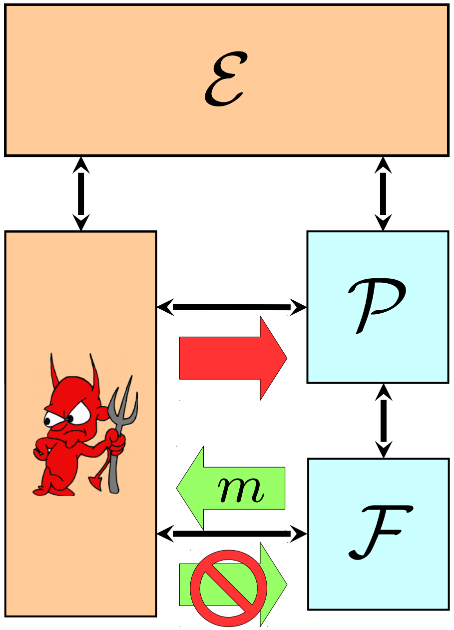

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We introduce responsive environments and responsive adversaries

- Natural solution,
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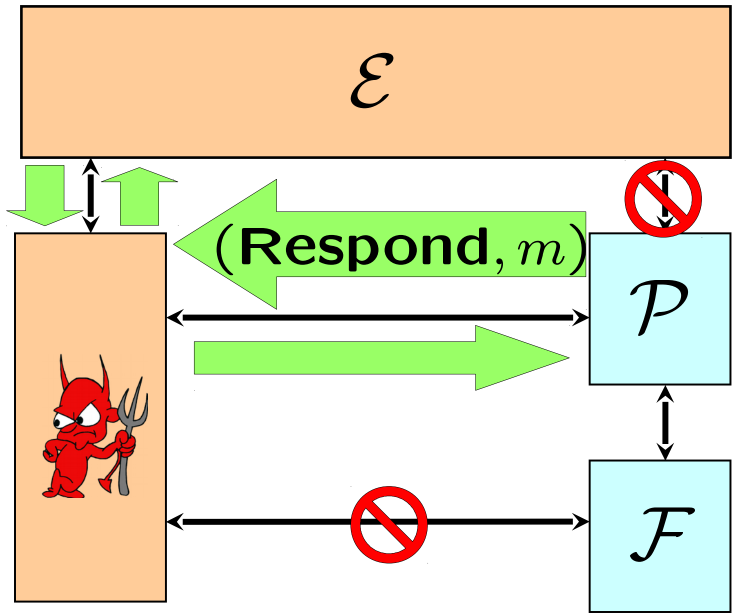

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- Natural solution, solves the problem entirely
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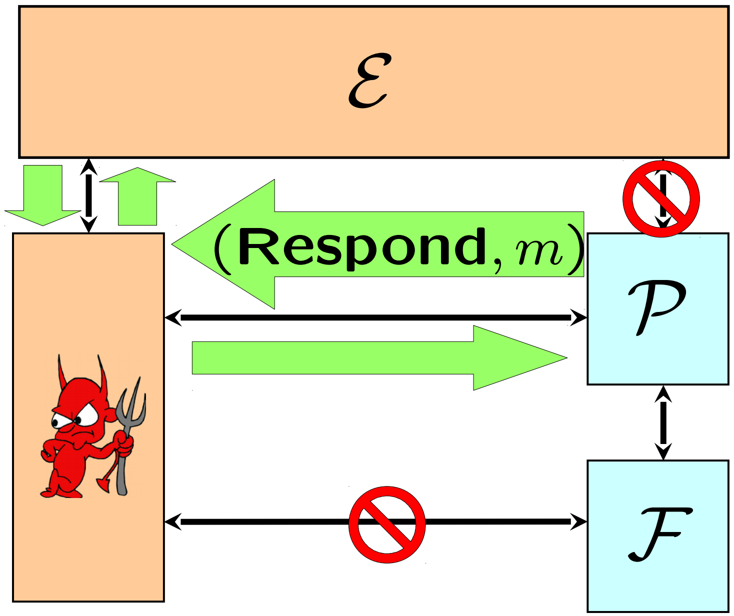

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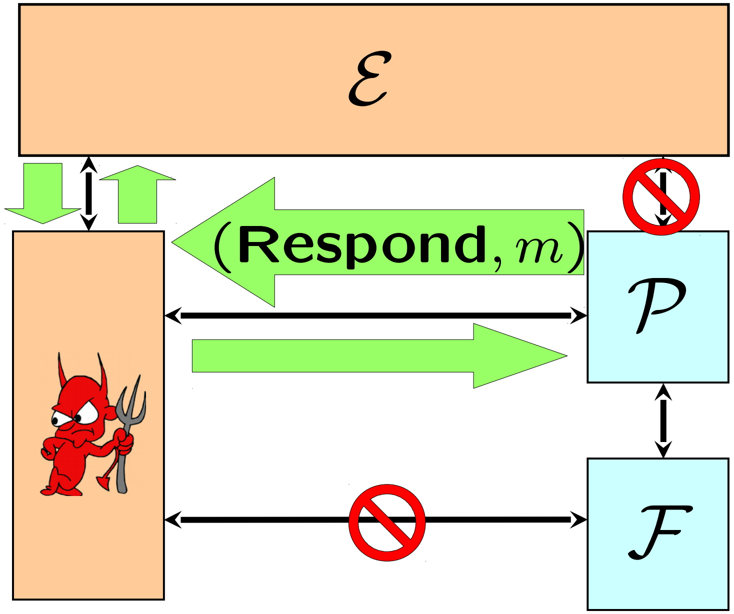

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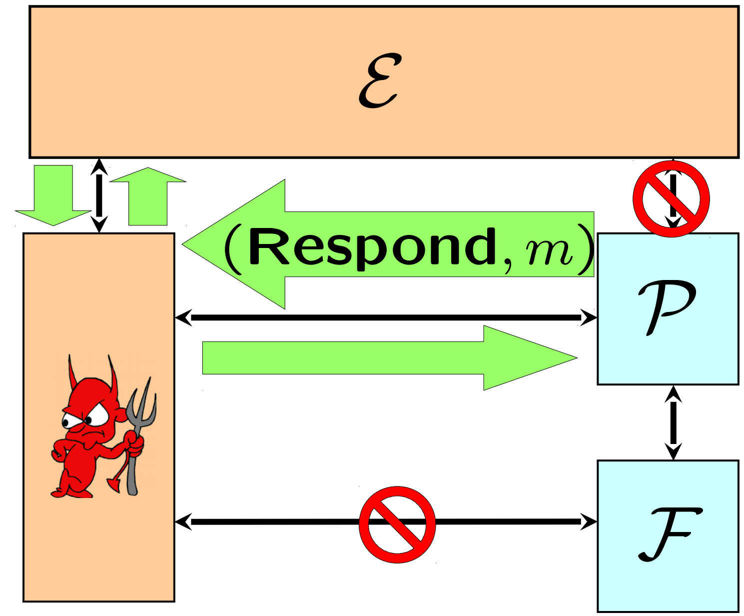
- Applicable to all UC-style models (exemplified for UC, IITM, GNUC)



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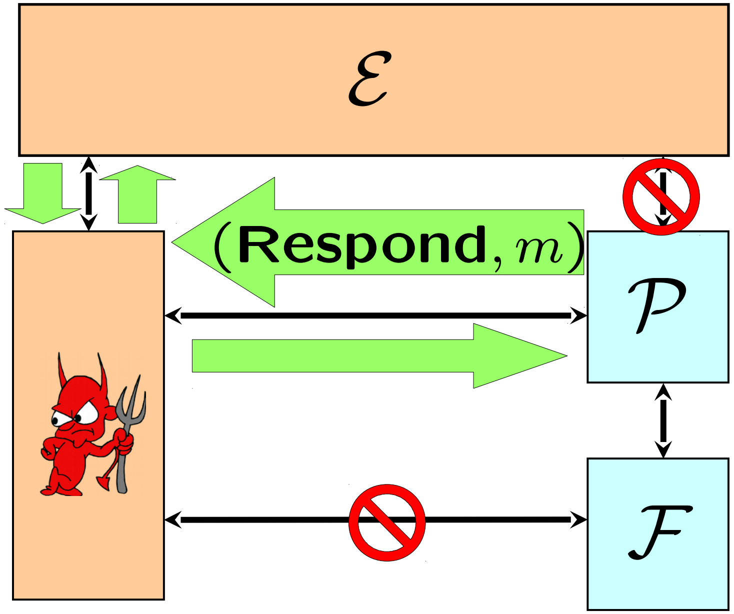
We provide detailed definitions and full proofs for the IITM model, including:



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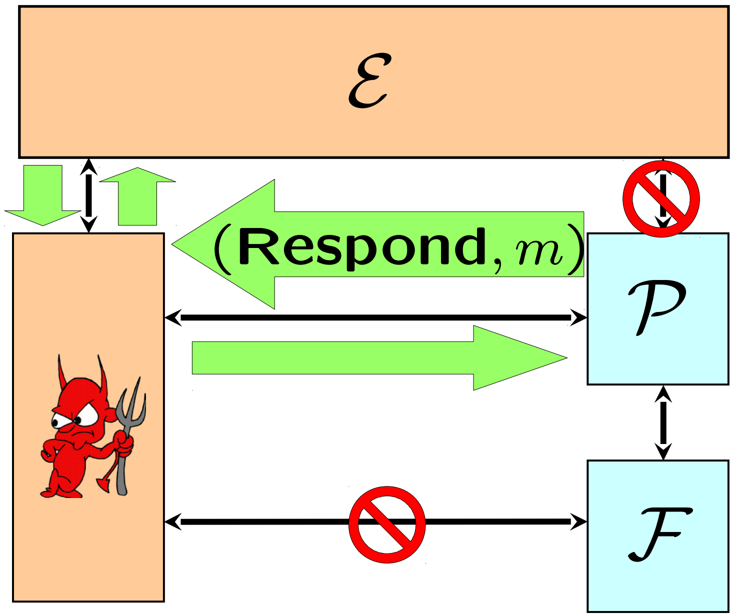

- Formal definitions of urgent requests, responsive environments, responsive adversaries

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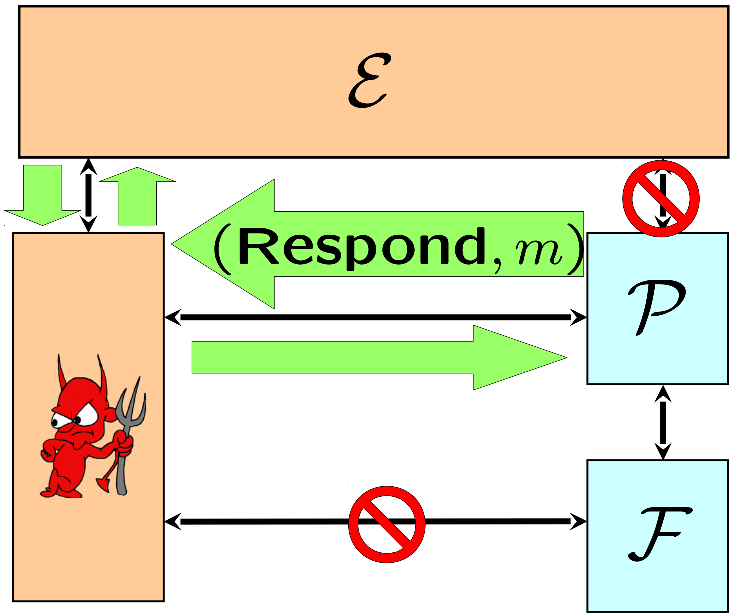

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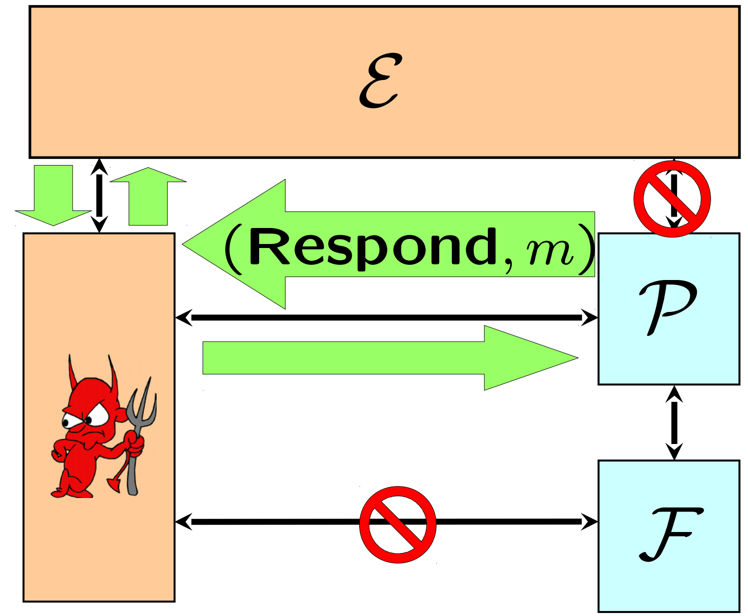

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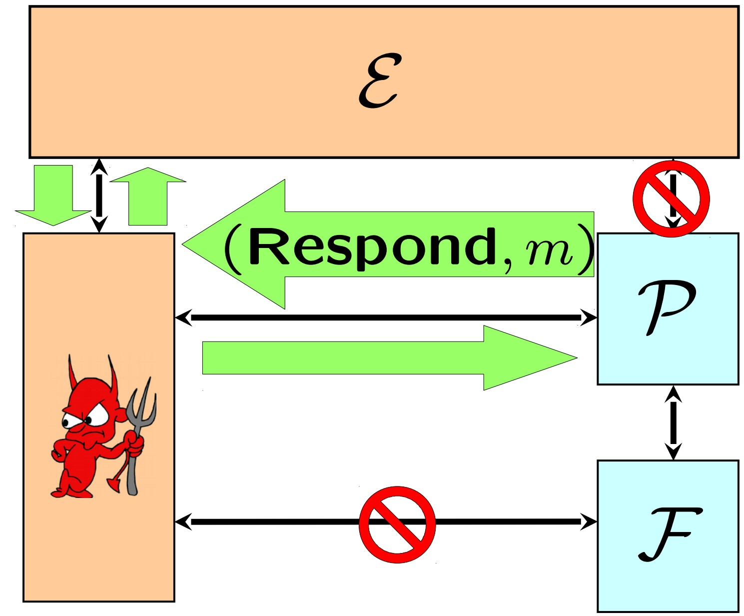

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- Various security notions (dummy UC, strong simulatability, black-box simulatability, ...)
- Reflexivity and transitivity of security notions
- Composition theorems

Solve problems from the literature

$\mathcal{F}_{\mathsf{NIKE}}$ from [Freire, Hesse, Hofheinz, 2014]

Upon input $(\texttt{init}, P_i, P_j)$ from P_i [...] consider two cases:

- Corrupted session mode: if there exists $(\{P_i, P_j\}, K_{i,j})$ in Λ_{keys}, set $key = K_{i,j}$. Else, **send** ($\texttt{init}, P_i, P_j)$ **to the adversary. After receiving** $(\{P_i, P_j\}, K_{i,j})$ **from the adversary**, set $key = K_{i,j}$ and add $(\{P_i, P_j\}, K_{i,j})$ to Λ_{keys}.
- Honest session mode: [...]

Return (P_i, P_j, key) to P_i.

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Upon receiving a value $(\mathtt{Setup}, sid)$ from any party P, verify that $sid = (M_L, sid')$ for some sid'. If not, then ignore the request. Else, if this is the first time that $(\mathtt{Setup}, sid)$ was received, **hand** $(\mathtt{Respond}, \mathtt{Setup}, sid)$ **to the adversary; upon receiving** $(\mathtt{Algorithms}, sid, \text{Verify}, \text{Sign}, \text{Simsign}, \text{Extract})$ **from the adversary**, store these algorithms. Output the stored $(\text{Algorithms}, sid, \text{Sign}, \text{Verify})$ to P.

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$\mathcal{F}_{\text{D-Cert}}$ from [Zhao, Zhang, Qin, Feng, 2014]

Upon receiving a value $(\texttt{Verify}, sid, m, \sigma)$ from some party S', **hand** $(\texttt{Respond}, \texttt{Verify}, sid, m, \sigma)$ **to the adversary. Upon receiving** $(\texttt{Verified}, sid, m, \phi)$ **from the adversary**, do:
[...]
Output $(\texttt{Verified}, sid, m, f)$ to S'.

immediate response

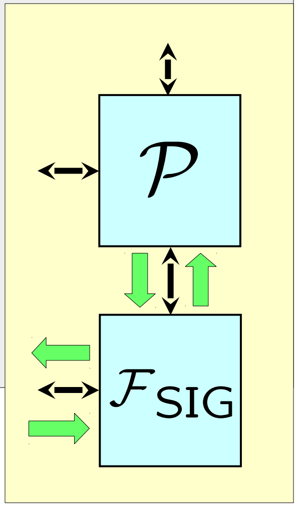
Solve problems from the literature

Realization of $\mathcal{F}_{\text{D-Cert}}$ from [Zhao, Zhang, Qin, Feng, 2014]

Signature Protocol: When activated with input $(\texttt{Sign}, sid, m)$, Party S does:

[...]

S **sends** $(\texttt{Sign}, (U, s), m)$ **to** $\mathcal{F}_{\text{SIG}}$**. Upon receiving** $(\texttt{Signature}, (U, s), m, \sigma)$ **from** $\mathcal{F}_{\text{SIG}}$, S outputs $(\texttt{Signature}, sid, m, \sigma)$.



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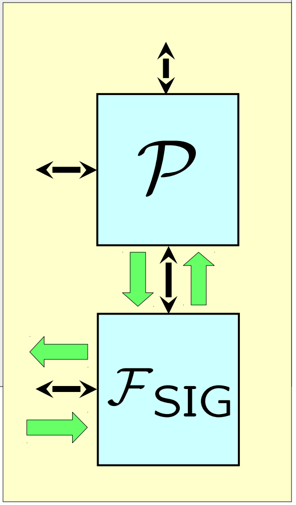

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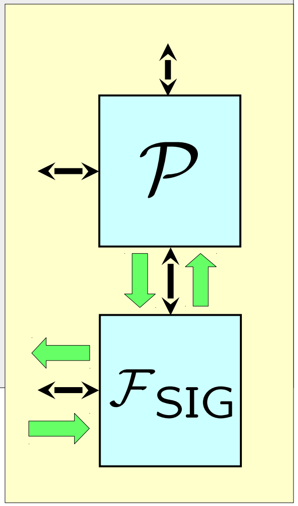

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Conclusion

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  * Often ignored in the literature
    - Underspecified protocols
    - Flawed proofs
    - Hard to reuse functionalities

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Thanks for your attention!